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Discards from experimental trammel nets in southern European small-scale fisheries

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Abstract

Trammel net discards in four southern European areas were considerable, with a total of 137 species (79.7% of the total) discarded 65, 105, 46 and 32 species in the Basque country (Spain), Algarve (Portugal), Gulf of Cadiz (Spain) and Cyclades islands (Greece), respectively. The overall discard rate in terms of catch numbers ranged from 15% for the Cyclades to 49% for the Algarve, with the high discard rate for the latter due largely to small pelagic fishes. Discards in the four areas consisted mainly of *Trisopterus luscus* (Basque country), *Scomber japonicus* (Algarve), *Torpedo torpedo* (Cadiz) and *Sardina pilchardus* (all three areas), and *Diplodus annularis* in the Cyclades. Strong seasonal variation in discarding was found, reflecting differences in *métiers* and the versatility of trammel nets as a gear. Discarding, both in terms of numbers of species and individuals decreased with increasing inner panel mesh size. The main reasons for discarding were: (1) species of no or low commercial value (e.g. *Scomber japonicus*; *Torpedo torpedo*), (2) commercial species that were damaged or spoiled (e.g. *Merluccius merluccius*), (3) undersized commercial species (e.g. *Lophius piscatorius*), and (4) species of commercial value but not caught in sufficient quantities to warrant sale (e.g. *Sardina pilchardus*). A decrease in soak time together with the appropriate choice of mesh sizes could contribute to a reduction in discarding and to improved sustainability and use of scarce resources in the small-scale, inshore multi-species fisheries of southern Europe.

Keywords: Discards; By-catch; Trammel nets; Selectivity; Coastal fisheries management

1. Introduction

Many fishing gears are associated with high discard rates, with the most common reasons for discarding being lack of commercial value, poor condition and undersized catches (below the minimum legal landing size) (e.g. Hall et al., 2000). In general, by-catch and subsequent discarding is inevitable due to varying degrees of lack of species and size selectivity of different gear. Thus, the relative importance of discards depends largely on the gear, the gear characteristics (e.g. mesh size, hanging ratios), fishing strategies, marketing constraints and legislation (e.g. Hall, 1996). Discarding is also characterized by high spatial and temporal variability (e.g. Kennelly, 1995). It is also increasingly evident that discarding can affect biodiversity and community structure, benefit opportunistic and scavenger species, as well as having a considerable impact on individual species and populations, including charismatic, protected or threatened species, especially marine mammals, reptiles and sea birds (e.g. Ramsay et al., 1997; Tingley et al., 2000; Kelleher, 2005).

With the increasing emphasis on conservation and management at the multi-species and ecosystem levels, there is an urgent need to evaluate discarding practices and to quantify discard composition and mortality in order to understand the impacts at the population, trophic and ecosystem levels (Hall et al., 2000; Borges et al., 2001). This approach will contribute to a better definition of technical measures, such as the implementation of by-catch reducing devices, minimal landing sizes (MLS), minimum mesh sizes, and time and area closures.

Trammel nets are widely used in southern European waters, due mainly to their great versatility, catching a greater variety of species and a wider size range than gill nets (Erzini et al., 2006; Stergiou et al., 2006). Thus, trammel net fishers can

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adapt to changes in abundance of the main target species more readily than those using more species- and size-specific gears. Declines in recent years of other *métiers* of the small-scale fisheries (mainly longline), have also contributed to the increase of the trammel net fishing activity, which is currently one of the most important in the small-scale fisheries of southern Europe (Erzini et al., 2001).

Elsewhere, we have studied the species- and size-selectivity of trammel nets in southern European waters (Spain, Portugal and Greece; Erzini et al., 2006; Stergiou et al., 2006). In this study, we quantify the discards of trammel nets, for which available information is scant (e.g. Borges et al., 2001; Purbayanto et al., 2001; Coelho et al., 2005). Given that large numbers of trammel net *métiers* may exist even within the same geographic area, with seasonal variation in use and non-uniform construction and gear characteristics, there is an urgent need to study the discarding impact of trammel nets and ways of mitigating it.

The objectives of this study were to identify and characterise the main trammel net discarded species and discarding practices in southern European waters, namely in the Cantabrian Sea (Basque country, Spain), the Algarve (southern Portugal), the Gulf of Cadiz (Spain) and the Cyclades islands (Greece). This was accomplished by quantifying discard species composition and discard rates on a seasonal and depth basis for experimental trammel nets of 24 different mesh-size combinations.

2. Material and methods

The experimental gear used in this study corresponds to the most commonly used trammel net *métiers* in the four areas (the Algarve, the Basque country, the Gulf of Cadiz and the Cyclades islands), both in terms of materials and construction (e.g. floats, leadlines, hanging ratios, vertical slack) and the combinations of inner and outer panel mesh sizes (see Erzini et al., 2006). Furthermore, the fishing strategy (e.g. setting time, soak time, fishing grounds) was determined entirely by the different skippers and corresponded to normal commercial fishing practices.

Experimental trammel nets using three mesh sizes for the inner panel and two mesh sizes for the outer panel were constructed in each area, giving a total of six trammel net types for each area corresponding to the most common *métier* (Fig. 1). Inner panel stretched mesh sizes ranged from 40 to 48 mm in the Cyclades to 100–140 mm in the Algarve, while outer panel stretched mesh sizes ranged from 220 to 300 mm in the Cyclades to 600 to 800 mm in the Algarve.

Fishing trials were carried out on a seasonal basis, during 1999–2000, using chartered commercial fishing vessels. Normal fishing practices were followed in all four areas. Depths of the fishing areas ranged between 15 and 100 m in the Algarve, 20–80 m in the Basque country, 10–30 m in the Gulf of Cadiz and 10–80 m in the Cyclades. Overall, 360, 271, 185 and 185 km of trammel nets were fished in the experimental fishing trials in the Algarve, Cantabrian Sea, Gulf of Cadiz and Cyclades islands, respectively.

In the Algarve and the Gulf of Cadiz, the gears were usually set in the afternoon or evening before sunset and hauled after sunrise and in the Cyclades the fleets were set either before sunrise or sunset and retrieved 1–2 h after sunrise and sunset, respectively. In the Basque country, the setting time of the nets was 24 h for most of the fishing days. More details of trammel net characteristics and construction as well as of the experimental fishing trials are given in Erzini et al. (2006).

Members of each team went on board each trip in order to sort the catch per trammel net type and record relevant information (e.g. depth, method of capture and discarding practices). All organisms that were caught were identified to the species level and all fish, crustaceans and molluscs were measured (total length, disc width or mantle length) to the nearest millimeter.

