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Discard analysis and damage to non-target species in the "rapido" trawl fishery

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Abstract This paper describes the catch composition in the rapido trawl fishery and the direct effects on non-target species. All data were collected on commercial fishing vessels so as to reflect commercial rapido-trawling practice. The effects on non-target species were measured using two different damage scales (three- and seven-level scales) depending on the morphology of the taxa. Damage assessment was performed taking into account the whole fishing process by collecting individuals that passed through the cod-end, individuals that were retained in the cod-end and dropped onto the deck and individuals that were collected at the end of the sorting operation just before their return to the sea. Due to differences in the habitat and spatial distribution of target species, discard/commercial ratio was very different among the three different target species fisheries: 1:6 in the queen scallop (*Aequipecten opercularis*) fishery, 2:1 in the flatfish (*Solea* spp., *Platichthys flesus*, *Psetta maximus* and *Scophthalmus rhombus*) fishery and 9:1 in the scallop (*Pecten jacobaeus*) fishery. Damage sustained by non-target species was species-specific and related to the morphology of different organisms. The sorting operation produced similar levels of injury to those of the gear itself: all discarded animals showed higher levels of damage after the sorting than before. Damage to animals that had passed through the cod-end followed the same pattern, and these data could give an estimate of the "unobserved mortality". Our observations indicated a higher impact on non-target species caused by the queen scallop fishery than that caused by the flatfish fishery. This could be due to the total amount of hard-shelled species (in the queen scallop fishery, *A. opercularis* accounted for 87% of the total catch biomass) in any given haul, since shells macerated the catch during towing. Discarded animals from the queen scallop fishery showed higher levels of damage than those collected in the flatfish fishery. The rapido trawl fishery seemed to exert a strong selective pressure on the macrobenthic community, being able to modify the epibenthic fauna structure which, in heavily exploited fishing grounds, was dominated by bivalves, gastropods, crabs, starfish and brittlestars.

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Introduction

The last decade has seen growing concern at the ineffectiveness of most fisheries assessment and management approaches, as reflected by trends in global landings statistics published by the FAO (Caddy 1999). The majority of fisheries-related research has hitherto been directed towards improving management of target species stocks (Kaiser 2000). However, there is also a need to consider fishing as a more ubiquitous agent in changing marine biodiversity (NRC 1995), with major effects at the ecosystem level that should be part of any assessment and management of fisheries (Jennings and Kaiser 1998).

Mobile fishing gears cause damage and mortality to benthic species and produce detectable changes on both benthic habitats and communities (Bergman and Hup 1992; Dayton et al. 1995; Kaiser and Spencer 1996b; Collie et al. 1997). This has provided the impetus to study the direct and indirect effects of fishing at the ecosystem level. The fate of non-target species is now becoming a subject to which conservation bodies and the scientific community are paying increasing attention in many parts of the world (Hall 1999; Hill and Wassenberg 2000).

The total amount of discarded catch (sensu Hall 1999) has been estimated at ca. 27% of the world's total landings (FAO 1994), but this estimate is only based on discarded commercial species and does not include non-target species. The quality and quantity of discards is related to gear and fishing ground features, so it is difficult to generalise about their consequences.

Estimates of by-catch biomass can be achieved by monitoring commercial vessels, but extrapolations of such data concerning the ecological effects of fishing of the whole fleet are inaccurate unless fishing effort and the ecology of different habitats are properly known. Even if precise by-catch data were available, this information would be of limited use in fisheries where a large proportion of non-target organisms pass through the net and is left to die or exposed to predation on the sea bed (Bergman and van Santbrink 2000).

As a first approximation, to understand the magnitude of global effects of fishing on non-target species, one could assume that these animals suffer 100% mortality due to the fishing process (Daan 1991). This assumption is too imprecise, however, if we want to explain processes with a multispecies approach, in which it is essential to consider the mortality of different commercial and non-commercial species that are discarded (Kaiser and Spencer 1995), a subject which is difficult to estimate for poorly studied non-target species (Pope et al. 2000).

For animals retained in the cod-end and subsequently deposited on deck, information can be obtained by means of survival studies, while survival estimates for species left on the sea bottom are more difficult to achieve (even if before vs. after density comparisons are possible, see Bergman and van Santbrink 2000).

However, survival tests are often expensive and time-consuming and, being carried out on board research vessels after experimental hauls, results cannot be regarded as representative of commercial fishing practises (for some methodological examples, see Wassenberg and Hill 1989, 1993; Fonds 1994; Kaiser and Spencer 1994, 1995; van Santbrink and Bergman 1994; Lehtonen et al. 1998; Wassenberg et al. 1998; Bergmann and Moore 2001a, b). On the other hand, in practise, it is difficult to operate on board commercial vessels using standard protocols and a sufficient number of replicates.

Another, and often complementary, approach evaluates injuries sustained by non-target species, estimated using damage scales, as proposed by Wassenberg and Hill (1989), Kaiser and Spencer (1995), Hill et al. (1996), Kaiser (1996), Farmer et al. (1998), and, more recently, by Prena et al. (1999), Bradshaw et al. (2000), Mensink (2000), Salini (2000), Bergmann and Moore (2001a, b) and Bergmann et al. (2001). This approach allows an evaluation of the relative fragility of non-target species, which could be an integral part of their sensitivity (sensu MacDonald et al. 1996); furthermore, a first estimate (underestimated and here referred to as "minimum lethal rate") of the mortality induced by the rapido fisheries can be obtained considering animals whose bodies have been completely crushed. This approach permits work on board commercial vessels, even if samples are subsequently processed in the laboratory; standardisation of methodologies seems to be easier than for survival tests, and enables comparison of the physical effects on non-target species of different fishing gears, as well as the study of the effects of the same gear on species living on different fishing grounds.

The aim of the present study was to analyse the direct effects of "rapido" trawls on non-target species, distinguishing between different types of fishing grounds to test the hypothesis that the same gear used on different fishing grounds can induce different types/amounts of damage on caught specimens.

Materials and methods

Rapido fishing

The "rapido" trawl is a bottom gear typically used in fisheries in the western Adriatic Sea. It consists of a modified beam trawl (Giovanardi et al. 1998; Hall-Spencer et al. 1999), with a rigid mouth fitted with iron teeth (5–7 cm long) along the lower part (Fig. 1).

During fishing, the gear is towed at high speed (11 km h^{-1}), with a spoiler that prevents the gear from rising off the bottom. A commercial vessel typically tows four sets of gear simultaneously and fishes an area of up to 0.13 km^2 h^{-1}. Rapido gear is used to target flatfish (*Solea* spp., *Platichthys flesus*, *Psetta maximus*, *Scophthalmus rhombus*) on inshore (3–6 km) muddy bottoms, and pectinids (*Pecten jacobaeus*, *Aequipecten opercularis*) on offshore (10–65 km) sandy bottoms. Vessels fishing for pectinids can be distinguished as "scallop boats" and "queen scallop boats" on the basis of which target species has the highest density in the exploited fishing grounds.

