Towards more selective Mediterranean trawl fisheries: are juveniles and trash excluder devices effective tools for reducing undersized catches?

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Summary: Mediterranean trawl fisheries are characterized by a critical combination of high fishing effort and low size at first capture for most commercial species. In this study we tested the use of sorting grids installed on bottom trawl nets to minimize the catch of undersized deep-water rose shrimp (*Parapenaeus longirostris*, DPS) and European hake (*Merluccius merluccius*, HKE). The catch of a traditional trawl net was compared with that obtained with the same net equipped with ad hoc designed juveniles and trash excluder devices (JTEDs) during an experimental survey. Three different JTEDs were tested: the first (G1-SM40) was built with a net of 40-mm square mesh; the second (G2-ST20) and third (G3-ST25) with vertical steel bars spaced 20 and 25 mm, respectively. The probability of retaining DPS and HKE by length class in trawl nets with and without JTED was analysed using generalized additive mixed models. With G1-SM40, the reduction of undersized individuals in the cod-end was about 60% and 44% for DPS and HKE, respectively. With G2-ST20, a 34% catch decrease of HKE individuals smaller than 20 cm total length was observed. A loss of marketable fractions of DPS was recorded with G1-SM40 (–25%) and G2-ST20 (30%). Finally, JTD G3-ST25 was efficient at reducing the catch of undersized specimens of DPS and HKE, but showed a higher loss of marketable fractions than the other JTEDs. Although further fishing trials would be required to maximize the sorting efficiency of the grids, the results obtained clearly indicated that grids can substantially reduce unwanted catches of undersized DPS and HKE in Mediterranean bottom trawl fisheries.

Keywords: sorting grids; JTED; Mediterranean trawl fisheries; *Parapenaeus longirostris*; *Merluccius merluccius*; trawl selectivity; Strait of Sicily.

Hacia unas pesquerías de arrastre mediterráneas más selectivas: ¿son los dispositivos de exclusión de juveniles herramientas eficaces para reducir las capturas de Talla de Referencia Mínima de Conservación (MCRS)?

Resumen: Las pesquerías de arrastre mediterráneas se caracterizan por una combinación crítica de un alto esfuerzo de pesca y un tamaño de captura por debajo de la talla legal para la mayoría de las especies comerciales. En este estudio, probamos el uso de rejillas separadoras instaladas en redes de arrastre de fondo para minimizar la captura de la gamba rosada (*Parapenaeus longirostris*; DPS) y la merluza (*Merluccius merluccius*; HKE). La captura obtenida con una red de arrastre tradicional se comparó con la obtenida con la misma red equipada con "Juveniles Trash Excluder Devices" (JTED) diseñados específicamente para cada caso durante un estudio experimental. Tres JTEDs diferentes se probaron: el primero (G1-SM40) se construyó con una res de 40 mm de malla cuadrada; el segundo (G2-ST20) y el tercero (G3-ST25) se fabricaron con barras verticales de acero separadas 20 y 25 mm, respectivamente. La probabilidad de retener DPS y HKE según clase de talla en redes de arrastre con y sin JTED se analizó utilizando Modelos Mixtos Aditivos Generalizados (GAMM). Usando G1-SM40, se consiguió una reducción de individuos de talla por debajo de la talla legal en el copo, de 60% y 40% para DPS y HKE respectivamente. Con respecto a HKE, utilizando G2-ST20 se observó una disminución en la captura del 34% de individuos de menos de 20 cm TL. Sin embargo, se registró una pérdida de fraccion comercializable de DPS usando G1-SM40 del –25% y usando G2-ST20 del 30%. Finalmente, el JTED G3-ST25 resultó eficaz para reducir la captura de especímenes de DPS y HKE de talla ilegal, pero se observó una mayor pérdida de fraccion comercializable que con los otros JTEDs. Aunque se necesitarían más ensayos de pesca para maximizar la eficiencia de las rejillas separadoras, los resultados obtenidos indicaron

claramente que las rejillas pueden contribuir a reducir sustancialmente las capturas no deseadas de DPS y HKE de talla ilegal en las pesquerías de arrastre de fondo del Mediterráneo.

INTRODUCTION

Mediterranean demersal fisheries are characterized by a critical combination of high fishing effort and low size at first capture of commercial species (Lleonart and Maynou 2003, Vasilakopoulos et al. 2014, Colloca et al. 2017). This is mainly due to the progressive growth in engine power of trawlers, the rapid technological advances in fish finding and fishing technology, and the traditional use of fine mesh size in the cod-end (Fiorentini et al. 2004). Due to its low selectivity, Mediterranean bottom trawling produces a high amount of discards and, although several technical solutions have been developed for discard reduction (e.g. Tokac et al. 2014, Sala et al. 2015, Brčić et al. 2017), the management measures adopted have been mostly limited to increasing the mesh size in the cod-end (e.g. Tsagarakis et al. 2017).