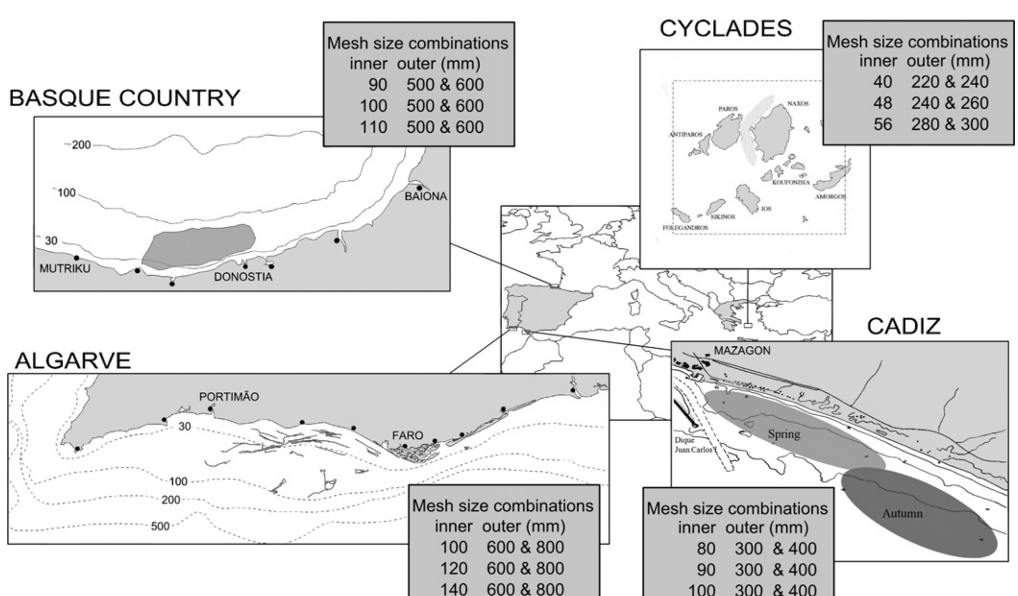

Fig. 1. Location of experimental fishing areas (Atlantic Ocean: Algarve, Portugal; Basque country, Spain; Cadiz, Spain; Mediterranean Sea: Cyclades, Greece) and the different trammel net mesh size combinations used.

The catches were classified according to value as 'commercial' and 'discard'.

At least 40 fishing trials were carried out in each area, over all four seasons in the Basque country ($n=49$), the Algarve ($n=40$) and the Cyclades islands ($n=41$). In the Gulf of Cadiz ($n=60$), fishing took place only in two seasons (spring and autumn) because of the seasonal nature of the trammel net fishery.

The discard/total catch ratio (D/T), in terms of numbers, was calculated separately for each individual inner/outer mesh size combination and season. For comparative purposes data were standardized to numbers per 1000 m of net.

Multivariate analysis of the data was carried out with PRIMER 6.0 (Clarke and Gorley, 2006) in order to identify groups of trammel net inner–outer panel combinations on the basis of region, season and mesh size. The constructed matrices comprised the numbers of each species per 1000 m of net from each inner/outer mesh combination for each season, after averaging all trials per season for each area [i.e., (all species) × (six inner/outer mesh combinations) × (four seasons in three areas, two seasons in Cadiz)]. Numbers-per-species were double square-root transformed in order to reduce the influence of extremely rare or abundant species, prior to calculation of similarity matrices based on the Bray–Curtis index (Bray and Curtis, 1957). These matrices were used for cluster analysis and non-parametric multi-dimensional scaling (MDS). Non-parametric permutation tests (ANOSIM with two crossed factors) were used to test for differences between regions, seasons and mesh sizes (Clarke and Warwick, 2001). SIMPER analysis (Clarke and Warwick, 2001) was used to determine which species contributed most (cumulative percentage) to the dissimilarity between seasons. The Kruskal–Wallis non-parametric ANOVA was used to test for differences in the median discard numbers between mesh sizes and Student–Newman–Keuls (SNK) multiple comparison was used to separate significant differences among medians (Sokal and Rohlf, 1995).

3. Results

3.1. Total discards

Overall, 15,981 individuals of 137 species from four taxonomic groups (125 fish, 6 crustacean, 5 mollusc and 1 reptile species) were discarded, representing 79.7% of the species caught and 31.1% of the total catch in number. Fish were the most important taxonomic group, with cartilaginous fish represented by 14 species (10.2%), while bony fish dominated with 111 species (81.0%). Reptiles were represented by just one species (0.7%), while mega-invertebrate discards consisted of six species of crustaceans (five decapods and one stomatopod, 4.4%) and five molluscs (one gastropod and four cephalopods, 3.6%).

Discards in numbers were high in all areas, with a combined D/T ratio of 31.1%. The highest D/T in numbers was for the Algarve (49.4%), followed by Cadiz (31.4%), the Basque country (22.3%) and Cyclades with only 14.7% (Fig. 2).

Overall, 65, 105, 46 and 32 species were entirely or partly discarded in the Basque country, Algarve, Gulf of Cadiz and

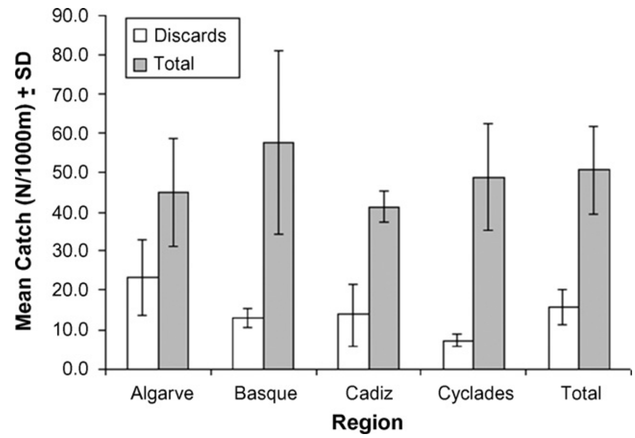

Fig. 2. Mean discards and total catches in numbers per 1000 m of net and standard deviation (S.D.) by area and for all areas combined.

Cyclades, respectively. The species composition of the discards differed significantly between the four areas (Fig. 3), with Cyclades located further away from the three remaining areas (1 factor ANOSIM; $R=0.979$, $p=0.001$). The trammel net sets from each area formed separate groups, with two main clusters and groups for each of the four areas (Fig. 3).

The discards in the four regions were due largely to *Trisopterus luscus* (Basque country), *Scomber japonicus* (Algarve), *Torpedo torpedo* (Cadiz), and *Sardina pilchardus* in the latter three regions, and *Diplodus annularis* in the Cyclades. Other important discarded species included *Trachinus draco* (Basque country), *Boops boops* (Algarve), *Halobatrachus didactylus* (Cadiz), and *Synodus saurus* (Cyclades).

Only two highly commercial species were discarded in all four areas: *Mullus surmuletus* and *Diplodus sargus*, although in small numbers (<1%). Of the 24 species that were discarded in at least three areas (17.6% of the total), 12 were shared by the Algarve, Basque country and Cadiz, with *S. pilchardus*, *S. japonicus* and *T. draco* being the most important in numbers.