Chioggia is a commercial fishing port south of Venice, with a fleet of 41 rapido vessels (mean ± SD: size = 52.4 ± 28.6 GT, power = 549.8 ± 252.9 HP engines), which represents about 65% of the Adriatic rapido fleet. On the basis of the target species, commercial fishing vessels of the Chioggia fleet can be grouped as shown in Table 1 (Pranovi, unpublished data). The size and engine power of commercial rapido vessels is significantly higher for pectinid boats than for flatfish boats because scallop grounds are located further offshore, the catches are heavier and the grounds are harder.

Sample collection

Samples (commercial and discard) were collected from the catch on commercial vessels in 1998 and 1999. A total of 20 hauls were examined from vessels with different target species: flatfish (nine tows), queen scallops (seven tows) and scallops (four tows)[1].

In order to discriminate between gear and sorting effects, haphazard samples (standardised volume by means of a 12 l basket) were collected: (1) immediately after the catch was dropped onto the deck ("gear") and (2) just before the discarded specimens were rejected at sea ("sort").

To assess damage to animals that passed through the cod-end, six 5 min hauls were taken on muddy and sandy bottoms using a commercial rapido trawl (80 mm cod-end stretched mesh size), equipped with an external cover (mesh size 56 mm). All animals collected in the cod-end and the cod-end cover were analysed. The samples were handled carefully to avoid additional damage, and were stored at –20°C after sorting by species.

[1]These samples were collected only to record data about commercial catch and discard

Freezing and thawing change the "consistency" of animals, and this can produce an increase of damage towards higher scores, due to the loss of limbs (crabs) or arms (brittlestars and starfish). All this, however, has only minor or no effects on the highest damage class (score = 6) and on the relative comparison of fishing processes.

Moreover, our experimental protocol did not distinguish between recent and ancient arm/limb losses, and so the damage evaluation carried out could be considered the integration of recent injuries experienced by the individual.

Finally the possibility of autotomy should be considered in echinoderms and crustaceans when they are threatened (entangled) or damaged (see Bergman and Moore 2001a,b). As demonstrated by Bergman and Moore, the survival chances between autotomised and trawl-induced damage were significantly different, but both could be considered part of "the fishing effects".

Damage assessment

Samples were kept for 12 h at 4°C then identified, counted and weighed (±0.1 g wet wt). Body size (to the closest 0.5 cm for Porifera, Mollusca Bivalvia, Echinoidea, Holoturoidea and Tunicata; to the closest 1 mm for Asteroidea, Ophiuroidea and Crustacea) was also recorded (carapace length for crabs, shell length for molluscs, disk diameter for brittlestars, arm length for starfish, body length for holoturians and sponges). Damage was then assessed using one of two scales, depending on the morphology of the taxa.

Three-level scale

As suggested by other authors (MacDonald et al. 1996; Mensink et al. 2000), we applied a three-level scale for damage assessment of most species:

0 no detectable damage,

1 visible damage,

2 body completely crushed.

The scores were assigned considering species morphology as shown in Table 2. For some taxa (e.g. Annelida, Holoturoidea, Tunicata) levels 0 and 1 were grouped since it was difficult to distinguish low–medium damage as external hard body structure was lacking.

Seven-level scale

Starfish and brittlestars were examined using a seven-level damage scale (Fig. 2) (Kaiser and Spencer 1995), counting the number of lost or severely damaged arms (score = 0–5) and the presence of heavy damage to the central disk (score = 6). Brachiuran damage was also assessed using a seven-level scale following Wassenberg and Hill (1989) (Fig. 2):

0 no damage,

1 one leg missing,

2 two or more legs missing,

3 one claw missing,

4 one claw and legs missing,

5 two claws missing, with or without other legs lost,

6 body crushed or pinched.

A score of 2 (on the three-level scale) and 6 (on the seven-level scale) provide minimum estimates of total discard mortality.

Table 1 Characteristics of the Chioggia rapido trawl fleet (*SD* standard deviation; *GT* gross tonnage; *HP* horse power)

Target species	*n*	Mean size (GT)	SD	Mean power (HP)	SD
Flatfish	7	28.34	18.49	279.57	118.05
Scallop	11	55.41	29.99	565.18	263.52
Queen scallop	5	45.17	21.70	528.00	231.49
Flatfish and pectinid[a]	10	47.84	15.09	550.43	197.09
Pectinid and mid-water trawl[a]	8	75.94	28.97	679.50	209.78

[a]Vessels which change target and/or fishing gear according to the fishing season

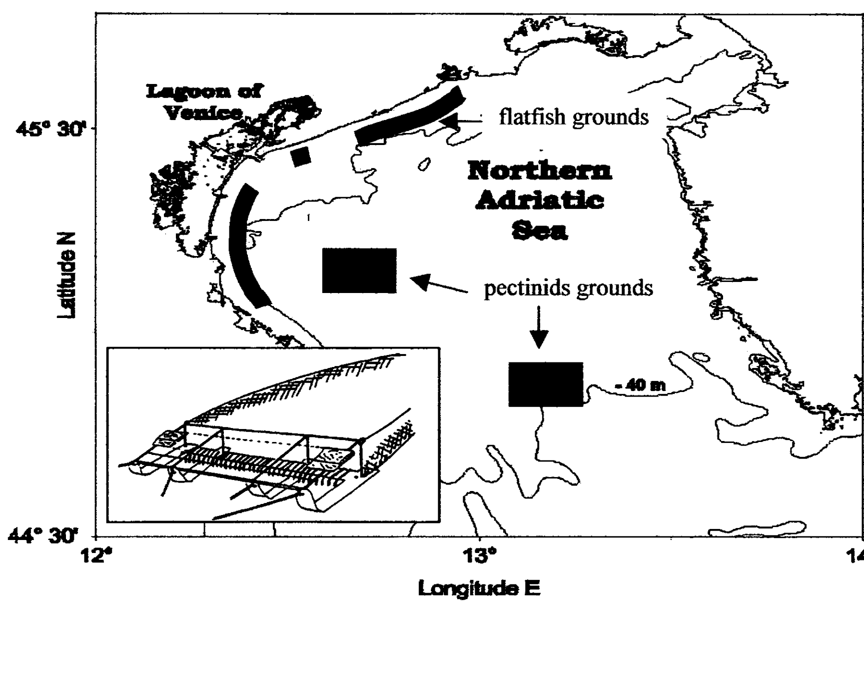

Fig. 1 Distribution of "rapido" fishing grounds. *Inset*: diagram of "rapido" gear

Table 2 Three-level scale used for damage assessment

Taxon	Damage = 1	Damage = 2
Porifera	Body not crushed or pinched[a]	Body crushed or pinched, severe damage
Bivalvia	Outer lip with light damage	Body crushed or pinched, major damage in a valve's border, hole in the shell
Gastropoda	Outer lip with light damage, siphonal canal broken	Body crushed or pinched, hole in the shell, operculum missing
Annelida	Body not crushed or pinched[a]	Body crushed or pinched, severe damage
Echinoidea	Most of aculea broken/lost	Body crushed or pinched, severe damage
Holoturoidea	Body not crushed or pinched[a]	Body crushed or pinched, severe damage
Tunicata	Body not crushed or pinched[a]	Body crushed or pinched, severe damage