In 2006, a specific regulation for the management of Mediterranean fisheries was approved by the European Union (Reg. UE 1967/2006), emphasizing the importance of the Mediterranean basin for the Common Fishery Policy (CFP). In this regulation, a set of measures were adopted to improve the sustainable exploitation of Mediterranean stocks. In particular, minimum conservation reference sizes (MCRS) were defined for the most important species, in addition to a minimum legal mesh size in the trawl net cod-end of 40-mm square mesh or 50-mm diamond mesh.

Over the last decade, the reduction of discarding of the non-commercial fraction in fisheries has become an increasingly important objective from the socioeconomic, ecological, and moral point of view (Bellido et al. 2011, Santiago et al. 2015, Maynou et al. 2018). The CFP has defined specific management measures to reduce discarding of catches of regulated species, including the landing obligation (Article 15 of EU Reg. 1380/2013) of all Mediterranean species subject to MCRS (Veiga et al. 2016). These species include the deep-water rose shrimp (DPS), *Parapenaeus longirostris* (Lucas, 1846), and the European hake (HKE), *Merluccius merluccius* (Linnaeus, 1758).

The DPS is one of the main target species of trawl fishery in several Mediterranean sectors and represents about 40% of total trawl landing in the Strait of Sicily (central Mediterranean) (Milisenda et al. 2017). In this area, DPS is caught by trawl vessels fishing on the outer continental shelf and upper slope in geographical sub-areas (GSAs) 12 (northern Tunisia), 13 (Gulf of Hammamet), 14 (Gulf of Gabes), 15 (Malta) and 16 (Southern Sicily). The available scientific information indicates that fishing fleets of Italy, Malta and Tunisia exploit a single shared DPS stock (Fiorentino et al. 2013) with a total catch of about 7540 t in 2016. This catch is mostly due to the Italian (70%) and Tunisian (30%) vessels, the Maltese yield being negligible. The main commercial species associated with DPS trawling is the European hake (*Merluccius merluccius*; HKE), amounting to about 10% of the total trawl landing.

According to Milisenda et al. (2017), the annual discards due to DPS trawl fisheries in the Strait of Sicily accounted for about 36% of the total catch. This fraction also included undersized specimens of species under MCRS according to Reg. UE 1967/2006, such as DPS and HKE, which are consequently subject to the European discard ban.

Reducing discards in multi-species trawling (Stergiou et al. 2009, Sala et al. 2015) is a main challenge in Mediterranean fisheries. In fact, the legal mesh size adopted is suitable for catching crustaceans, cephalopods and medium-size fish such as red mullets, but it is too small to avoid the catch of juveniles of large-sized fish such as hake and monkfish (Caddy 1990). For the latter species, the adoption of a bigger cod-end mesh size would be required to increase their size of first capture, as observed in numerous experiments carried out in Mediterranean waters testing different combinations of mesh geometry and mesh size in the trawl cod-end (Kaykaç et al. 2009, Dereli et al. 2016 and references herein).

However, a significant mesh size increase would easily break up the current catch profile of Mediterranean bottom trawlers, with a significant loss of small-sized marketable species and individuals of other commercial species (e.g. Ragonese et al. 2001). Alternative selection tools and technical solutions to the classical mesh size increase in the cod-end have proved to be effective in improving trawl selectivity without a major loss of commercial fish and shellfish (e.g. Tokac et al. 2014, Brčić et al. 2017, Sola and Maynou 2018). These include changes in the cod-end circumference (Sala et al. 2016), the use of square-mesh panels inserted in front of the cod-end (e.g. Brčić et al. 2015) and the adoption of sorting grids (Sardà et al. 2005,

Massutí et al. 2009, Özvarol 2016). In particular, the studies carried out on sorting grids have revealed clear advantages associated with their use in mixed trawl fisheries, such as improved selectivity and by-catch reduction (e.g. Massutí et al. 2009, Aydın and Tosunoğlu 2011), a stable selection pattern during the tow (Suuronen and Sardà 2007), and a higher survival rate of specimens escaping from the grid bars compared with a conventional cod-end mesh (e.g. Brčić et. al. 2015, Lucchetti et al. 2016). The main disadvantages are related to handling on board trawl nets equipped with grids, the potential occlusion of the grids by debris, and their sporadic reduced sorting capacity when a high number of fish arrive simultaneously (Suuronen and Sardà 2007). Although all these studies point to the positive impact of sorting grids on the size at first capture of commercial fish and crustaceans (e.g. Massutí et al. 2009, Aydın and Tosunoğlu 2011), their adoption in Mediterranean trawl fisheries is still very low. Lack of sorting grid implementation could be linked to several causes, including fishers' resistence to changing fishing traditions and customs, and, consequently their unwillngness to modify their fishing gear substantially. Other possible causes are linked to the lack of a suitable technology transfer from researchers to fishing enterprises (e.g. Morrissey and Almonacid 2005), as well as the overall weakness of fishing management in the Mediterranean region (Colloca et al. 2017).

In this study we tested the efficiency of sorting grids in improving the selectivity of trawlers targeting DPS in the Strait of Sicily. Three different types of sorting grids were designed in collaboration with some trawl vessel captains of the Mazara del Vallo fleet and tested during ad hoc designed fishing trials. The objective of the study was to quantify the effects of the sorting grids on the catch of undersized specimens of DPS and HKE and to elucidate both the technical constraints and the possible trade-offs in terms of fishery sustainability.