3.2. Discards by season

There was a strong seasonal influence on the species composition and relative abundance of the discards in three areas: Algarve, Basque country and Cadiz (Fig. 4). All differences were significant (1 factor ANOSIM; Basque country, $R=1.000$, $p=0.001$; Algarve, $R=0.858$, $p=0.001$; Cadiz, $R=0.993$, $p=0.002$) except for Cyclades ($R=0.201$, $p=0.012$).

Although there was no clear seasonal pattern in discard numbers per 1000 m of net, these were generally higher in autumn in the two southern Iberian areas (Algarve and Cadiz), in contrast to the Cyclades and Basque country where discarding was more important in summer and winter, respectively (Table 1). The highest D/T values were also obtained in autumn in the Algarve and in Cadiz, in winter in the Cyclades and in spring–summer in the Basque country (Table 1).

In the Algarve, S. *japonicus* and to a lesser extent S. *pilchardus*, *Microchirus azevia* and *Scorpaena notata* were the most commonly discarded species over the year. However, the first two species were more important in autumn-winter,

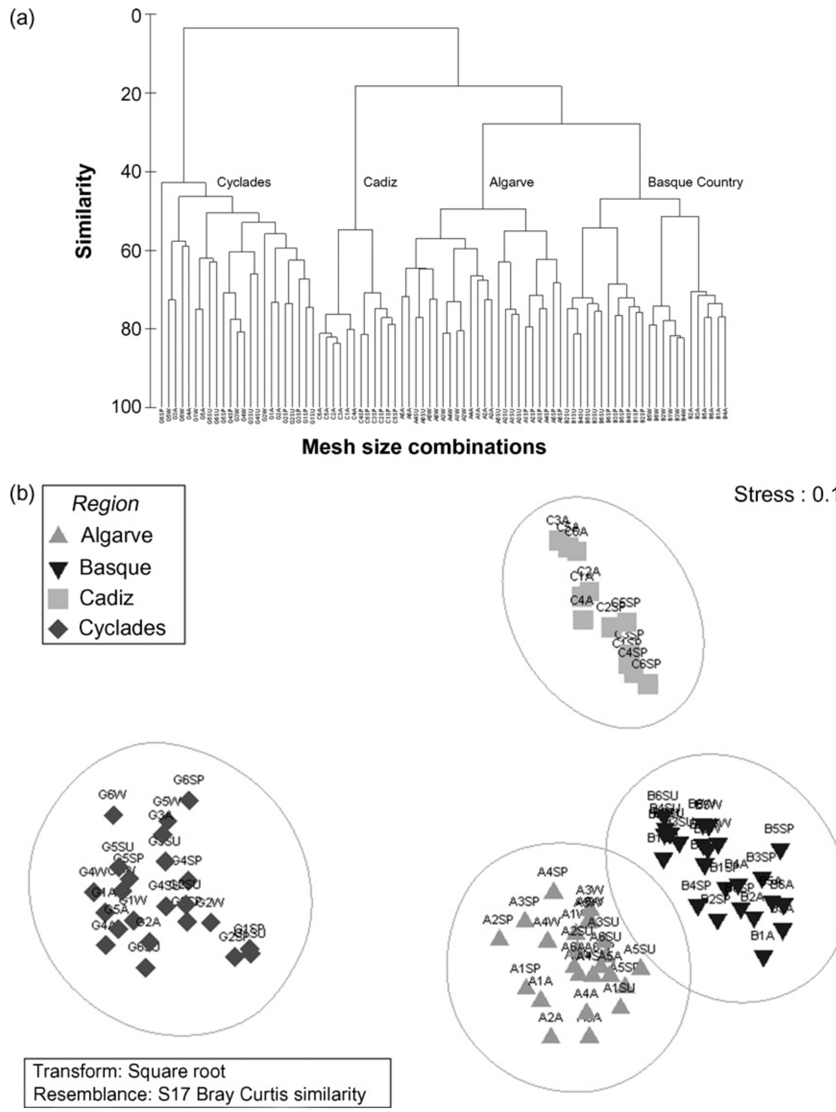

Fig. 3. Cluster analysis (a) and MDS (b) of discard species composition by numbers for the four study areas (A, Algarve; B, Basque country; C, Cadiz and G, Cyclades), by season (SU, summer; A, autumn; W, winter and SP, spring) and trammel net inner and outer panel combination (1–6, see Section 2) (circles, resemblance level of 40%).

while *T. draco* (spring) and *B. boops* (autumn) contributed most to the seasonal differences found, especially between spring and autumn (ANOSIM; $R = 0.998$, $p = 0.002$; SIMPER, one way analysis: spring *versus* autumn, average dissimilarity = 54.5%).

In the Basque country, *T. luscus*, *T. draco*, *Maja squinado* and *Merluccius merluccius* were discarded throughout the year. Nevertheless, the first two species had higher discard values in autumn and summer, respectively, while *S. scombrus* (winter), *T. marmorata* and *Lophius piscatorius* (spring) and *S. pilchardus* (winter/summer) were the species most responsible for the dissimilarity between seasons (ANOSIM all seasons: $R = 1$, $p = 0.002$). The average dissimilarities between seasons were very similar, with values ranging from 48.6% (winter *versus* autumn) to 56.4% (winter *versus* spring) (SIMPER, one way analysis).

Table 1
Discards in numbers (mean number per 1000 m of trammel net and standard deviation, S.D.) and discard/total catch ratio (D/T, %) by area and season (–, no data)

	Winter			Spring			Summer			Autumn			Total
	Mean	S.D.	D/T	Mean	S.D.	D/T	Mean	S.D.	D/T	Mean	S.D.	D/T	D/T
Algarve	26.11	8.75	41.0	16.73	6.83	46.0	15.99	5.82	45.2	37.62	17.18	63.01	49.4
Basque	16.45	2.54	17.8	12.48	1.86	28.2	12.55	3.07	26.5	10.68	1.70	21.54	22.4
Cadiz	–	–	–	8.20	3.34	16.8	–	–	–	19.23	3.23	49.55	31.4
Cyclades	5.81	2.38	17.5	7.92	3.83	13.5	9.05	4.82	14.8	6.31	3.83	15.00	14.7