[a]Taxa for which scores 0 and 1 were grouped, since it was difficult to distinguish low–medium damage

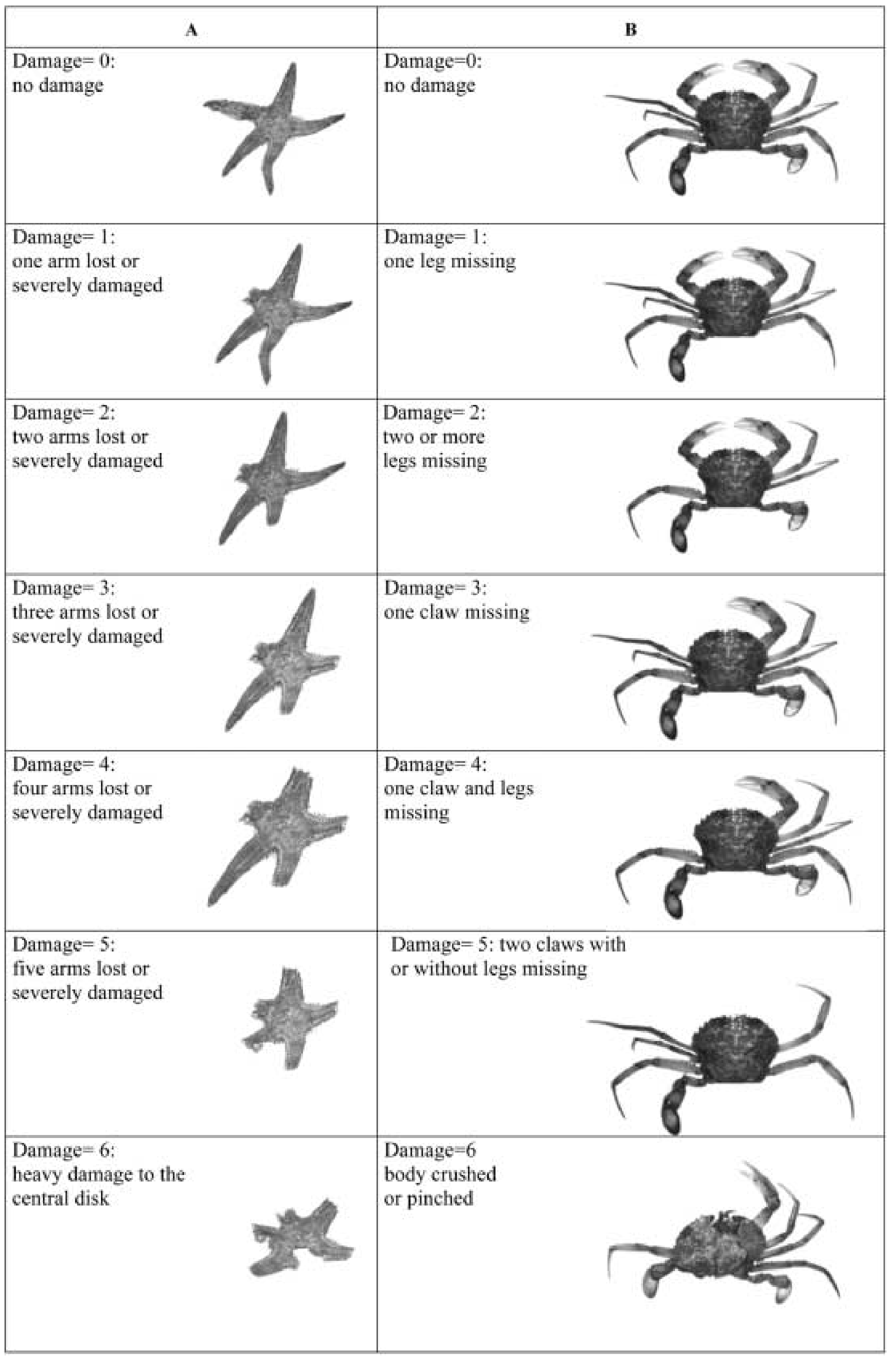

Fig. 2a, b Examples of seven-level damage scale applied to starfish (**a**) and crabs (**b**)

Data analysis

Comparison between different phases of the fishing process and different fishing grounds was performed by means of Mann–Whitney *U*-test. To evaluate the correlation between body size and mean damage level a Spearman's rank correlation test was applied. The Statistica 4.0 software package was used for all statistical analyses.

Results

Catch description

The total catch and discard/commercial catch ratio were very different depending on the target species. The total catch was ca. 700 kg day^{-1} in the flatfish fishery, whereas it always exceeded 3000 kg day^{-1} in the pectinid fishery (Table 3). In the queen scallop fishery, *Aequipecten opercularis* accounted for 87% of the total catch, whereas only 30% of the flatfish catch was comprised of flatfish and only 10% of the scallop fishery was comprised of *Pecten jacobaeus*. The discard/commercial ratio also showed high fluctuations between the three target species fisheries (Table 3), with the lowest value recorded for queen scallops and the highest for scallops.

This trend also holds true in terms of biomass and abundance of discards per kilogram of main target species: the recorded values varied by more than two orders of magnitude (Table 4).

Commercial catch composition

Due to differences in catch volumes and weights, commercial hauls were usually shorter (43.2 ± 5.7 min, $n = 7$) on pectinid grounds than on flatfish grounds (55.3 ± 9.5, $n = 9$). Comparison of catch composition per haul (Table 5) revealed that in the queen scallop fishery 97% of the commercial catch was *A. opercularis*, whereas in the flatfish and scallop fisheries the target species contributed to only about 50% of the commercial catch (flatfish 50% and scallops 53%), with a high percentage of incidental catch species such as octopus (*Eledone* spp.), cuttlefish (*Sepia officinalis*) and mantis shrimp (*Squilla mantis*).

Table 3 Mean catch composition (wet weight per day per vessel) and discard/commercial ratio recorded in the rapido fishery grouped into three target species (*SD* standard deviation)

	Flatfish		Queen scallop		Scallop	
	Mean (kg)	SD	Mean (kg)	SD	Mean (kg)	SD
Commercial catch (kg)	219	92	2971	1552	309	32
Discard (kg)	497	109	454	51	2894	195
Total catch (kg)	716	157	3425	1570	3203	213
Discard/ Commercial	2.27	0.47	0.15	0.10	9.37	0.99

Table 4 Mean quantity of non-target species caught per kilogram of target species in the rapido trawl fishery; 1 kg corresponds on the average to: 5 flatfish, 54 *Aequipecten opercularis*, 9 *Pecten jacobaeus* (*SD* standard deviation)

	Flatfish		Queen scallop		Scallop	
	Mean	SD	Mean	SD	Mean	SD
Biomass (kg)	4.6	1.1	0.15	0.1	20.5	2.6
Abundance (number of individuals)	735	215	27	10	2212	618

Discarded catch composition

The composition of the discarded catch fraction was quite different among the three fisheries (Fig. 3); this could be related to the assemblages in which the target species live (Pèrés and Picard 1964), as demonstrated also by previous studies (Giovanardi et al. 1998; Hall-Spencer et al. 1999; Pranovi et al. 2000).