MATERIALS AND METHODS

Study area

The study area, located in the northern part of the Strait of Sicily [GSA 16 of the General Fishery Council for the Mediterranean (GFCM); Fig. 1] off the southwestern coast of Sicily, is characterized by a wide continental shelf with an intense hydrographic circulation pattern, a stable upwelling system and high biodiversity (Di Lorenzo et al. 2018). These abiotic and biotic features lead to a high productivity of fish resources which are exploited by a multinational fleet in national and international waters. In the Italian fleet, DPS is mainly exploited by about 240 bottom trawlers larger than 18 m length overall (LOA), mostly located in the ports of Mazara del Vallo, Sciacca and Porto Palo di Capo Passero, with an operational depth range of 100 to 400 m.

Sorting grids trials

A six-day trawl survey was organized by hiring a local commercial bottom trawler registered in the harbour of Mazara del Vallo with an LOA of 21.5 m and engine power of 316 kW. The trawler was equipped with a traditional polyamide trawl net with a nominal mesh cod-end size of 40-mm square mesh. The net design had a nominal mesh size of 50-mm diamond
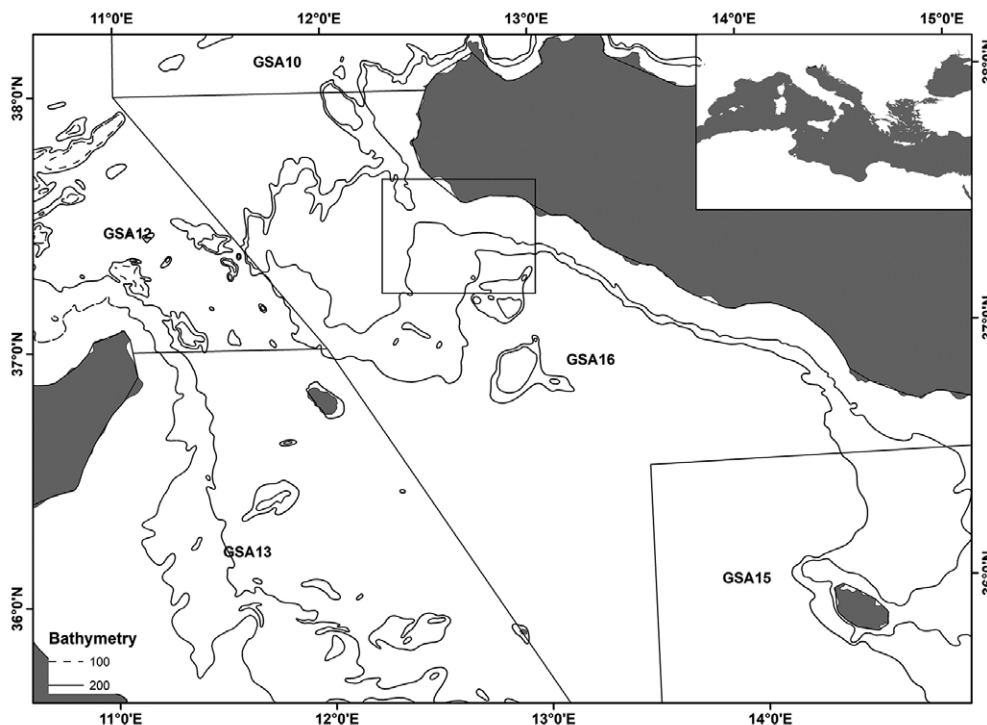

Fig. 1. – The study area highlighted with a black square box.

Table 1. – Days, number of repeated hauls, geographic coordinate and mean depth for each designed JTED and its relative control in the experimental survey. G1-SM40, JTED covered with a net of 40-mm square mesh; G2-ST20, JTED with steel bars spaced 20 mm; G3-ST25, JTED with steel bars spaced 25 mm.