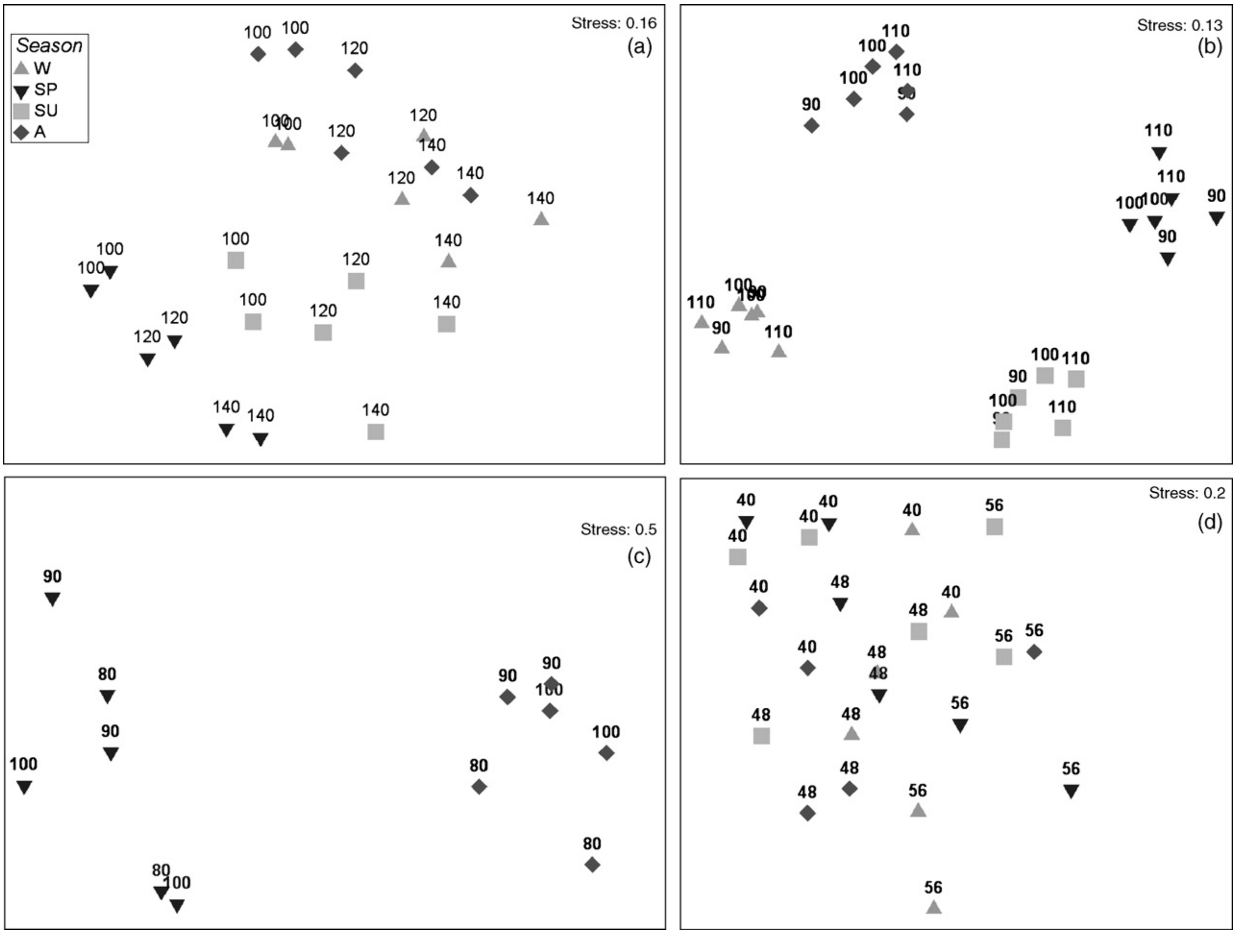

Fig. 4. MDS of the discards by numbers for each of the four areas (Algarve (a), Basque country (b), Cadiz (c) and Cyclades (d)), by season (SU, summer; A, autumn; W, winter and SP, spring) and inner panel mesh sizes (Algarve: 100, 120, 140 mm; Basque country: 90, 100, 110 mm; Cadiz: 80, 90, 100 mm; Cyclades: 40, 48, 56 mm).

S. pilchardus, *T. torpedo*, *H. didactylus* and *Raja asterias* were the main species discarded in Cadiz, where fishing trials took place in only two seasons. *Pomadasys incisus* and *Diplodus bellottii* were mainly discarded in spring, while *T. torpedo*, *H. didactylus*, *Mugil cephalus* and *Raja undulata* were discarded in autumn contributing most to the difference between seasons (SIMPER, one way analysis: autumn *versus* summer, average dissimilarity = 45.1%).

Four species *D. annularis*, *Diplodus vulgaris*, *S. saurus* and *Chelidonichthys lastoviza* accounted for the majority of the discards in the Cyclades. The different proportions of these species together with *Xyrichtys novacula and Pagrus pagrus* (in autumn) accounted for most of the differences between autumn and spring and summer (SIMPER, one way analysis: autumn *versus* summer and autumn *versus* spring, average dissimilarity = 52.0 and 51.3%, respectively).

3.3. Discards by mesh size

No significant differences in discards species composition between the six inner/outer panel combinations in each area were found except for Cyclades (1 factor ANOSIM; Basque country, $R = -0.195$, $p = 0.986$; Algarve, $R = 0.089$, $p = 0.182$; Cadiz, $R = -0.406$, $p = 0.927$; and Cyclades, $R = 0.260$, $p = 0.004$). Nevertheless, there was an increase in D/T with decreasing inner panel mesh size (Tables 2–5). In fact, discards species composition differed between inner mesh sizes, especially between extremes, for all areas except Cadiz (2 factor ANOSIM; Algarve, $R = 0.694$, $p = 0.001$; Basque country, $R = 0.403$, $p = 0.008$; Cadiz, $R = 0.222$, $p = 0.204$; and Cyclades, $R = 0.811$, $p = 0.001$) (Fig. 4).

In terms of discarded quantities, no significant differences were found between the different outer panel meshes used in each area, between all the mesh outer and mesh inner panel combinations or between the inner panel meshes for all areas ($p > 0.10$), except the Algarve. In the latter area, there was a significant decrease in discarding with increasing inner panel mesh size (Table 2 and Fig. 4), with significant differences (Kruskal–Wallis ANOVA on ranks; $H = 7.982$, $p = 0.018$), especially between the smallest and the largest inner panel mesh sizes (100 mm versus 140 mm, SNK: $q = 3.964$, $p < 0.05$).

Discards in numbers of various commercially important benthic and demersal species such as *M. azevia* and *Pagellus acarne* in the Algarve, *M. merluccius* in the Algarve and Basque country, *T. luscus* in the Basque country and *Pagellus erythrinus* in the Cyclades were greater for the smaller inner mesh sizes

Table 2
Total discards in numbers by inner mesh size (100, 120 and 140 mm) for species accounting for more than 1% of the total discards in number in the Algarve

Species	100	%	120	%	140	%	Subtotal	%	Cumulative %
Scomber japonicus	508	20.3	900	35.9	1096	43.8	2504	30.6	30.6
Sardina pilchardus	662	46.0	509	35.3	269	18.7	1440	17.6	48.1
Boops boops	256	42.9	243	40.7	98	16.4	597	7.3	55.4
Scorpaena notata	368	68.7	134	25.0	34	6.3	536	6.5	62.0
Trachinus draco	183	42.6	153	35.6	94	21.9	430	5.2	67.2
Microchirus azevia	137	35.4	142	36.7	108	27.9	387	4.7	71.9
Chelidonichthys obscurus	155	45.7	113	33.3	71	20.9	339	4.1	76.1
Pagellus acarne	137	63.4	51	23.6	28	13.0	216	2.6	78.7
Trachurus trachurus	73	42.0	59	33.9	42	24.1	174	2.1	80.8
Serranus cabrilla	101	60.5	56	33.5	10	6.0	167	2.0	82.9
Sepia officinalis	43	34.1	58	46.0	25	19.8	126	1.5	84.4
Merluccius merluccius	40	37.0	38	35.2	30	27.8	108	1.3	85.7
Citharus linguatula	56	55.4	29	28.7	16	15.8	101	1.2	87.0
Phycis phycis	39	41.5	33	35.1	22	23.4	94	1.1	88.1
D/T	39.2		34.6		26.2				

Discard/total catch ratio (D/T) in percentage.