Table 6 shows the biomass of the most important taxa recorded in the discarded fraction of the catch of the three target fisheries (see the electronic supplementary material for further details).

In the flatfish fishery, discards were dominated by Gastropoda (71%), mainly *Hexaplex trunculus*, *Bolinus brandaris* and *Aporrhais pespelecani*, species typical of the inshore muddy fauna, and the mean overall discarded biomass was the lowest recorded (40 kg per trawl). The highest discarded biomasses (271.4 kg per trawl) were recorded in the scallop fishery, where Porifera (33%), Echinodermata (32%) and Tunicata (21%) represented the main taxa caught.

In the queen scallop fishery (70 kg per trawl) the discard was dominated by Echinodermata, Arthropoda and Mollusca Bivalvia (36, 24 and 15%, respectively).

Damage to non-target species

For meaningful statistical analysis we concentrated on data for the most abundant and/or representative

Table 5 Commercial catch composition (kg haul^{-1}) in the three target species fisheries (*SD* standard deviation)

	Flatfish		Queen scallop		Scallop	
	Mean (kg)	SD	Mean (kg)	SD	Mean (kg)	SD
Aequipecten opercularis	–	–	499.98	362.39	–	–
Pecten jacobaeus	–	–	3.56	2.35	17.96	6.03
Flatfish	8.91	1.85	0.39	0.1	1.92	1.69
Cephalopoda	3.29	3.23	6.41	4.7	12.43	2.21
Squilla mantis	4.29	1.01	–	–	–	–
Other fish	0.63	0.18	0.41	0.35	1.21	0.60
Other taxa	0.71	0.40	0.08	0.10	0.19	0.25
Total commercial catch	17.82	3.49	510.83	360.91	33.70	3.44

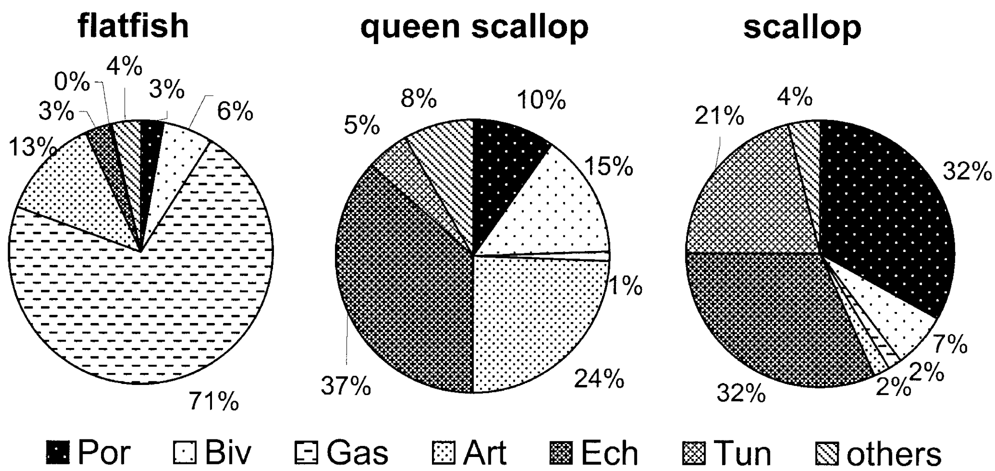

Fig. 3 Composition of discarded catch of flatfish, queen scallop and scallop boats (*Por* Porifera; *Biv* Mollusca Bivalvia; *Gas* Mollusca Gastropoda; *Ech* Echinodermata; *Tun* Tunicata)

species. The complete list of "minimum lethal rate" percentages for each discarded species is given in the electronic supplementary material.

Table 6 Discard composition (kg haul^{-1}) in the three target species fisheries (*SD* standard deviation)

	Flatfish		Queen scallop		Scallop	
	Mean (kg)	SD	Mean (kg)	SD	Mean (kg)	SD
Porifera	1.08	1.62	6.74	6.57	89.44	8.42
Cnidaria	0.01	0.02	0.12	0.23	10.29	3.70
Mollusca Gastropoda	28.96	7.72	0.83	1.06	4.12	3.50
Mollusca Bivalvia	2.55	1.70	10.31	9.65	18.66	7.81
Mollusca Cephalopoda	0.36	0.75	3.12	7.83	0	0
Annelida	0	0	1.71	2.74	0.27	0.32
Arthropoda	5.13	5.81	17.03	15.05	5.27	1.43
Echinodermata	1.24	1.30	25.47	32.46	86.52	12.13
Tunicata	0.09	0.27	3.58	6.08	57.02	9.03
Pisces	1.03	1.38	0.50	0.86	0.03	0.06
Total by-catch	40.45	8.89	69.69	7.82	271.36	18.25

Three-level damage scale

In the queen scallop fishery the highest mean level of damage was recorded for the bivalve *Atrina fragilis*, with >60% of the individuals showing maximum levels of damage (Table 7). Comparison of the two phases of on-deck handling showed no significant changes in the mean damage ($P=0.643$). Instead, the bivalve *Aequipecten opercularis* – the most abundant species in the catch – had a low damage score (Fig. 4), which significantly increased during the sorting ($P<0.001$).

In the flatfish rapido trawl fishery, almost all discards had low damage scores with no statistically significant differences before and after sorting. The percentages of maximum damage were also low with the sponge *Suberites domuncula*, and the gastropod *Hexaplex trunculus* showed no severe damage (Table 7; Fig. 5).

Seven-level damage scale

This scale was applied to taxa which were important components of the muddy and sandy bottom fauna (e.g.

Table 7 Mean impact (*mean imp.*) and "minimum lethal rate" (*max. imp.*) percentage (three-level scale) for the most abundant discarded species recorded before and after the sorting on queen scallop and flatfish boats (*n* number of individuals; *SD* standard deviation; *P*-level significance level, Mann–Whitney *U*-test)

Fishery	Species	Gear				Sort				*P*-level
		n	Mean imp.	SD	Max. imp. (%)	*n*	Mean imp.	SD	Max. imp. (%)	
Queen scallop	*Aequipecten opercularis*	2239	0.10	0.42	4.38	494	0.60	0.81	20.45	0.000
	Atrina fragilis	8	1.38	0.92	62.50	12	1.67	0.49	66.67	0.643
	Pecten jacobaeus[a]	222	0.27	0.67	11.71	–	–	–	–	–
	Total no.	2491	0.72	0.63	29.88	506	1.14	0.76	43.56	
Flatfish	*Aporrhais pespelecani*	70	0.07	0.08	1.43	210	0.27	0.47	0.95	1.000
	Bolinus brandaris	152	0.32	0.49	1.32	257	0.36	0.55	3.50	0.877
	Hexaplex trunculus	445	0.02	0.12	0	448	0.06	0.28	0.89	1.000
	Suberites domuncola	5	0	0	0	12	0	0	0	1.000
	Total no.	654	0.26	0.33	3.90	1050	0.17	0.17	1.34	