| Data	28/10/15	29/10/15	30/10/15	31/10/15	6/11/15	7/11/15	Haul	Time (start)	Time (end)	Lat. (start)	Long. (start)	Lat. (end)	Long. (end)	Mean depth (m)
Design	control	G1-SM40	control	G2-ST20	control	G3-ST25	1	13:30	14:30	37°27′62″	12°26′37″	37°27′16″	12°26′07″	110
							2	17:30	18:30	37°23′58″	12°24′78″	37°23′10″	12°24′65″	120
							3	21:30	22:30	37°17′40″	12°25′11″	37°17′75″	12°25′13″	126
							4	01:30	02:30	37°22′51″	12°24′80″	37°22′83″	12°24′94″	123
							5	05:30	06:30	37°27′26″	12°33′46″	37°27′16″	12°34′35″	98
							6	09:30	10:30	37°29′08″	12°28′55″	37°28′49″	12°29′22″	100
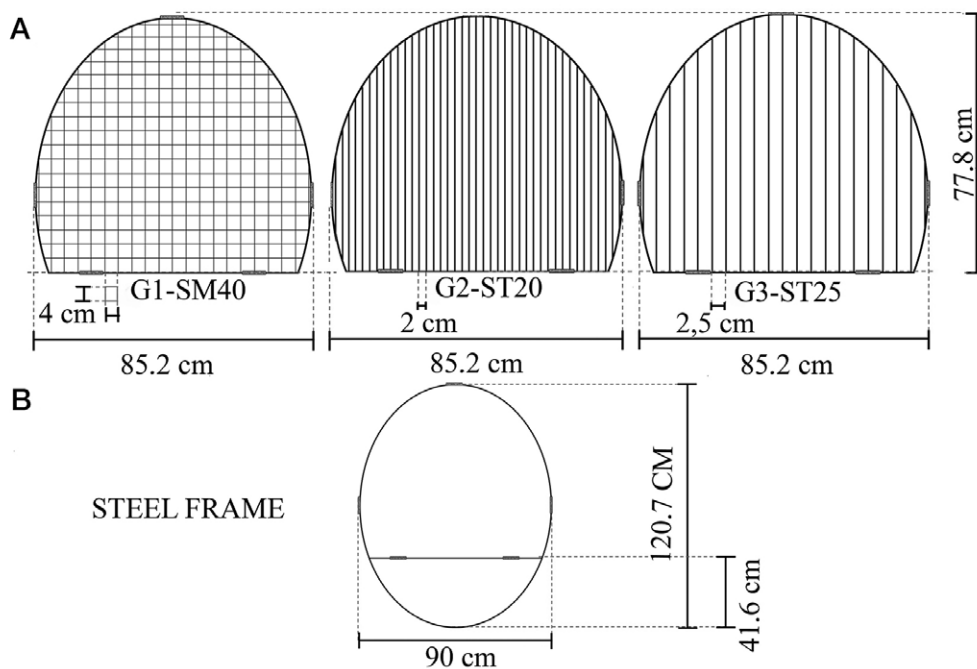
Fig. 2. – The designed sorting grid (JTED) with two parts: A, interchangeable grids in a steel frame; B, the fixed steel frame.

mesh in the extension section and the following characteristics: 305 meshes in the extension circumference, 210 meshes around the cod-end circumference and 125 meshes in the cod-end length.

Three different types of juvenile and trash excluder devices (JTEDs) were designed to be installed on the trawl net and tested during the survey. JTEDs were based on the configuration proposed by Bahamon et al. (2007), including a funnel panel specifically adapted to the characteristics of the local trawl nets. An interchangeable system was designed to adapt the grids on a fixed frame. It was characterized by a main steel frame fixed on the extension section of the net, on which the three different grids were fixed (Fig. 2). The grids differed in both their material and bar spacing. The first grid type (G1-SM40) was built with a net of 40-mm square mesh while the second (G2-ST20) and third (G3-ST25) were made from vertical steel bars spaced 20 and 25 mm apart, respectively (see Fig. 2).

Sampling design and data analysis

The sampling design was based on 36 trawl hauls of 1 hour carried out during day and night on six days

between late October and early Novemeber 2015 at a constant trawling speed of about 3 knots and between 100 and 130 m. Although the trial was planned for six consecutive days, after the fourth day the experiment was suspended due to adverse weather conditions. Half the hauls were carried out using JTEDs (6 hauls for each JTED type) installed on the net and the other 18 hauls (control) were repeated without JTEDs at the same depths and geographical positions (Table 1).

All specimens of DPS and HKE were measured, and those below MCRS, i.e. 20 mm carapace length for DPS and 20 cm total length for HKE, were identified as undersized (US).

To assess change in the length composition of catch obtained with and without JTED a model able to fit a continuous curve along the length classes was preferred to the traditional paired tests by length classes (Zuur et al. 2007, Fryer et al. 2003). As a first step, we estimated the probability of retaining a fish at length in the JTED trawl related to the total catch in the control (trawl net without JTED) according to the method proposed by Fryer et al. (2003) and Holst and Revill (2009) for experimental paired hauls. Since it was not possible to hire two fishing vessels and a paired haul

sampling design, we assumed the same catch probability for JTED and control hauls carried out at the same time of day, depth and geographical position. This assumption was corroborated by the absence of statistical differences in length frequency distributions among the control hauls (Kolmogorov-Smirnov test, p>0.05).

According to Fryer et al. (2003), the probability, P_{St}, of catching specimens of the size class "S" at the daytime "t" was computed as

$$P_{St} = \frac{S_t \text{ with JTED}}{S_t \text{ with JTED} + S_t \text{ without JTED}}$$

In this context, P_{St} is an estimate of the observed catch efficiency for each size class with JTED in comparison with without JTED. A P_{St} value of 0.5 indicates lack of difference in the selectivity between trawl nets with (test) and without (control) JTED. $P_{St}>0.5$ means a catch of size class S that is higher in the test than in the control, whereas the opposite occurs with $P_{St}<0.5$. P_{St} values of 0.33 and 0.66 correspond, for example, to a catch difference of –50% and +50%, respectively, between test and control.