(Tables 2, 3 and 5). Although for most species there was a decrease in discards with increasing mesh size in the inner panel, this was not the case for species of the genus *Raja*, namely *R. montagui* in the Basque country (Table 3), and *R. asterias* and *R. undulata* in Cadiz (Table 4). Discards of elasmobranchs of the genus *Torpedo* also increased slightly with increasing inner panel mesh size, especially for *T. marmorata* in the Basque country (Table 3). There was no clear relationship between discard rates of small pelagics and inner panel mesh size, with more *S. pilchardus* discarded from smaller inner mesh trammel nets in the Algarve (Table 2) and Basque country (Table 3), while there was no pattern in Cadiz (Table 4). In contrast, more *S. japonicus* were discarded by the larger inner panel mesh sizes in the Algarve (Table 2).

3.4. Causes for discarding

The least discarded species were the target species in each area, namely *Solea vulgaris* in the Basque country, *Solea senegalensis* and *Sepia officinalis* in the Algarve and Cadiz (Table 6). In the Cyclades, the main target species were *M. surmuletus*, *Scorpaena porcus* and *P. erythrinus*. The main reason for discarding of these and other commercially valuable species such as *T. luscus*, *T. draco* and *M. merluccius* in the Basque country, *M. azevia*, *P. acarne* and *P. erythrinus* in the Algarve, and *M. merluccius* in Cyclades was damage or poor condition (Table 6).

Other under-sized commercial species that were also discarded in large numbers included *L. piscatorius* and *M. squinado* in the Basque country, *D. bellottii* and *Argyrosomus regius* in

Table 3
Total discards in numbers by inner mesh size (90, 100 and 110 mm) for species accounting for more than 1% of the total discards in number in the Basque country

Species	90	%	100	%	110	%	Subtotal	%	Cumulative %
Trisopterus luscus	239	39.2	206	33.8	165	27.0	610	16.0	16.0
Sardina pilchardus	230	40.4	199	35.0	140	24.6	569	15.0	31.0
Trachinus draco	180	46.2	122	31.3	88	22.6	390	10.2	41.2
Scomber scombrus	94	33.1	100	35.2	90	31.7	284	7.5	48.7
Merluccius merluccius	90	49.2	53	29.0	40	21.9	183	4.8	53.5
Torpedo marmorata	43	24.9	54	31.2	76	43.9	173	4.5	58.1
Lophius piscatorius	42	26.1	61	37.9	58	36.0	161	4.2	62.3
Maja squinado	43	27.7	44	28.4	68	43.9	155	4.1	66.4
Trachurus trachurus	68	50.7	37	27.6	29	21.6	134	3.5	69.9
Chelidonichthys obscurus	42	41.6	36	35.6	23	22.8	101	2.7	72.5
Chelidonichthys lucernus	40	41.2	27	27.8	30	30.9	97	2.5	75.1
Micromesistius poutassou	30	36.1	35	42.2	18	21.7	83	2.2	77.3
Microchirus variegatus	47	63.5	19	25.7	8	10.8	74	1.9	79.2
Scomber japonicus	25	36.8	19	27.9	24	35.3	68	1.8	81.0
Raja montagui	12	20.0	19	31.7	29	48.3	60	1.6	82.6
Callionymus lyra	26	45.6	16	28.1	15	26.3	57	1.5	84.1
Boops boops	37	66.1	10	17.9	9	16.1	56	1.5	85.5
Solea solea	17	36.2	19	40.4	11	23.4	47	1.2	86.8
Triglidae	16	34.0	19	40.4	12	25.5	47	1.2	88.0
Aspitrigla cuculus	14	31.8	16	36.4	14	31.8	44	1.2	89.2
D/T	39.2		32.7		28.1				

Discard/total catch ratio (D/T) in percentage.

Table 4
Total discards in numbers by inner mesh size (80, 90 and 100 mm) for species accounting for more than 1% of the total discards in number in Cadiz

Species	80	%	90	%	100	%	Subtotal	%	Cumulative %
Torpedo torpedo	188	35.1	162	30.3	185	34.6	535	21.0	21.0
Sardina pilchardus	199	37.5	136	25.7	195	36.8	530	20.8	41.8
Halobatrachus didactylus	138	46.9	100	34.0	56	19.0	294	11.5	53.4
Raja asterias	51	24.1	72	34.0	89	42.0	212	8.3	61.7
Raja undulata	48	23.8	60	29.7	94	46.5	202	7.9	69.6
Torpedo marmorata	63	39.6	48	30.2	48	30.2	159	6.2	75.9
Mugil cephalus	63	44.4	35	24.6	44	31.0	142	5.6	81.5
Diplodus bellottii	48	37.8	32	25.2	47	37.0	127	5.0	86.4
Trachinus draco	30	52.6	5	8.8	22	38.6	57	2.2	88.7
Alosa alosa	7	16.3	8	18.6	28	65.1	43	1.7	90.4
Argyrosomus regius	9	29.0	11	35.5	11	35.5	31	1.2	91.6
Pomadasys incisus	9	32.1	9	32.1	10	35.7	28	1.1	92.7
D/T	15.6		13.6		14.4				

Discard/total catch ratio (D/T) in percentage.

Table 5
Total discards in numbers by inner mesh size (40, 48, and 56 mm) for species accounting for more than 1% of the total discards in number in the Cyclades

Species	40	%	48	%	56	%	Subtotal	%	Cumulative %
Diplodus annularis	371	42.5	376	43.1	126	14.4	873	61.7	61.7
Synodus saurus	98	70.5	21	15.1	20	14.4	139	9.8	71.5
Diplodus vulgaris	18	22.0	35	42.7	29	35.4	82	5.8	77.3
Pagellus erythrinus	53	100.0	0	0.0	0	0.0	53	3.7	81.0
Chelidonichthys lastoviza	30	58.8	10	19.6	11	21.6	51	3.6	84.6
Chromis chromis	47	100.0	0	0.0	0	0.0	47	3.3	87.9
Xyrichthys novacula	15	62.5	5	20.8	4	16.7	24	1.7	89.6
Bothus podas	11	50.0	4	18.2	7	31.8	22	1.6	91.2
Pagrus pagrus	7	31.8	9	40.9	6	27.3	22	1.6	92.7
D/T	49.2		34.7		16.0				

Discard/total catch ratio (D/T) in percentage.

