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Seasonal variation in mortality of red mullet (*Mullus barbatus*) escaping from codends of three different sizes in the Aegean Sea

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Summary: This study was performed off the southern coast of Yassıca Island in the İzmir Bay on the Turkish coast of the Aegean Sea to investigate the mortality of red mullet (*Mullus barbatus*, Mullidae) escaping through 40-mm square-mesh and 44- and 50-mm diamond-mesh codends attached to a conventional demersal trawl net. In total, 48 replicate experimental hauls were performed in the summer and winter of 2011 and 2012. Mean escape mortality for all hauls in winter (33.2%±6.51) was significantly higher (p<0.0001) than that in summer (26.5%±6.19). Furthermore, mortality was also highest among the smallest fish, particularly during winter. Irrespective of season, the escape mortality of red mullet was lowest from the 40-mm square-mesh codend (mean, 25.5%±4.58). These observations emphasize the importance of investigating the survival potential of escaping fish when considering the benefits of different selective devices in the management of a fishery.

Keywords: escape mortality, bottom trawl, size-related mortality, seasonal variation, mesh size, mesh shape, Aegean Sea.

Variación estacional en la mortalidad post pesca del salmonete (*Mullus barbatus*), capturado con arrastre de fondo en el mar Egeo

Resumen: El estudio se llevó a cabo frente a la costa sur de la isla de Yassica en la Bahía de Izmir, costa turca del mar Egeo para investigar la mortalidad post captura del salmonete (*Mullus barbatus*, Mullidae) que escapa de las redes de pesca con copos de malla cuadrada de 40 mm, y romboidales de 44 y 50 mm acoplados a una red tradicional de arrastre demersal. En total, se realizaron 48 lances experimentales durante el verano e invierno de 2011 y 2012. La media de la mortalidad post captura para todos los lances en invierno (33.2%±6.51) fue significativamente mayor (p<0.0001) que en verano (26.5%±6.19). Además, la mortalidad fue más alta entre los individuos más pequeños, especialmente en invierno. Independientemente de la estación, la mortalidad post captura del salmonete fue inferior con el copo de luz de malla cuadrada de 40 mm (media, 25.5%±4.58). Estas observaciones ponen de manifiesto la importancia de la investigación de la supervivencia potencial de los peces que escapan de las redes de pesca a la hora de considerar los beneficios de distintos dispositivos selectivos en la gestión de una pesquería.

Palabras clave: mortalidad post captura, arrastre de fondo, mortalidad dependiente de la talla, variación estacional, luz de malla, forma de la malla, mar Egeo.

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INTRODUCTION

Bottom trawl fisheries, which are generally multispecies in the Mediterranean Sea, have rather poor selectivity (Özbilgin et al. 2006, Sardà et al. 2006). Modifying a fishing gear to reduce the capture of juvenile fish, allowing undersized fish to escape, is one of the main management tools for sustainable fisheries (Suuronen 2005, Breen et al. 2007, Sacchi 2008). However, increasing trawl selectivity may only be justified if a significant proportion of the escaping fish survive (Suuronen 2005, Gilman et al. 2013). Escape mortality has been described by ICES (2005) as "fish that die after actively escaping from a gear prior to the catch being landed by the fishing operation" (Suuronen 2005, Broadhurst et al. 2006). Information on survival rates is available for approximately 40 fish species from many locations during the past half-century: off the coasts of Scotland (Sangster et al. 1996, Main and Sangster 1988), Norway (Soldal and Engås 1997), the USA (DeAlteris and Reifsteck 1993) and Australia (Broadhurst et al. 1997), and in the Baltic Sea (Suuronen et al. 1996a, b), and the Barents Sea (Ingólfsson et al. 2007).

Turkish bottom trawlers in the Aegean Sea (coastal waters of Turkey) typically catch over 50 fish species and are responsible for a considerable amount of bycatch and discards (Özbilgin et al. 2006). A number of scientific studies have been carried out to improve trawl codend selectivity in the Aegean Sea (Petrakis and Stergiou 1997, Metin et al. 2005). However, few studies have investigated the escape mortality of fish escaping from the trawl codend in the Mediterranean Sea (Metin et al. 2004, Düzbastılar et al. 2010a, b, c).