The observed P_{St} values of DPS and HKE of each JTED type were modelled using GAMMs, where haul time was treated as random effects to remove the variance linked to the expected change in abundance/catchability of the two species during the day (Holst and Revill 2009). The final GAMMs were preferred to generalized linear models and generalized additive models based on normal residual distribution, explained variance and the Aikake information criterion (Zuur et al. 2007). The statistical analysis was performed using the R package mgcv (Wood 2006).

Finally, in order to better visualize the grid efficiency according to the behaviour of the investigated species, the relative proportion of undersized species, P_{us}, in the catch was calculated separately for day- and nighttime hauls as well as for JTED type, as

$$P_{us} = \frac{\Sigma n_{us} \text{ test}}{\Sigma n_{us} \text{ test} + \Sigma n_{us} \text{ ctrl}}$$

where, n_{us} is the number of speciems below the MCRS.

RESULTS

The absolute number of specimens caught between test and control was significantly different only for DPS (test=5691; control=9970), while for HKE no significant difference was found (test=1566; control=1569) (Fig. 3). The length frequency distributions of DPS and HKE showed a similar shape between test and control. However, the proportion of undersized specimens was lower in test hauls, with clear differences between the two species. In the case of DPS, mainly G1-SM40 led to a reduction in the catch of shrimps of less than 20 mm carapace length (CL) (–6%), while all three grids produced less catch of HKE <20 cm TL (G1-SM40 –20%; G2-ST20 –6%; G3ST25 –7%) compared with the control (Fig. 3).

The parameters and R^2 of the fitted mean probability functions of the final GAMMs are presented in Table 2. The GAMM for JTED G1-SM40 showed
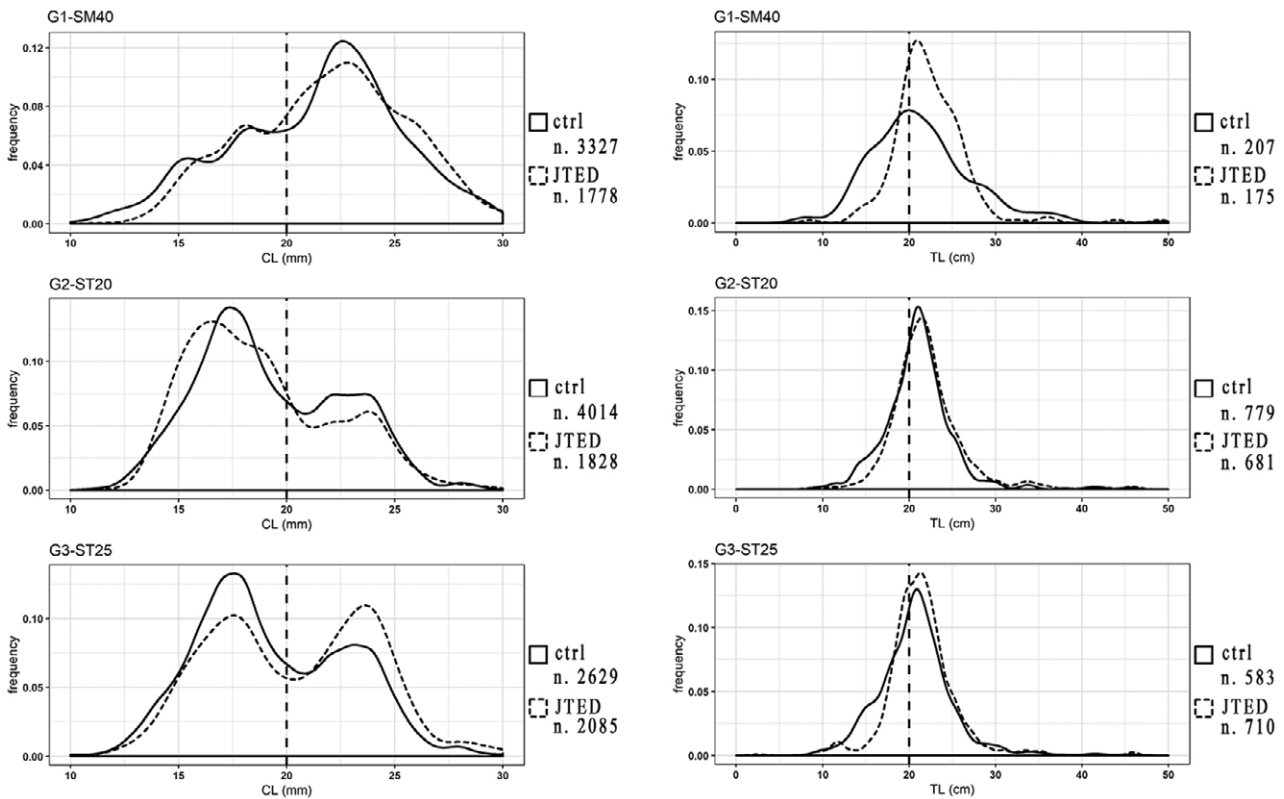

Fig. 3. – Comparison of the length frequency distributions of deep-water rose shrimp (DPS; left) and European hake (HKE; right), retained in the cod-end during the hauls with JTEDs (dashed line) and without grids (control [ctrl], solid line).