Table 6
Discard proportion of target species (commercial) and principal causes for discards in each area (*N* = total number of individuals caught; *%D* = percentage discarded): damaged/poor condition, <MLS (below minimum legal size), and no commercial value

Algarve			Basque country			Cadiz			Cyclades		
Commercial	*N*	*%D*	Commercial	*N*	*%D*	Commercial	*N*	*%D*	Commercial	*N*	*%D*
Sepia officinalis	2093	6.0	*Solea vulgaris*	3248	1.4	*Sepia officinalis*	3481	0.0	*Mullus surmuletus*	854	0.2
Solea senegalensis	426	12.4				*Solea senegalensis*	649	0.0	*Scorpaena porcus*	155	0.7
									Pagellus erythrinus	622	8.5
<MLS	*N*	*%D*	<MLS	*N*	*%D*	<MLS	*N*	*%D*	<MLS	*N*	*%D*
			Lophius piscatorius	482	33.4	*Diplodus bellottii*	127	100	*Diplodus annularis*	911	97.5
			Maja squinado	380	40.8	*Argyrosomus regius*	164	18.9	*Pagrus pagrus*	27	81.5
									Diplodus vulgaris	205	40.0
Damaged/poor condition	*N*	*%D*	Damaged/poor condition	*N*	*%D*	Damaged/poor condition	*N*	*%D*	Damaged/poor condition	*N*	*%D*
Microchirus azevia	1432	26.1	*Trisopterus luscus*	2042	29.9				*Merluccius merluccius*	67	16.4
Pagellus acarne	537	40.2	*Trachinus draco*	1439	27.1						
Pagellus erythrinus	192	44.8	*Scomber scombrus*	1531	18.8						
			Merluccius merluccius	975	18.6						
Non-commercial	*N*	*%D*	Non-commercial	*N*	*%D*	Non-commercial	*N*	*%D*	Non-commercial	*N*	*%D*
Scomber japonicus	2578	97.1	*Sardina pilchardus*	983	57.9	*Sardina pilchardus*	600	88.33	*Synodus saurus*	139	100.0
Sardina pilchardus	1441	99.9	*Torpedo marmorata*	173	100.0	*Torpedo torpedo*	535	100.0	*Chelidonichthys lastoviza*	51	100.0
Boops boops	602	99.2	*Scomber japonicus*	68	100.0	*Halobatrachus didactylus*	294	100.0	*Chromis chromis*	47	100.0
Scorpaena notata	549	97.6	*Callyonimus lyra*	57	100.0	*Raja asterias*	212	100.0			
Citharus linguatula	103	98.1	*Boops boops*	56	100.0	*Raja undulata*	212	95.3			
Callyonimus lyra	84	100.0	*Mola mola*	34	100.0	*Torpedo marmorata*	159	100.0			

Cadiz, and *D. annularis*, *P. pagrus* and *D. vulgaris* in Cyclades (Table 6). *L. piscatorius* were discarded in Basque country mainly because small sizes were not marketable, as there is no MLS for this species, in Spain.

S. pilchardus was the most important discarded species in common to the Basque country, Algarve and Cadiz and the causes for discarding were various: insufficient numbers caught to warrant sale at auction, insufficient time on board for handling, damage or poor condition, and no or low value during seasons other than summer when sardine attains the highest prices. Other species discarded because of no or low commercial value included *B. boops* and *S. japonicus* (Basque country and Algarve), *T. marmorata* (Basque country and Cadiz) and *S. saurus* (Cyclades) (Table 6). However, on occasion, discarding was not 100% for species such as *S. pilchardus* and *S. japonicus* that were retained by the fishers for bait for longlines and traps.

Fishers also kept for their own consumption under-sized species such as *A. regius* in Cadiz, or species that are not normally sold, such as *M. squinado* in the Algarve. In some cases, under-sized species of commercial species such as *D. sargus* and *Dicentrarchus labrax*, especially in Cadiz as well as *L. piscatorius* and *M. squinado* in the Basque country, were released alive. However this was never done for low value or unmarketable species such as Mugilidae and Torpedinidae. In the latter cases, the fish were usually killed to avoid electric shocks, prior to removal from the trammel net.

4. Discussion

Discarding was important in terms of the number of species and numbers discarded in the four fisheries studied. A total of 65, 105, 46 and 32 species were discarded in the Basque country, the Algarve, Gulf of Cadiz and Cyclades, respectively. The number of the species discarded was higher in the Basque country and in the Algarve, with 27 and 25 species accounting for 95% of the total discards in numbers, whereas only 15 and 12 species contributed 95% of the discards in Cadiz and Cyclades. The same was also true of the total catch species diversity (Stergiou et al., 2006). This is probably due to the fact that the fishing in the latter two areas was more restricted in terms of depths, especially in Cadiz where the fishing grounds were close to shore.

The number of species discarded from trammel nets is far greater than that of other static gears such as longlines or gill nets used in the same area in the Algarve (Borges et al., 2001). This is due to the greater diversity of trammel net catches compared to other static gear (Martins et al., 1992; Erzini et al., 2003) and can be accounted for by the species and size selectivity of trammel nets (Stergiou et al., 2006; Erzini et al., 2006). The variety of catching mechanisms, including gilling, wedging, entangling and pocketing or trammelling associated with trammel nets accounts for the greater diversity of species caught, as well as for the generally wider size ranges caught compared to gill nets with mesh sizes similar to the inner panel mesh sizes of the trammel nets used in this study (Erzini et al., 2006).

Overall discard rates (D/T, in numbers) ranged from 15% in the Cyclades to 49% in the Algarve, with the latter percentage due largely to the discarding of large numbers of small sized pelagic species (e.g. *S. japonicus* and *S. pilchardus*). Borges et al. (2001) report that 13% in weight of the catches of smaller boats fishing with trammel nets close to shore in the Algarve are discarded. In this area much higher discard rates have been reported for active gears: 37% (Monteiro et al., 2001) to 70% (Borges et al., 2001) for deepwater crustacean trawlers, 62% for trawlers (Borges et al., 2001; Erzini et al., 2002), and 50.5% in numbers for demersal purse seiners (Gonçalves et al., 2004). A lower mean discard rate (27%) was reported for pelagic purse seiners (Borges et al., 2001; Erzini et al., 2002).

Similarly, studies from the Greek Seas also show that discards are lower in small-scale fisheries when compared with active gears. Thus, Tzanatos et al. (2007) report about 10% for the small-scale fisheries discards in the Patraikos Gulf. Likewise, in the Evvoikos Gulf the discard rate was considerably higher for beach-seines than gill and trammel nets both in terms of numbers and weights (beach seines >28%; gill and trammel nets <4%) (Stergiou et al., 1996). In addition, the discard rate of trawlers in the Greek seas (ranging between 39% and 49%: Machias et al., 2001) is much higher than those of trammel nets.

Few other studies have focused on by-catch and discarding practices of trammel nets. Some studies on trammel net selectivity provide information on the catches of under-sized commercial species (e.g. Fabi et al., 2002). Acosta and Appeldoorn (1995) refer to the dominance of sharks and rays in the catches of Puerto Rican trammel nets targeting finfish in coral reefs.