This study reports on escape mortality data obtained in 2011 and 2012 in the summer and winter seasons for red mullet (*Mullus barbatus* Linnaeus, 1758) escaping from 40-mm square-mesh and 44- and 50-mm diamond-mesh codends mounted in a conventional trawl net off the Turkish coast of the Aegean Sea. The effect of seasonal variation on the codend escapee survival for this species is presented for the first time.

MATERIALS AND METHODS

The experiments were conducted in the İzmir Bay, between latitude 38°23′-38°24′N and longitude 26°47′-26°48′E (Fig. 1), at depths ranging from 10 to 30 m. To investigate seasonal effects (winter vs. summer), experimental trials were performed in January and September 2011, and in February and September 2012. Bottom temperature around the cages was recorded by a dive computer (Suunto D6). In total, 48 hauls with 15-min sampling time were conducted (Table 1). The fishing gear was a conventional bottom trawl with 900 meshes around the fishing circle (Düzbastılar et al. 2012).

Three different codends, all made of the same twisted polyethylene (PE) material (380d/21, 3×7), were tested: 40 mm square-mesh (40S) and 44- and 50-mm diamond-mesh (44D and 50D). The use of a 40-mm square-mesh codend was adopted in September 2008 as an alternative for the 44-mm diamond-mesh codend in Turkish waters of the Mediterranean Sea (Anonymous

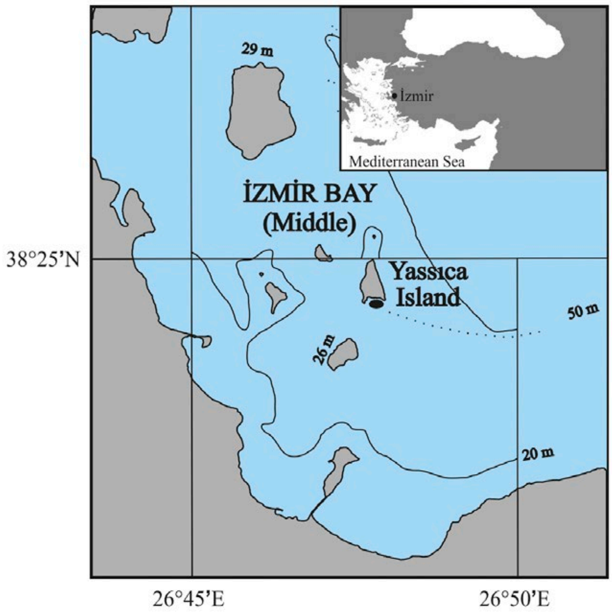

Fig. 1. – The experimental area, off İzmir Bay. The dotted line and filled ellipse show the trawling route and cage location, respectively.

2008). European Commission Regulation 1967/2006 enforces minimum mesh sizes of 40-mm square mesh or 50-mm diamond mesh for trawl codends in EU Mediterranean waters (EC 2006).

To determine the mesh sizes, 60 stretched mesh openings (3 lines of 20 consecutive meshes in the towing direction) near the aft part of each codend were measured using a digital calliper with a 39.2266 N (4 kg) weight tied vertically to the stationary jaw. Mean values were 40.28±0.10; 44.04±0.07 and 51.34±0.19 for 40S, 44D and 50D, respectively. In order to fish homogeneously, codends were randomly changed at the end of each haul.

Research vessel, R/V *EGESÜF* (26.8 m length, ~405 kW engine) was used for trawling. A constant towing duration of 15 min with a mean towing speed of 2.7 knots (as determined from GPS) was applied for all hauls to minimize any potential sampling time effects on mortality (Breen 2004). Commercial tows in the study area typically vary between 1 and 6 hours. The experimental trawl hauls started at depths of approximately 30 m and finished at approximately 10 m, to enable divers to recover the samples at the end of the tow. In the Aegean Sea, commercial trawlers must fish 1.5 miles from the shore, according to the Turkish commercial fishing regulations (Anonymous 2008). Thus, trawlers generally work at depths ranging from 50 to 150 m.