Table 2. – GAMM parameters from comparison of trawl net equipped with JTED (test gear) with trawl net without JTED (control gear) with catch in number per hour. G1-SM40, JTED covered with a net of 40-mm square mesh; G2-ST20, JTED with steel bars spaced 20 mm; G3-ST25, JTED with steel bars spaced 25 mm.

Comparison	Species	DF	R square	F statistic	p-value
G1-SM40 vs control	DPS	7.99	0.21	9.963	<0.001
G1-SM40 vs control	HKE	4.56	0.23	5.507	<0.001
G2-ST20 vs control	DPS	7.38	0.11	13.05	<0.001
G2-ST20 vs control	HKE	5.64	0.11	12.85	<0.001
G3-ST25 vs control	DPS	5.02	0.10	4.013	<0.001
G3-ST25 vs control	HKE	5.94	0.24	13.6	<0.001

that the estimated P_{St} of DPS increased from 0 to 0.3 for shrimps between 10 and 18 mm CL, corresponding to a decrease in catch probability of 100% to 60% compared with the control. P_{St} appeared constant at about 0.3 for 18-25 mm CL DPS, increasing progressively up to 0.5 (no differences from the control) for 30 mm CL shrimps (Fig. 4). In the case of HKE, the estimated P_{St} ranged between 0.2 and 0.5 for 15-20 cm TL, although with a higher uncertainty due to the low catch. P_{St} increased up to 0.6 for 20-24 cm TL, but over this size there was no clear significant catch effect of the grid (Fig. 5). The estimated P_{St} values using G2-ST20 for DPS were quite similar to those obtained with G1-SM40. In fact, the P_{St} increased from 0 to 0.3 for
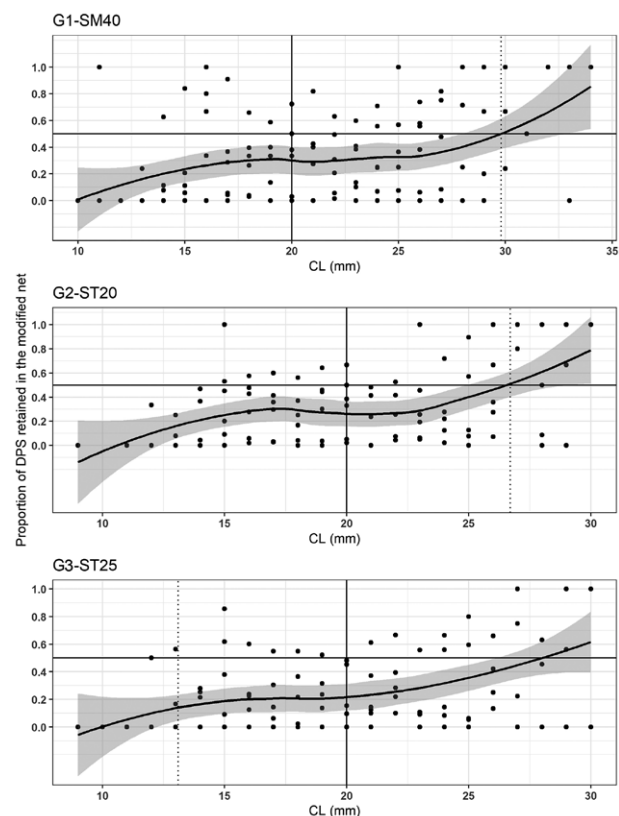

Fig. 4. – Proportion of fish retained in trawl nets equipped with JT-EDs (=JTED/(JTED+ control) vs. length for deep-water rose shrimp (DPS). The value of 0.5 means both gears catch equal numbers, the solid line gives the mean, and the grey band gives the 95% confidence limit. MCRS (DPS, 20 mm; HKE, 20 cm). G1-SM40, JTED covered with a net of 40-mm square mesh; G2-ST20, JTED with steel bars spaced 20 mm; G3-ST25, JTED with steel bars spaced 25 mm.