[a]All animals caught were retained

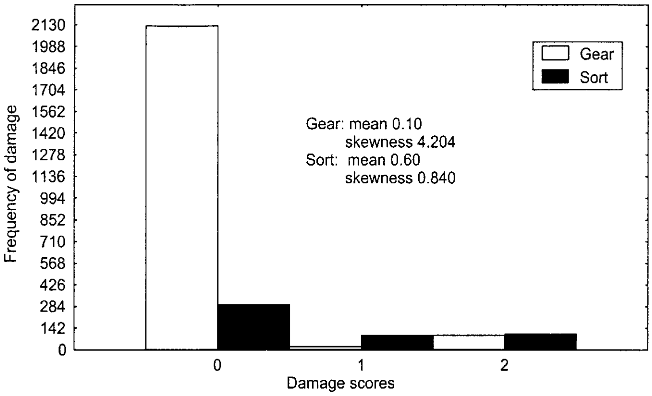

Fig. 4 *Aequipecten opercularis*. Frequency of damage for the two phases of on-deck handling in the queen scallop fishery (*gear* individuals dropped onto deck; *sort* individuals before returned to sea)

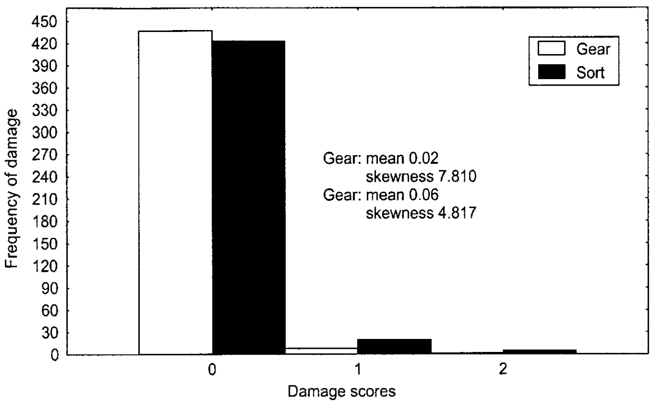

Fig. 5 *Hexaplex trunculus*. Frequency of damage for the two phases of on-deck handling in the queen scallop fishery (*gear* individuals dropped onto deck; *sort* individuals before returned to sea)

swimming crabs *Liocarcinus* sp., sandstars *Astropecten irregularis* and the brittlestars *Ophiura ophiura*; see Table 8).

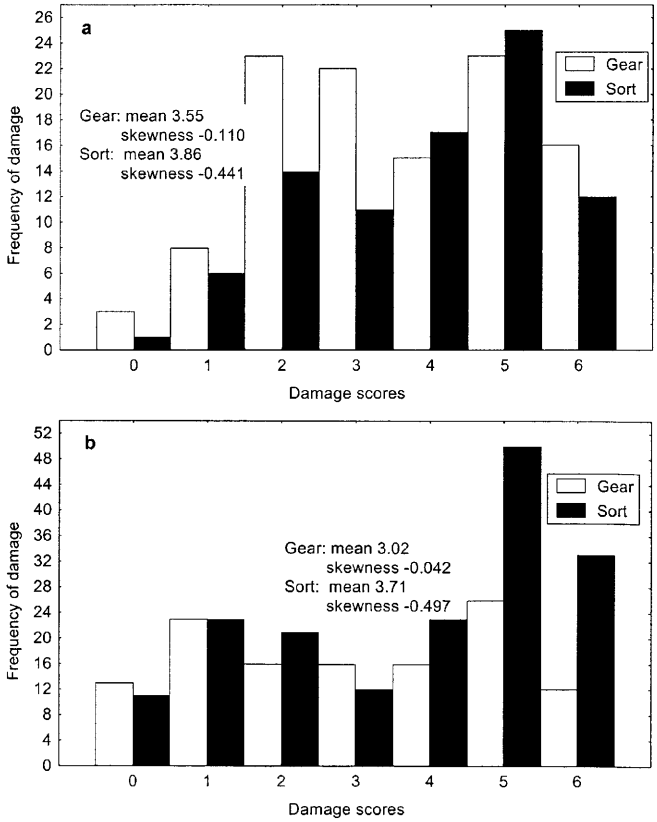

Fig. 6a, b *Liocarcinus* sp. Frequency of damage for the two phases of on-deck handling in the queen scallop (**a**) and flatfish (**b**) fisheries (*gear* individuals dropped onto deck; *sort* individuals before returned to sea)

All discards in the queen scallop fishery showed high values of mean damage. *Liocarcinus* sp., *O. ophiura*, *Ophiotrix fragilis* and *Ophiura albida* showed significant increases in mean damage during sorting operations ($P < 0.001$, $P < 0.001$, $P < 0.001$, $P < 0.01$, respectively; Table 8; Figs. 6, 7, 8).

Trends recorded for discards from the flatfish fishery were similar, with significant increases in damage due to

Table 8 Mean impact (*mean imp.*) and "minimum lethal rate" (*max. imp.*) percentage (seven-level scale) for the most abundant discarded species recorded before and after the sorting on queen scallop and flatfish boats (*n* number of individuals; *SD* standard deviation; *P*-level significance level, Mann–Whitney *U*-test)

Fishery	Species	Gear				Sort				*P*-level
		n	Mean imp.	SD	Max. imp. (%)	*n*	Mean imp.	SD	Max. imp. (%)	
Queen scallop	*Liocarcinus* sp.	86	3.22	2.22	26.74	96	4.75	1.50	43.43	0.000
	Astropecten irregularis	110	3.55	1.66	14.55	86	3.86	1.57	13.95	0.214
	Ophiura ophiura	283	5.25	0.55	29.68	355	5.47	0.51	47.32	0.000
	Ophiotrix fragilis	160	5.69	0.54	70.63	158	5.98	0.14	98.10	0.000
	Ophiura albida	59	5.14	0.43	16.95	83	5.41	0.49	40.96	0.008
	Total	747	4.48	1.22	30.76	781	5.09	0.82	48.75	
Flatfish	*Liocarcinus* sp.	169	1.65	2.04	10.06	234	2.39	2.20	16.67	0.001
	Astropecten irregularis	122	3.02	1.93	9.84	173	3.71	1.94	19.08	0.003
	Ophiura ophiura	99	5.28	0.50	30.30	125	5.44	0.59	47.20	0.031
	Ophiotrix fragilis	1	4.00	0	0	1	5.00	0	0	1.000
	Ophiura albida	4	5.25	0.5	25	4	5.50	0.58	50.00	0.564
	Total	395	3.84	1.55	15.04	537	4.41	1.34	26.59	