The experimental protocol for sampling and monitoring fish after they escape from the codends was similar to that used by Metin et al. (2004) and Düzbastılar et al. (2010a, b, c). Codend covers were used to collect escapees (Fig. 2). At the end of each haul, the cover was detached from the trawl net. The cover was then moved by divers to an inshore site, where it was anchored to the seabed to form a cage for later monitoring of the fish. During this process, divers moved the cover very slowly to reduce the effect of water flow on fatigued fish in the cage. *EGEDERİN* (10 m length, 121 kW)

Table 1. – Details of the experimental trials (40S, 40 mm nominal square-mesh codend; 44D, 44 mm nominal diamond-mesh codend; 50D, 50 mm nominal diamond-mesh codend; OC, open codend).

	2011 experiments				2012 experiments			
Season	Date	Haul No.	Codend (Cage)	Cage depth (m)	Date	Haul No.	Codend (Cage)	Cage depth (m)
Winter	26 Jan.	1	44D-1	3.4	10 Feb.	1	44D-1	5.2
		2	50D-1	5.0		2	50D-1	5.1
		3	40S-1	7.6		3	40S-1	4.9
		4	40S-2	4.7		4	40S-2	5.0
		5	40S-3	7.7		5	44D-2	4.5
		6	50D-2	7.5		6	50D-2	5.1
		7	50D-3	5.0	11 Feb.	7	44D-3	5.1
		8	44D-2	5.2		8	40S-3	4.9
		9	44D-3	8.2		9	50D-3	5.2
	28 Jan.	10	OC-1	6.3		10	OC-1	4.6
		11	OC-2	6.0		11	OC-2	5.0
		12	OC-3	6.5		12	OC-3	4.4
Summer	16 Sep.	1	40S-1	5.4	18 Sep.	1	40S-1	3.0
		2	50D-1	5.2		2	50D-1	3.0
		3	44D-1	4.9		3	44D-1	3.1
		4	OC-1	5.1		4	OC-1	3.4
		5	40S-2	5.2		5	44D-2	3.2
		6	50D-2	5.0		6	50D-2	3.4
	17 Sep.	7	50D-3	5.6		7	OC-2	3.4
		8	40S-3	5.4		8	50D-3	3.3
		9	44D-2	4.3	19 Sep.	9	40S-2	3.4
		10	OC-2	5.1		10	OC-3	3.6
		11	44D-3	4.1		11	40S-3	3.5
		12	OC-3	6.3		12	44D-3	3.4

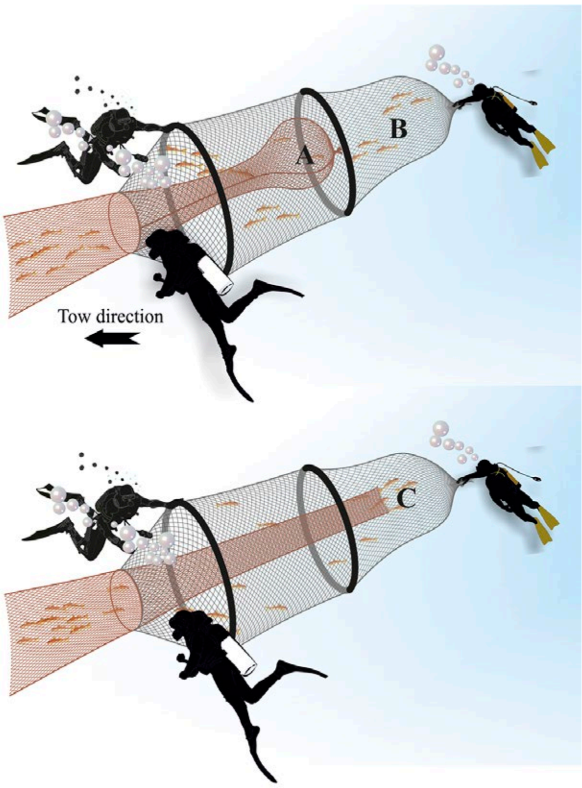

Fig. 2. – A, fish retained in the codend; B, fish that escaped from the codend; C, fish caught in the cover with the open codend.

was used as a support boat for diving operations. For the control group, fish escaping from an open codend were caught in the same type of codend cover.