As for the catch compositions (see Stergiou et al., 2006), in most cases there was a strong seasonal effect that was reflected in the discards composition. Some of the most important fisheries in most of the areas were highly seasonal in nature (e.g. *S. officinalis* in the Algarve and the Gulf of Cadiz). The changes in discard composition were clearly shown in the multivariate analysis where four distinct groups were found in the Basque country and in the Algarve, corresponding to fishing trials carried out in the four seasons over a 1-year period. In contrast, only two groups were formed in the Gulf of Cadiz and in the Cyclades. In the case of the former, this was due to the fact that fishing trials were carried out during two periods of the year only, rather than over the whole year. In the case of the Cyclades, the results suggest that seasonal changes in the inshore fish communities could not be as pronounced in the eastern Mediterranean as they are in the eastern Atlantic and that inner mesh size selectivity could be more relevant in this case.

With the exception of *S. pilchardus* and *S. japonicus*, the numerically most important discarded species in the four areas, *T. luscus* and *T. draco* (Basque country), *B. boops* and *S. notata* (Algarve), *T. torpedo* and *H. didactylus* (Cadiz), *D. annularis* and *S. saurus* (Cyclades) were benthic or demersal species that are characteristic of soft bottom and soft bottom associated with rocky areas (Whitehead et al., 1984).

In addition to differences due to season, discard rates also changed as a function of mesh size. While outer panel mesh size had little or no effect on the discard rates, the smaller mesh inner panels clearly affected discard rates, which generally decreased with increasing inner panel mesh size. This pattern is also evident in the commercial component of the catches (Stergiou et al., 2006).

The combinations of inner and outer panel mesh sizes that had the least discards and the highest catch rates of the target species were within the mesh size ranges used normally by the commercial fishermen in each area (Erzini et al., 2006; Stergiou et al., 2006) even though the best combinations which include larger inner mesh sizes are not often used by local fishers (personal observation). The use of larger inner panel mesh sizes not only reduces by-catch and discards, but also reduces handling time on board, as removal of fish from trammel nets is one of the most time consuming tasks for fishers (Moth-Poulsen, 2003).

While in the Cyclades fish were discarded largely because they were either undersized or unmarketable, in the other areas poor condition was an important reason, especially when soak time was longer than usual due to bad weather. Thus, there was considerable discarding of commercially important species due to spoilage. Discarding due to damage or poor condition may be reduced by optimizing soak time, especially in the summer, when water temperatures are higher, leading to faster loss of quality of dead fish and invertebrates. An increase in scavenging, especially by species of the order Amphipoda (personal observation), in spring also contributed to spoilage and consequently to discarding. A decrease in soak time during the warmer months could contribute to higher quality of the landings since the fishing boats do not have cold storage refrigeration on board and rely on ice bought on land.

It is interesting to note that there are species such as *B. boops* and *S. japonicus* that are a target species in the Cyclades but are always discarded in the Algarve and Basque country. Also, elasmobranchs (e.g. *Torpedo* spp. and *Raja* spp.) are particularly important in the Gulf of Cadiz discards, with *T. marmorata*, although discarded in all four areas, is marketed only in the Algarve.

By-catch reduction devices have been tested in a variety of fishing gears and include panels/rigid grids (e.g. Stone and Bublitz, 1996; Campos et al., 2003) and turtle exclusion devices (e.g. Crowder et al., 1995) in trawls, pingers attached to gillnets to avoid/reduce the by-catch of cetaceans (e.g. Kraus et al., 1997) and panels in purse seines (e.g. Beltestad and Misund, 1995; Gonçalves et al., 2004). However, apart from experiments with different mesh sizes (e.g. Erzini et al., 2006), there has been no research on trammel net by-catch reduction. Nevertheless, a reduction in the number of fleets, soak time and choice of fishing ground as well as the use of larger mesh sizes in the inner panel may have a beneficial effect on catch composition, by-catches and discards.

The release of under-sized fish observed during the course of this study is a positive result. However, the few studies on post-release survival show that capture by trammel nets is quite traumatic, resulting in wounds and levels of stress that lead to relatively high mortality rates, of up to 27% or 40% in the case of *Sillago japonica* (Purbayanto et al., 2001) or *Pagrus major* (Chopin et al., 1996), respectively. The former authors concluded that gilling, which is strictly a function of mesh size, was the most important factor affecting post-release survival. Thus, the physiological responses of fish to capture depend not only on their life stage and reproductive cycle, but also on characteristics of the gear, the catching mechanisms and the fishing strategy (Chopin and Arimoto, 1995). Given the relation between soak time and post-capture mortality (Chopin et al., 1996), this is one of the factors that can most easily be manipulated, especially during the warmer seasons when survival rates are lower.

Some concern should be taken to avoid the catch of some rare or threatened species (IUCN, 2004), like *Caretta caretta*, *Alosa fallax* and *Alosa alosa*, through avoidance of certain areas in specific times of year. Moreover, research is required on the impacts and recovery of epifaunal benthic communities affected by these fisheries and also on the fate of discards of all these gears and their impact on the ecosystem.

In Europe, there is legislation regulating fishing activity, namely through technical measures such as minimum mesh sizes, height of static nets, delimitation of fishing grounds and depths, and duration of soak time (e.g. European Regulation CE n° 3071/95, 894/97, 850/98). Although the current study may help to establish appropriate mesh sizes, it is perhaps more important to ensure proper monitoring and enforcement of current legislation, especially with regard to mesh size and soak time regulations. This is indicated also by the fact that our results show that the current minimum landing sizes have no practical effect as undersized individuals of some of the most important commercial species are still caught and, thus, discarded.

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References

Acosta, A., Appeldoorn, R.S., 1995. Catching efficiency and selectivity of fillnets and trammel nets in coral reefs from southwestern Puerto Rico. Fish. Res. 22, 175–196.

Beltestad, A.K., Misund, O.A., 1995. Size selection in purse seines. In: Solving Bycatch: Considerations for Today and Tomorrow. Alaska Sea Grant College Program Report N° 96-03, University of Alaska Fairbanks, pp. 227–233.

Borges, T.C., Erzini, K., Bentes, L., Costa, M.E., Gonçalves, J.M.S., Lino, P.G., Pais, C., Ribeiro, J., 2001. By-catch and discarding practices in five Algarve (southern Portugal) métiers. J. Appl. Ichthyol. 17, 104–114.

Bray, J.R., Curtis, J.T., 1957. An ordination of the upland forest communities of southern Wisconsin. Ecol. Monogr. 27, 325–349.

Campos, A., Fonseca, P., Erzini, K., 2003. Size selectivity of diamond and square mesh cod ends for four by-catch species in the crustacean fishery off the Portuguese south coast. Fish. Res. 60, 79–97.

Chopin, F.S., Arimoto, T., 1995. The condition of fish escaping from fishing gears—a review. Fish. Res. 21, 315–327.

Chopin, F.S., Arimoto, T., Inoue, Y., 1996. A comparison of the stress response and mortality of sea bream *Pagrus major* captured by hook and line and trammel net. Fish. Res. 28, 277–289.