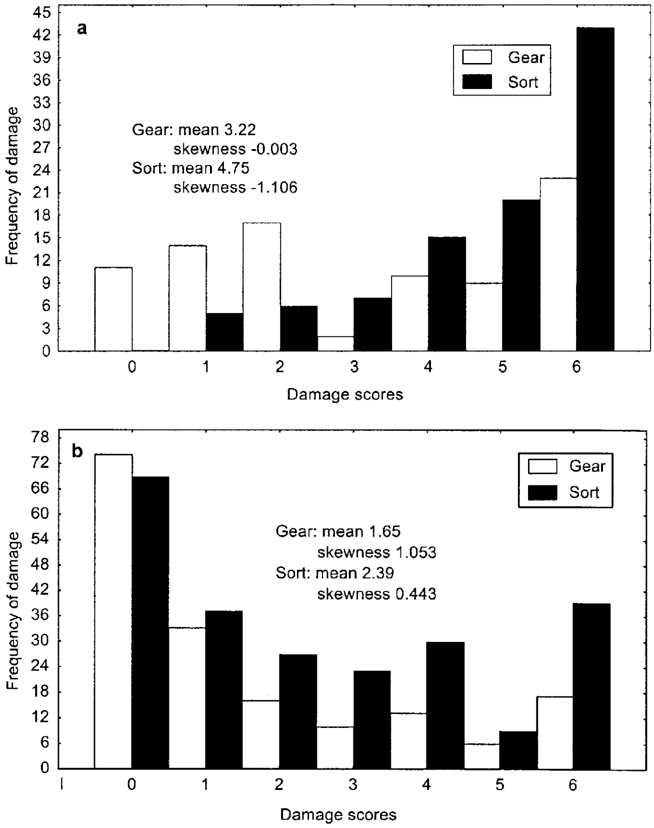

Fig. 7a, b *Astropecten irregularis*. Frequency of damage for the two phases of on-deck handling in the queen scallop (**a**) and flatfish (**b**) fisheries (*gear* individuals dropped onto deck; *sort* individuals before returned to sea)

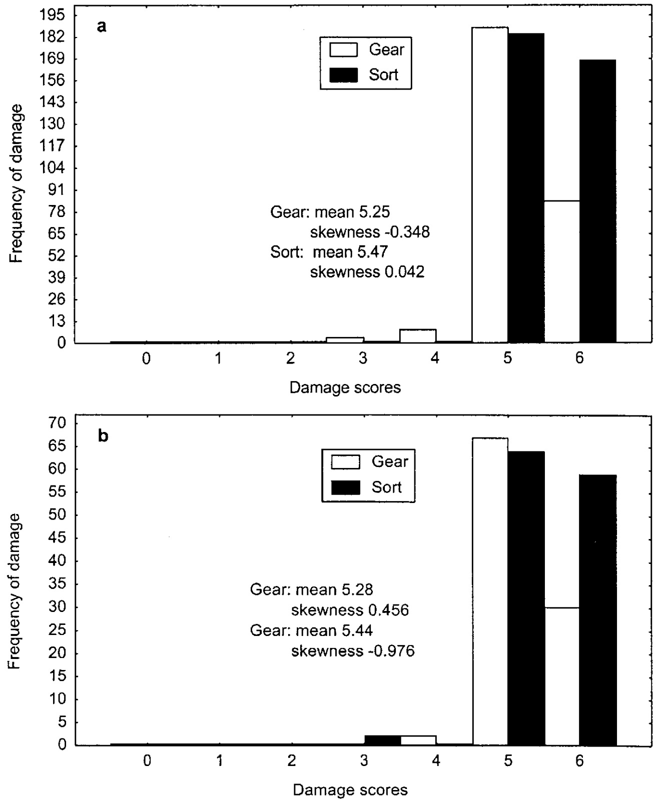

Fig. 8a, b *Ophiura ophiura*. Frequency of damage for the two phases of on-deck handling in the queen scallop (**a**) and flatfish (**b**) fisheries (*gear* individuals dropped onto deck; *sort* individuals before returned to sea)

the sorting process for *Liocarcinus* sp., *A. irregularis* and *O. ophiura* ($P < 0.01$, $P < 0.01$, $P < 0.05$, respectively; Table 8; Figs. 6, 7, 8). Considering the same handling level (gear or sort), damage recorded in the flatfish fisheries was always significantly lower than that recorded in the queen scallop fishery ($P < 0.001$ and $P < 0.05$, respectively) in *Liocarcinus* sp. and *A. irregularis* for specimens dropped onto the deck and only in *Liocarcinus* sp. ($P < 0.001$) for individuals collected just before being returned to the sea.

O. ophiura showed similar levels of damage in the flatfish and queen scallop fisheries at the same fishing process level. The number of individuals collected on muddy bottoms permitted no statistically meaningful comparisons for *O. fragilis* and *O. albida*.

A positive correlation between body size and mean damage (Table 9) was found for *Liocarcinus* sp. in the queen scallop fishery after the sorting process ($R = 0.390$, $P = 0.001$), whereas a negative correlation was found in the flatfish fishery ($R = -0.153$, $P = 0.025$). *A. irregularis* had a positive correlation in both target species fisheries after the sorting process ($R = 0.270$, $P = 0.019$ in queen scallop fishery; $R = 0.240$, $P = 0.003$ in flatfish fishery). Finally, *O. albida* had a positive correlation in the queen scallop fishery at the gear level ($R = 0.257$, $P = 0.049$). All other tested species showed no significant correlation.

Cod-end cover experiments

Only few species, such as crabs, starfish and brittlestars, showed significantly increased damage (Table 10). For example, *Liocarcinus* sp. on sand ($P = 0.001$) together with *A. irregularis* and *O. ophiura* on mud ($P < 0.05$ and $P < 0.001$, respectively). Data collected allow preliminary consideration of rapido selectivity. Catch volume ratio between cover and cod-end was 1:4 on sandy grounds and 2:1 on muddy grounds, showing a quicker net clogging effect on sandy fishing grounds than on muddy ones. This effect, probably due to the abundance, morphology and body size of dominant species living on the sandy bottom (Hall-Spencer et al. 1999), indicated a quick selectivity loss of the rapido gear, which could affect the damaging action on the animals caught.

Discussion

Rapido trawl fisheries can be grouped on the basis of the main target species or the type of ground exploited. The two scallop species studied belong to the same assemblage community ("Biocoenose des Fonds Détritique Côtiers" sensu Pérès and Picard 1964) and are often

Table 9 Spearman's rank correlation between body size and damage (significant correlations are evidenced in bold)

Fishery			*Liocarcinus* sp.	*Astropecten irregularis*	*Ophiura ophiura*	*Ophiotrix fragilis*	*Ophiura albida*
Queen scallop	Gear	*n*	73	98	276	154	59
		R	–0.158	0.131	–0.022	–0.120	**0.257**
		P-level	0.181	0.199	0.718	0.138	**0.049**
	Sort	*n*	74	75	341	156	80
		R	**0.390**	**0.270**	–0.053	0.114	–0.091
		P-level	**0.001**	**0.019**	0.333	0.157	0.423
Flatfish	Gear	*n*	165	107	99	1	4
		R	0.019	0.140	0.054	–	–1.000
		P-level	0.813	0.150	0.597	–	–
	Sort	*n*	215	149	124	1	4
		R	**–0.153**	**0.240**	0.124	–	0
		P-level	**0.025**	**0.003**	0.169	–	1
Queen scallop	Cod-end	*n*	112	7	0	350	–
		R	**–0.578**	–	–	**0.167**	–
		P-level	**0.000**	–	–	**0.002**	–
	Cover	*n*	19	4	11	18	–
		R	–0.009	–	0.129	0.390	.
		P-level	0.971	–	0.706	0.110	–
Flatfish	Cod-end	*n*	1	67	46	2	–
		R	–	–0.203	–0.146	–	–
		P-level	–	0.099	0.335	–	–
	Cover	*n*	5	7	99	5	–
		R	0.289	–0.364	0.000	0.559	–
		P-level	0.637	0.423	0.996	0.327	–