The cages for housing the sampled populations (i.e. the anchored covers) had an internal volume of 7.5 m^3 and were horizontally stretched out on the seabed using ropes and wooden rods at depths of 3.0 to 8.2 m. They were made of knotless, polyamide (PA) netting (24-mm stretched mesh size) to minimize abrasive injury. The length of the cages after they had been fixed on the seabed was 7.5 m. Their maximum circumference was maintained by two rigid hoops of 1.6 m diameter. The cages were rigged with three 1-m-long horizontal zippers to retrieve any dead fish and to feed the survivors. They were observed by divers three times a day (07:00-08:00; 12:00-13:00 and 16:30-17:30) over a period of 7 days. The behaviour of the captive fish was monitored by divers using underwater camera systems (Sony PC350E, Sea and Sea housing).

During the monitoring period, dead fish were removed and transferred to the laboratory for measuring. Total (TL) and standard lengths (SL) were measured to the nearest mm. If the caudal fin of a fish was injured, SL was transformed to TL. Escape mortality (F_E) was calculated as $F_E = n_m/(n_m+n_s)$, where n_m is the number of dead fish and n_s is the total number of survived fish in a fish cage. At the end of the observation period, the cages were retrieved, survivors were counted and their lengths were measured.

To investigate possible effects of fish condition on escape mortality, Fulton's condition factor (K) was determined. The factor describes the relationship between total length and weight of an individual fish in terms of

$$K = W L^{-3}$$

where K is the Fulton's condition factor, W the weight of the fish and L the length (total length, TL) (Ricker 1973). The length-weight relationship (LWR) was derived by applying the equation

$$W = aL^b$$

where a and b are the coefficients calculated by the least squares method (Sparre 1987). Sex (male and female) was determined by internal examination.

Table 2. – Densities of all fish species retained in the cages (no. of specimens m^{-3}).

Years	Cage No.	40S 1	40S 2	40S 3	44D 1	44D 2	44D 3	50D 1	50D 2	50D 3	OC 1	OC 2	OC 3	Average	SD
2011	Winter	74.4	33.6	55.6	15.7	23.1	36.3	51.7	26.0	37.5	114.0	115.6	47.7	52.6	33.1
	Summer	158.8	97.6	136.5	52.4	59.6	63.9	158.0	154.5	81.5	73.8	157.0	126.6	110.0	42.8
2012	Winter	67.1	51.3	21.1	66.7	22.3	33.3	51.3	41.2	33.1	40.6	23.6	38.1	40.8	15.8
	Summer	174.9	60.8	67.7	41.7	56.4	59.1	125.1	117.2	68.9	156.0	89.3	64.6	90.1	43.1

Table 3. – Red mullet. Summary data on fish escaping from the test and open codends (n, total fish number in cages; F_E, escape mortality in percentage; TL_{mean}, mean length).

	2011								2012							
	Winter				Summer				Winter				Summer			
	n	F_E	TL_{mean} (cm) Dead	Surviving	n	F_E	TL_{mean} (cm) Dead	Surviving	n	F_E	TL_{mean} (cm) Dead	Surviving	n	F_E	TL_{mean} (cm) Dead	Surviving
40S	402	31.3	12.3	12.6	1338	22.4	10.1	10.5	326	26.3	11.4	11.9	1064	22.2	9.2	9.9
44D	70	30.3	11.8	12.0	323	33.4	10.0	10.0	276	46.3	11.1	11.2	219	35.4	8.5	9.6
50D	207	37.4	12.1	12.7	957	24.6	9.8	10.3	328	27.4	10.5	11.5	681	21.3	8.9	9.6
OC	252	48.3	12.4	13.9	873	39.7	10.5	11.2	134	51.5	11.1	12.7	779	49.1	10.1	10.8