Clarke, K.R., Gorley, R.N., 2006. PRIMER v6: User Manual/Tutorial. PRIMER-E, Plymouth.

Clarke, K.R., Warwick, R.M., 2001. Change in Marine Communities: An Approach to Statistical Analysis and Interpretation. Natural Primer-E Ltd., Plymouth Marine Laboratory, Plymouth, United Kingdom.

Coelho, R., Erzini, K., Bentes, L., Correia, C., Lino, P.G., Monteiro, P., Ribeiro, J., Gonçalves, J.M.S., 2005. Semi-pelagic longline and trammel net elasmobranch catches in Southern Portugal: catch composition, catch rates and discards. J. Northwest Atl. Fish. Sci. 35, 531–537.

Crowder, L.B., Hopkins-Murphy, S.R., Royle, J.A., 1995. Effect of turtle excluder devices (TEDs) on loggerhead sea turtle strandings with implications for conservation. Copeia 4, 773–779.

Erzini, K., Costa, M.E., Bentes, L., Borges, T.C., 2002. A comparative study of the species composition of discards from five fisheries from the Algarve (southern Portugal). Fish. Manage. Ecol. 9, 31–40.

Erzini, K., Gonçalves, J.M.S., Bentes, L., Lino, P.G., Ribeiro, J., Stergiou, K.I., 2003. Quantifying the roles of competing static gears: comparative selectivity of longlines and monofilament gill nets in a multi-species fishery of the Algarve (southern Portugal). Sci. Mar. 67, 341–352.

Erzini, K., Gonçalves, J.M.S., Bentes, L., Moutopoulos, D.K., Casal, J.A.H., Soriguer, M.C., Puente, E., Errazkin, L.A., Stergiou, K.I., 2006. Size selectivity of trammel nets in southern European small-scale fisheries. Fish. Res. 79 (1–2), 183–201.

Erzini, K., Puente, E., Stergiou, K.I., Hernando, J. A. (Coordinators), 2001. Trammel net selectivity studies in the Algarve (Southern Portugal), gulf of Cadiz (Spain), Basque country (Spain) and Cyclades islands (Greece). Final Report UE-DG XIV-98/014, p. 435 + annexes.

Fabi, G., Sbrana, M., Biagi, F., Grati, F., Leonori, I., Sartor, P., 2002. Trammel net and gill net selectivity for *Lithognathus mormyrus* (L., 1758), *Diplodus annularis* (L., 1758) and *Mullus barbatus* (L., 1758) in the Adriatic and Ligurian seas. Fish. Res. 54, 375–388.

Gonçalves, J.M.S., Monteiro, P., Bentes, L., Coelho, R., Corado, M., Araújo, J., Canário, A., Erzini, K., 2004. Experimental By-catch Reducing Devices (BRD) in the demersal purse-seine fishery and evaluation of survivorship. FCT/POCTI/BSE/43113/2001, Final report, Universidade do Algarve, CCMAR, Faro, p. 126 + annexes.

Hall, M.A., 1996. On bycatches. Rev. Fish Biol. Fish. 6 (3), 319–352.

Hall, M.A., Alverson, D.L., Metuzals, K.I., 2000. By-catch: problems and solutions. Mar. Poll. Bull. 41, 204–219.

IUCN, 2004. 2004 IUCN Red List of Threatened Species, http://www.iucnredlist.org>, downloaded on October 23, 2006.

Kelleher, K., 2005. Discards in the world's marine fisheries: an update. FAO Fish. Tech. Paper 470, 1–131.

Kennelly, S.J., 1995. The issue of bycatch in Australia's demersal trawl fisheries. Rev. Fish Biol. Fish. 5, 213–234.

Kraus, S.D., Read, S.J., Solow, A., Baldwin, K., Spradlin, T., Anderson, E., Williamson, J., 1997. Acoustic alarms reduce porpoise mortality. Nature 388, 525.

Machias, A., Vassilopoulou, V., Vatsos, D., Bekas, P., Kallianiotis, A., Papaconstantinou, C., Tsimenides, N., 2001. Bottom trawl discards in the northeastern Mediterranean Sea. Fish. Res. 53 (2), 181–195.

Martins, R., Santos, M.N., Monteiro, C.C., Paes da Franca, M.d.L., 1992. Contribuição para o estudo da selectividade das redes de emalhar de um pano fundeadas na costa Portuguesa no biénio 1990–1991. INIP, Relat. Téc. Cient., 1–26.

Monteiro, P., Araújo, A., Erzini, K., Castro, M., 2001. Discards of the Algarve (Southern Portugal) crustacean trawl fishery. Hydrobiologia 449, 267–277.

Moth-Poulsen, T., 2003. Seasonal variations in selectivity of plaice trammel nets. Fish. Res. 61, 87–94.

Purbayanto, A., Tsunoda, A., Akiyama, S., Arimoto, T., Tokai, T., 2001. Survival of Japanese whiting *Sillago japonica* and by-catch species captured by a sweeping trammel net. Fish. Sci. 67 (1), 21–29.

Ramsay, K., Kaiser, M.J., Moore, P.G., Hughes, R.N., 1997. Consumption of fisheries discards by benthic scavengers: utilization of energy subsidies in different marine habitats. J. Animal Ecol. 66, 884–896.

Sokal, R.R., Rohlf, F.J., 1995. Biometry: The Principles and Practice of Statistics in Biological Research, 3rd ed. W.H. Freeman and Co., New York.

Stergiou, K.I., Moutopoulos, D.K., Soriguer, M.C., Puente, E., Lino, P.G., Zabala, C., Monteiro, P., Errazkin, L.A., Erzini, K., 2006. Trammel net catch species composition, catch rates and métiers in southern European waters: a multivariate approach. Fish. Res. 79 (1–2), 170–182.

Stergiou, K.I., Petrakis, G., Politou, C.-Y., 1996. Small-scale fisheries in the south Euboicos Gulf (Greece): species composition and gear competition. Fish. Res. 26, 325–336.

Stone, M., Bublitz, C.G., 1996. Cod trawl separator panel: potential reducing halibut bycatch. In: Solving Bycatch: Considerations for Today and Tomorrow. Alaska Sea Grant College Program Report No. 96-03, University of Alaska Fairbanks, pp. 71–78.

Tingley, D., Erzini, K., Goulding, I., 2000. Evaluation of the state of knowledge concerning discards practices in European fisheries. MegaPesca, 1–76.

Tzanatos, E., Somarakis, S., Tserpes, G., Koutsikopoulos, C., 2007. Discarding practices in a Mediterranean small-scale fishing fleet (Patraikos Gulf, Greece). Fish. Manage. Ecol. 14 (4), 277–285.

Whitehead, P.J.P., Bauchot, M.-L., Hureau, J.C., Nielsen, J., Tortonese, E. (Eds.), 1984. Fishes of the North-eastern Atlantic and the Mediterranean, vols. I–III. UNESCO.