Table 10 Mean impact (*mean imp.*) and "minimum lethal rate" (*max. imp.*) percentage (three- and seven-level scale) for the most abundant discarded species recorded before and after the sorting on queen scallop and flatfish boats (*n* number of individuals; *SD* standard deviation; *P*-level significance level, Mann–Whitney *U*-test)

Fishery	Species	Cod-end				Cover				*P*-level
		n	Mean imp.	SD	Max. imp. (%)	*n*	Mean imp.	SD	Max. imp. (%)	
Queen scallop	*Aequipecten opercularis*	728	0.20	0.59	9.62	49	0.06	0.32	2.04	0.135
	Liocarcinus sp.	112	2.06	2.02	12.50	23	3.91	2.29	47.83	0.001
	Astropecten irregularis	7	5.00	0	0	8	4.63	0.74	12.50	0.224
	Ophiura ophiura	0				11	5.09	1.76	54.55	
	Ophiotrix fragilis	357	5.39	0.53	41.18	19	5.42	0.90	63.16	0.328
	Total	1,274	3.16	2.47	15.83	113	3.30	2.33	35.57	
Flatfish	*Bolinus brandaris*	24	0.33	0.48	0	26	0.31	0.47	0	0.877
	Hexaplex trunculus	44	0	0	0	84	0	0	0	1.000
	Liocarcinus sp.	1	4.00	0	0	5	4.20	1.92	20.00	1.000
	Astropecten irregularis	72	4.03	1.61	19.44	18	4.89	1.37	33.33	0.024
	Ophiura ophiura	46	5.35	0.57	39.13	102	5.82	0.38	82.35	0.000
	Ophiotrix fragilis	2	6.00	0	100.00	5	5.82	0.45	80.00	0.699
	Ophiura albida	0				2	5.50	0.71	50.00	
	Total	189	3.29	2.54	26.43	242	3.50	2.55	35.95	

caught together but tend to dominate on different grounds (see also Pérès and Picard 1964).

The occurrence of certain target species dictates the fishing fleet's movements: "flatfish boats" operate inshore (3–6 km) and exploit a dispersed resource, whereas "pectinid boats" operate on confined grounds of variable but limited extent as fishing there has become uneconomical due to stock depletion (Maurizio and Castagnolo 1986). This strategy has led to progressive shifts of commercial pectinid grounds. At present, the most productive queen scallop grounds are located adjacent to and within Croatian waters (where the rapido fishery is strictly regulated; Cetnić and Soldo 1999).

On the basis of catch composition data it is appropriate to define flatfish and scallop rapido fisheries as multi-target fisheries, since the mean wet weight of accessory/incidental catch (FAO 1994) often exceeded the biomass of the target species. This incidental catch is landed and marketed, whereas in northern European countries it is usually discarded (Hall-Spencer et al. 1999).

Due to differences in the habitat and spatial distribution of target species, discard/commercial ratios were very different among the three different target species fisheries. In the queen scallop fishery the ratio was 1:6, but in the flatfish fishery, which exploits very scattered resources, and the scallop fishery, which exploits grounds with high concentrations of non-target species (mainly sponges and tunicates; see Hall-Spencer et al. 1999), the ratios were inverted (respectively 2:1 and 9:1). The high discard/commercial catch ratio may be attributable to the low density of target species as a result of over-exploitation. In 1986–1987, rapido trawlers caught 2000 kg scallops day^{-1}, cf. present catches of 100–150 kg day^{-1}.

Habitat differences also affect the discard composition, particularly the epifauna (see different dominance in taxa of the three target species fisheries). However, as has been stressed by others (FAO 1994; Kaiser and Spencer 1995), quantification of discards alone is a poor indicator of the effects of fishing gear on biological communities.

Assessment of physical damage sustained by non-target species during all phases of the fishing process could improve knowledge of the direct impact of rapido fishing gear, as different taxa are affected by different parts of the fishing process (Sangster 1994).

Working on commercial fishing vessels makes accurate data collection more difficult than in controlled experimental trawls from research vessels. However, our study has the advantage of reflecting commercial rapido fishing practise, including on-deck handling, and so to assess the damages on discarded species due to the actual sorting procedures by fishermen on the discarded species. Therefore, the obtained picture may be more useful for management decisions.

In spite of growing scientific interest in by-catch damage assessment, no standard protocol for data collection and statistical analysis exists to date. Authors utilise different methods to assess damage and mortality, particularly as different taxa need to be treated differently.

In this study we applied two scales in relation to the morphology of different organisms. The injuries induced by rapido gear were species-specific and strongly correlated with the morphology (rounded, with or without appendages), body structure (external protection or soft body) and body size. Species with external shells (e.g. bivalves, gastropods and hermit crabs) were well protected (Bergmann et al. 2001) and rarely damaged by the rapido gear (Hall-Spencer et al. 1999).

Species with a rounded morphology and intermediate body size, such as the sponge *Suberites domuncula*, were rarely seriously damaged. In contrast, the important "structural" bivalve *Atrina fragilis* (MacDonald et al. 1996; Warwick et al. 1997; Hall-Spencer et al. 1999) sustained high levels of damage (60%), possibly due to its large size (to 20 cm shell length). Also, 100% of the echinoids with medium–large body size, such as *Echinus* sp., were crushed by the gear.

Damage to soft-bodied species was difficult to evaluate: 40% of *Ocnus planci* were injured, but it was uncertain whether such damage was lethal. Crabs, starfish and brittlestars had intermediate levels of damage, such as arm loss or crushing as described for beam and *Nephrops* otter trawls (Kaiser and Spencer 1995; Bergmann et al. 2001).

The comparison between damage suffered by the same species caught in the queen scallop fishery (on sand) and the flatfish fishery (on mud) indicated that animals were more severely injured by the scallop fishery, with significant differences shown for *Liocarcinus* sp. and *Astropecten irregularis*. This effect could be related to the amount of hard-shelled species in the catch (in the queen scallop fishery *A. opercularis* accounted for up to 87% of the total catch), since shells macerated the catch during towing and hauling.

We have been able to estimate the injuries caused by sorting: all discarded animals showed higher levels of damage after sorting than before. Handling and trampling during the sorting procedure produced similar levels of injury to those of the gear itself.

Damage to animals that passed through the cod-end followed similar patterns to those for captured individuals, i.e. species with appendages and no hard shell suffered major damage (20% to >60% of crabs and echinoderms caught in the net cover had the highest damage level). These data may be of use for estimates of "unobserved mortality" (sensu Hall 1999), which probably represents an important part of the total mortality caused by trawling (Bergman and van Santbrink 2000).