The red mullet survival data were analysed using generalized linear modelling (GLM) (McCullagh and Nelder 1999), fitted using the binomial error distribution and logit-link function. The significance of several explanatory variables was explored using GLM, including mesh size and shape, season (summer and winter), fish length, and various interactions between them. The 2011 and 2012 data were modelled separately to avoid over-parameterisation. In addition, to address concerns that there may be captive density-dependent mortality, a term for cage stocking density (fish m^{-3}) was included in the GLM; however, this proved to be not significant for both years (P values for 2011: 0.7727; 2012: 0.1071) and hence it was excluded from the final models. For both models, due to over-dispersion, it was necessary to estimate the dispersion parameter (Φ_{2011}: 1.73; Φ_{2012}: 1.52).

An F test was used to analyse the LWR parameters between fish in codends and covers. The statistical significance of differences between K factors was determined with multi-factor ANOVA (MANOVA). Fitting of the GLM was performed using the R statistical program (R Development Core Team 2007), while the SPSS 15.0 statistical program was used for the other statistical analyses.

RESULTS

In total, 36661 individuals belonging to 66 species were caught during the experiments. Of these, approximately 80% were teleost. Higher catches were obtained in the summer experiments (Table 2).

2011 experiments: escape mortality

In winter, the mean water temperature at the study site was 13°C. In total, 54 species and 8179 individuals were caught. Of these, 45 species were teleost. With respect to relative numbers of codend escapees sampled in the cages (including open codend cages), red mullet was the most abundant species (2309), followed by annular seabream (1014) (*Diplodus annularis,* Sparidae), brown comber (823) (*Serranus hepatus*, Serranidae), solenette (694) (*Buglossidium luteum*, Soleidae), common pandora (596) (*Pagellus erythrinus*, Sparidae), scaldfish (572) (*Arnoglossus laterna*, Bothidae) and blotched picarel (515) (*Spicara maena*, Centracanthidae).

Escape mortality percentages and size distribution of red mullet in winter are shown in Figures 3 and 4 and Table 3. A total of 2309 red mullet were caught during the experiments, both in codend and cover. Of these, 679 red mullet ranging from 8.5 to 16.5 cm TL were caught in the test cages. A total of 252 individuals ranging from 10.0 to 18.5 cm TL were obtained in open codend cages. Mean mortalities were 31.3%±10.07, 30.3%±30.78 and 37.4%±18.11 for fish escaping from 40-mm square-mesh and 44- and 50-mm diamond-mesh codends, respectively. Mean mortality in open codend cages was 48.3% (±11.09).

In summer, the water temperature around the cages was 25°C. In total, 43 species and 13054 individuals were caught, of which 34 species were teleost. Of these, red mullet (4268) was again the most abundant species, followed by blotched picarel (2295), sardine (1197) (*Sardina pilchardus*, Clupeidae), red bandfish (891) (*Cepola macrophthalma*, Cepolidae), brown comber (772), annular seabream (618) and black goby (584) (*Gobius niger*, Gobiidae). A total of 2618 red mullet ranging from 6.5 to 15.5 cm TL were caught in the test cages, while 873 individuals ranging from 6.5 to 20.0 cm TL were captured in the open codend cages. Mean mortalities were 22.4%±4.75, 33.4%±13.92 and 24.6%±18.67 for red mullet escaping from 40-mm square-mesh and 44- and 50-mm diamond-mesh codends, respectively (Figs 3 and 5, and Table 3). Mean mortality for open codend cages was 39.7%±23.08.