Fig. 5. – Proportion of fish retained in trawl nets equipped with JT-EDs (=JTED/(JTED+ control) vs. length for European hake (HKE). The value of 0.5 means both gears catch equal numbers, the solid line gives the mean, and the grey band gives the 95% confidence limit. MCRS (DPS, 20 mm; HKE, 20 cm). G1-SM40, JTED covered with a net of 40-mm square mesh; G2-ST20, JTED with steel bars spaced 20 mm; G3-ST25, JTED with steel bars spaced 25 mm.
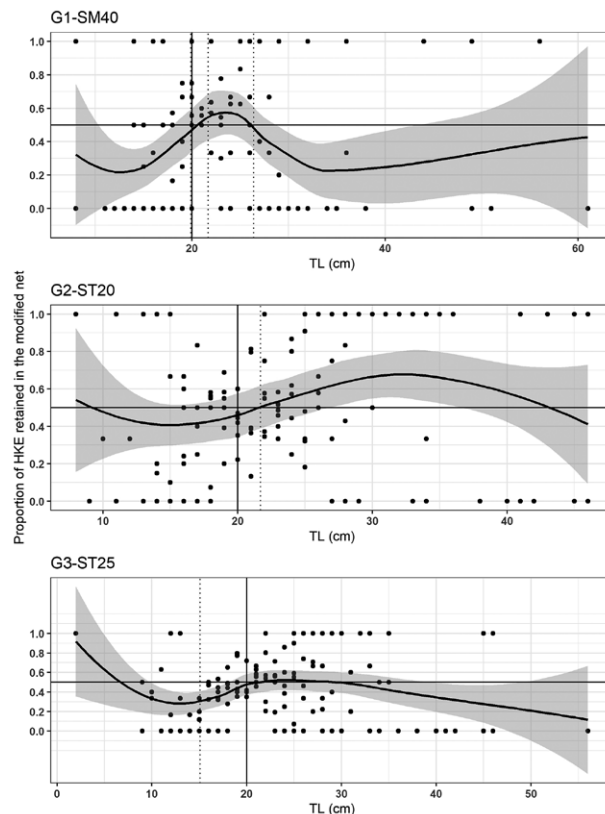
shrimps between 9 and 18 mm CL (decreasing in catch probability between 100% and 60% compared with control), remained quite costant at about 0.28 between 18 and 23 mm CL, and after that, size increased progressively up to 0.5 (no differences from the control) at 27 mm CL (Fig. 4). In the case of HKE, P_{St} ranged between 0.4 and 0.5 for 10-21 cm TL (decreasing catch probability by up to 20% compared with the control), increased to 0.6 (increasing the catch probability by up to 20% compared with the control) for 15-26 cm TL, and after that size there was high uncertainty due to the low catch (Fig. 5). With G3-ST25 the estimated DPS P_{St} values ranged between 0.1 and 0.2 for 10-20 mm CL (decreasing catch probability by up to 69% compared with the control), and after this size the P_{St} increased slowly to 0.6 for 20-30 mm CL. The estimated P_{St} HKE ranged between 0.3 and 0.5 for 10-20 cm TL (decreasing catch probability by up to 35% compared with the control), and over this size there was no clear significant catch effect of the grid (Fig. 5).

The P_{us} values with G1-SM40 were 0.37 and 0.19 for DPS and 0.25 and 0.51 for HKE during the diurnal and nocturnal hauls, respectively (Table 3). For G2-ST20 the P_{us} values during the diurnal and nocturnal hauls were 0.38 and 0.16 for DPS and 0.40 and 0.47 for HKE, respectively. Similarly, with G3-ST25 the P_{us} values during the diurnal and nocturnal hauls were

Table 3. – Probability of undersized specimens of deep-water rose shrimp (DPS) and European hake (HKE), recorded during the daily and nightly hauls with and without JTEDs. G1-SM40, JTED covered with a net of 40-mm square mesh; G2-ST20, JTED with steel bars spaced 20 mm; G3-ST25, JTED with steel bars spaced 25 mm.

Haul	Grid type	DPS Probability of undersize	sd	HKE Probability of undersize	sd
day	G1-SM40	0.37	0.13	0.25	0.04
night	G1-SM40	0.19	0.09	0.51	0.27
day	G2-ST 20	0.38	0.11	0.40	0.04
night	G2-ST 20	0.16	0.13	0.47	0.11
day	G3-ST 25	0.33	0.12	0.48	0.12
night	G3-ST 25	0.18	0.09	0.44	0.11

0.33 and 0.18 for DPS and 0.48 and 0.44 for HKE, respectively. These values were similar between diurnal (0.37, 0.38 and 0.33) and nocturnal hauls (0.19, 0.16 and 0.18) for DPS, clearly showing an efficient reduction of undersized shrimp catch in the cod-end of ~45% in daytime and ~73% at nighttime, compared with the control. The P_{us} for HKE were different (0.25, 0.40 and 0.48) during the diurnal hauls, showing a reduction of undersized hake of 0.38% to 72%, while were close to 0.5 during the nocturnal hauls (0.51, 0.47 and 0.46) showing no differences in the retention of undersized HKE between test and control at night (Table 3).

DISCUSSION

The results of our catch comparison experiment showed that the use of JTEDs mounted on traditional trawl nets of Mediterranean trawlers can be beneficial in reducing the by-catch of undersized individuals (i.e. individuals below the MCRS) of two important commercial species, the deep-water rose shrimp and the European hake. The three different types of JTEDs that were tested produced significant and sometimes contrasting differences in the catch of small individuals of the two species. The JTED consisting of a stretched square mesh size of 40 mm (G1-SM40) produced a high sorting ability for both species in terms of reduction of juvenile catch (DPS –60%, $\bar{P}_{St}$=0.26; HKE –44%, $\bar{P}_{St}$=0.37) with a minor loss of the marketable fraction for DPS (DPS – 25%, $\bar{P}_{St}$=0.48; HKE –39%; $\bar{P}_{St}$=0.40).