Data on damage and body size showed no clear correlation. In many cases all size classes sustained similar injuries, and a significant correlation was only found in *A. irregularis* (large specimens were more damaged), *Liocarcinus* sp. (positive correlation at gear level in queen scallop fishery and negative correlation after the sorting in flatfish fishery) and *Ophiura albida* (positive correlation at gear level). Similarly, Bergmann et al. (2001) showed that smaller *Liocarcinus holsatus* had a higher probability of being damaged, while larger starfish (*Asterias rubens*), brittlestars (*Ophiura ophiura*) and *A. opercularis* showed a higher probability of damage.

Data collected highlighted that the evaluation of the fragility of a species (sensu MacDonald et al. 1996) and/or damage caused by fishing gear obtained from experimental studies on research vessels could lead to underestimates, especially in fisheries (e.g. rapido) where sorting of the catch represents an important source of damage to discards.

Evaluation of physical damage provides a minimum estimate of mortality induced by rapido trawls on discarded species, since it remains unknown what proportion of the fauna dies due to other causes, such as internal injury and physiological stress. Kaiser and Spencer (1995) reported 100% mortality within 48 h for crabs with 50% of limbs lost and Bergmann and Moore (2001a) reported for *Liocarcinus depurator* with two ablated appendages a long-term (14–21 days) mortality of up to 70%. Moreover, repeated capture may increase the extent of damage to individuals.

To determine realistic survival chances of discarded species it is necessary to carry out survival tests, which are expensive, time-consuming and need to be performed under controlled conditions hardly realisable either on board research vessels and/or under "field-experimental" conditions (e.g. in cages at the sea bed, cf. Potter et al. 1991; Bergmann and Moore 2001b).

Preliminary survival tests on discards carried out directly on board commercial vessels (Pranovi, unpublished data) indicated that it was possible to observe a positive correlation between damage and survival rates in the winter. In the summer, however, almost all animals died, due to the thermal shock caused by a strong thermocline in the Adriatic Sea (Hall-Spencer et al. 1999) and due to high air temperature values (=35°C) (sorting takes 40–60 min), independent of the extent of damage (for physiological stress due to aerial exposure, see also Spicer et al. 1990; Zainal et al. 1992). These factors could further increase mortality of non-target species due to fishing.

Even if it is difficult to attribute long-term changes in benthic communities to impacts of trawling alone (Jones 1992), damage to non-target species has been widely described (Hutchings 1990; Jones 1992; Jennings and Kaiser 1998) and previous studies (Giovanardi et al. 1998; Hall-Spencer et al. 1999; Pranovi et al. 2000) have highlighted the disturbance caused by rapido trawling to benthic community structure and epibenthic species.

Trawl fisheries can exert a strong selective pressure on benthic communities and modify its structure due to removal of sensitive species and homogenisation of habitats (Jones 1992; Collie et al. 1997; Veale et al. 2000).

As described for the NW Atlantic (Collie et al. 1997), dredged areas are dominated by large hard-shelled molluscs, crabs and echinoderms. Our data depicted a quite similar situation: on the rapido fishing grounds, epifauna was characterised by bivalves (*A. opercularis*) and gastropods (*Hexaplex trunculus*, *Bolinus brandaris*, *Aporrhais pespelecani*), crabs (*Liocarcinus* sp.), starfish (*A. irregularis*) and brittlestars (*O. ophiura*, *O. fragilis*). Rapido-fishing had different effects on these groups. While molluscs did not sustain high levels of damage, crabs, starfish and brittlestars incurred serious damage and had a high proportion of individuals with potentially lethal damage.

All species cited above (except *A. opercularis*) are predators that can act as facultative scavengers, and responses, in terms of presence, to mobile gear may be expected (Groenewold and Fonds 2000). The role of scavengers in marine ecosystems disturbed by human activities has been widely described (Britton and Morton 1994; Kaiser and Spencer 1996a; Hall 1999; Hill and Wassenberg 2000). In intensively exploited fishing grounds the presence of these species could be a trade-off between different selective pressures, as described also by Prena et al. (1999). On the one hand, they are removed, damaged and killed by the fishing gear; on the other hand, those that survive disturbance (same echinoderms are recognised to have strong regeneration power) may benefit from locally increased carrion (Papaconstantinou and Labropoulou 2000) and decreased competition and predation (Ramsay et al. 1997). Veale et al. (2000) have recently found no evidence that scavenger populations benefit from exposure to fishing disturbance, because fishing inputs of carrion seem to be too unpredictable. But it is possible that in intensively exploited fishing grounds, such as rapido grounds, these inputs reach levels high enough to became a "regular" supply for scavenger populations. Moreover, the reproductive resilience and the opportunistic feeding behaviour of *Ophiura* spp. (Tyler 1977; Feder 1981) and swimming crab (Abellò 1989; Freire 1996) make them able to rapidly re-colonise frequently fished areas and capitalise upon any food items available.

Conclusions

Analysis of physical damage sustained by discards from rapido trawls provided information about the direct impact of the gear on epibenthic invertebrates on different types of sea bottom and during different phases of the fishing process.

Damage due to direct contact with the gear was primarily related to the species' morphology and size. Catch composition and habitat type also affected damage to discarded specimens.

Working on board commercial vessels allowed assessment of the impacts of sorting on discarded non-target invertebrates, which have often been disregarded in past experimental studies.

Catch efficiency of rapido trawls for benthic invertebrates up to 70% for larger epifaunal species (Hall-Spencer et al. 1999) and our estimates indicate that ca. 30 and 60 t year^{-1} (respectively on muddy and sandy bottoms) of invertebrates were killed (belonging to the highest level of damage). These values could be strongly underestimated since they disregarded the reduced survival rates due to the injuries suffered by the animals during the fishing process (Bergmann and Moore 2001a,b). Moreover, the aerial exposure to high temperature is one of the most detrimental influences on captured invertebrates, and could increase mortality rates at every level of damage.

Data collected indicate that damages caused by fishing practises may act as a selective pressure on epibenthic organisms, and may thereby modify community structure. Long-term changes in benthic community structure due to demersal fishing have been widely described (Reise 1982; Riesen and Reise 1982; Kaiser and Spencer 1996b; Collie et al. 1997, 2000; Philippart 1998; Hall-Spencer and Moore 2000). Well-protected (i.e. hard-shelled) and/or opportunistic (scavengers) species could be favoured, contributing to a shift in the community composition.

In the flat, trawlable area of the N Adriatic Sea, fishing effort is very high (Ardizzone 1994). Our preliminary estimates indicate that the rapido flatfish vessels potentially fish the whole inshore area at least eight times per year (an underestimate of fishing intensity since suitable fishing grounds are more restricted). This leads to considerable disturbance, which may be unsustainable in the long-term both for the exploited target species and for the benthic community as a whole (see also Hall-Spencer et al. 1999; Pranovi et al. 2000).

In the light of such considerations, an important management measure would be the reduction of fishing effort by restricting boat numbers, and a spatial and temporal re-allocation of effort (Horwood 2000). To reduce the amount and damage to discards, gear modifications and discard quotas would probably be inadequate and difficult to enforce for Italian trawl fisheries. An improvement to the sorting process could be the introduction of automatic sieving on board to reduce trampling damage, but this hypothesis should be verified.

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