The results clearly demostrated also the good efficiency in reduction of undersized specimens using G2-ST20 (DPS –59%, $\bar{P}_{St}$=0.27; HKE –34%, $\bar{P}_{St}$=0.43) and G3-ST25 (DPS –73%, $\bar{P}_{St}$=0.18; HKE –38%, $\bar{P}_{St}$=0.40). However, the latter showed quite a high loss of the marketable DPS fraction (–36%).

The observed differences between day and night in catch proportion of undersized DPS and HKE in trawl nets equipped with and without JTED might be associated with the juveniles' daily feeding migrations towards the sea surface at night (e.g. Savenkoff et al. 2006, Carpentieri et al. 2008), as well as to the different behaviour of the two species (e.g. swimming capability). In particular, the reduced occurrence of DPS during nocturnal hauls is associated with a reduced catch proportion of undersized specimens: from 45% less during the day to 73% less at night than the control. The scarce occurrence of HKE juveniles close to the bottom at night (Orsi Relini et al. 1997) could affect

the similar estimated probability (P_{us}~0.5; both gears catching equal numbers of specimens) of retaining a fish among the nocturnal hauls with and without JTEDs. Vice-versa, during the diurnal hauls, when HKE juveniles aggregate near the bottom, the JTEDs' efficiency is clearly recognizable for the tested grids (G1-SM40 –62%, P_{us}~0.25; G2-ST20, –39%, P_{us}~0.4; G3-ST25 –50%, P_{us}~0.33). Even if our results need to be confirmed across seasons, oceanographic conditions, benthic communities and substrata typology, the adoption of the JTED G1-SM40 could significantly reduce the trawl catches of undersized DPS and HKE, suggesting its potential usefulness to minimize the overall discard franction. Consequently, seeking compliance with the landing obligation, the JTED G1-SM40 should be tested in commercial trawlers operating in different conditions to verify its overall sorting ability also for other species and to evaluate its potential to improve the status of Mediterranean overexploited stocks. It is worth noting that this selection device is low-cost and, according to our experience, easy to mount on commercial trawl nets.

Our findings are consistent with previous results obtained in other areas of the Mediterranean Sea, emphasizing the sorting ability of grids mounted on trawl nets. In fact, in the eastern Mediterranean demersal trawl fishery, Aydın and Tosunoğlu (2011) evaluated the use of sorting grids of 10- and 15-mm bar spacing, demonstrating a substantial improvement for DPS selectivity. In the same area, Aydın et al. (2011) analysed the efficiency of sorting grids with 20-mm bar spacing, demonstrating a substantial separation between fish and shrimp. However, a loss of 23% and 25% of legal-sized DPS in the cod-end was recorded using 44-mm diamond and 40-mm square mesh, respectively. In the Balearic Islands (western Mediterranean), a flexible sorting grid with 15- and 20-mm bar spacing improved trawl selectivity by increasing the L_{50} for DPS and HKE and decreasing the discarded fraction (Massutí et al. 2009). However, although some studies have explored the survival rate of discarded species in Mediterranean trawl fisheries (e.g. Revill 2012, Tsagarakis et al. 2018, Özvarol and Bolat 2017), there is little knowledge on the mortality rates of DPS and HKE that escape through sorting grids. This aspect should be closely investigated through experimental surveys in the near future to obtain an overall assessment of the effects produced by the adoption of the grids on the stocks of the two species (Vitale et al. 2018).

The overexploitation of most demersal stocks in the Mediterranean (e.g. Colloca et al. 2013) increases the need to find technological solutions to improve gear selectivity, reduce discards, minimize the impacts on habitats and increase the survival rate of individuals discarded by fishers or escaping through the cod-end. In our study the engagement of local fishers was extremely useful to design appropriate sorting grids for the traditional trawl nets used by Sicilian trawlers to target DPS. Due to the increasing importance of trawling for deep-water shrimp in the Mediterranean Sea (Pinello et al. 2018), the identification of ad-hoc technical tools to reduce the catch of juveniles is im-

portant for the sustainability of the fishery. In order to achieve this objective in the shrimp trawl fishery, a spatial-based approach including the closure of the nurseries of main commercial species to bottom trawling was considered a promising management measure (Maiorano et al. 2009, Russo et al. 2014, Colloca et al. 2015). The GFCM recently adopted the closure of three stable nurseries of DPS and HKE in the northern sector of the Strait of Sicily (REC.CM-GFCM/40/2016). A next step in the management of the fishery could be to integrate this "drastic" measure with the adoption of new technological solutions able to consistently reduce the impact on juveniles/undersized specimens. In this context, JTED G1-SM40 could be a useful selective device for achieving the management goals of the EU (i.e. art. 14 of EU Reg. 1380/2013) and the GFCM. Although more quantitative data should be gathered to generalize the results obtained in this study, the adoption of ad hoc–designed sorting grids such as G1-SM40 may be important for improving the exploitation pattern of Mediterranean trawlers and have a positive impact on important species such as DPS and HKE.

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