2012 experiments: escape mortality

A total of 4798 individuals and 49 species were caught in 12 experimental hauls in winter; of these, 40 species were teleost. Red mullet (1378) was the most abundant species, followed by common pandora (780), solenette (631) and blotched picarel (590). Mean water temperature was 13°C at the cage site. In the test hauls, 930 red mullets ranging from 7.0 to 16.5 cm TL

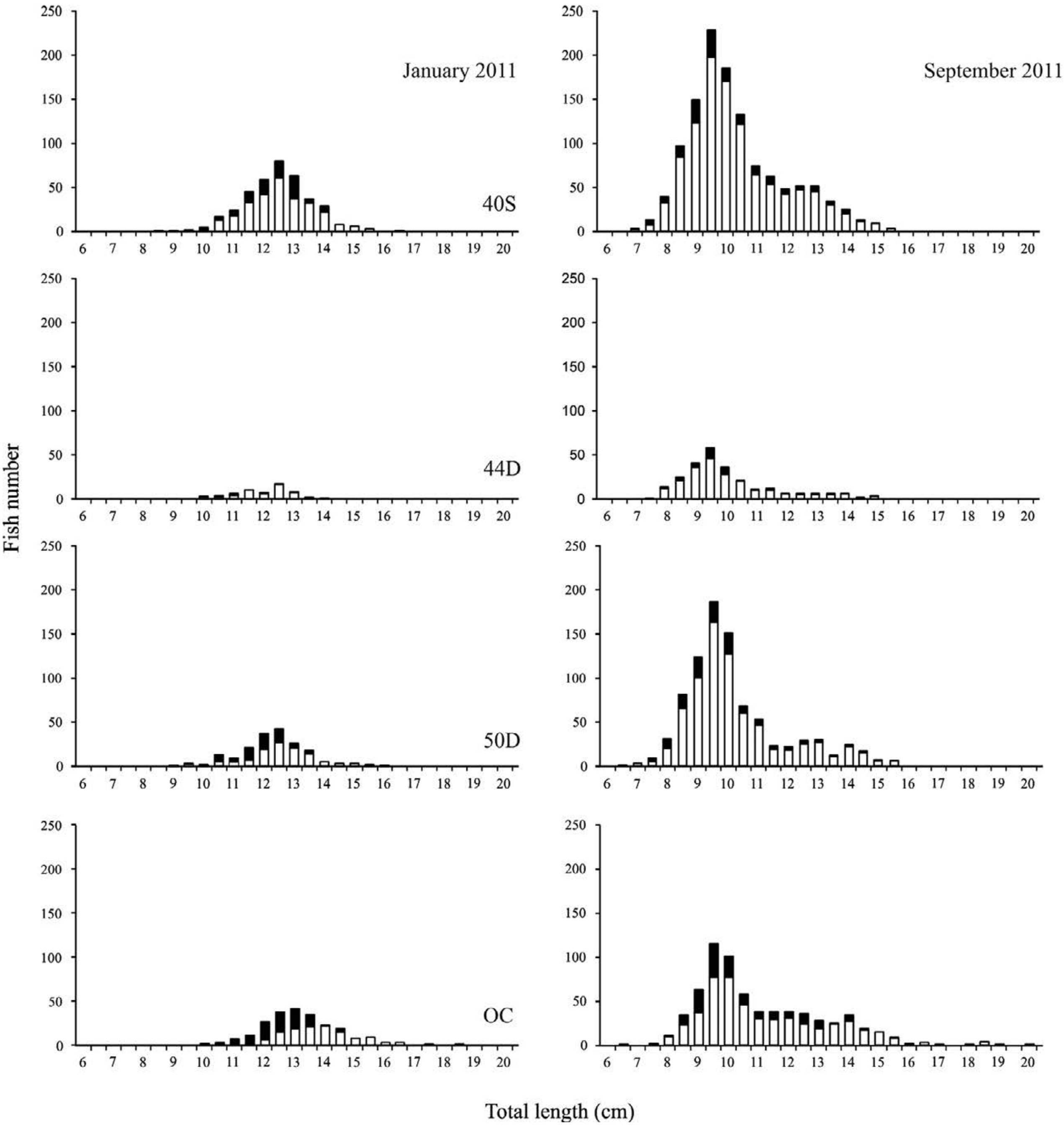

Fig. 3. – Red mullet. Number of dead fish (black) and survivors (white) in each length class for test and open codend cages in winter and summer of 2011.

were caught, while in open codend hauls 134 individuals ranging from 9.0 to 18.0 TL were caught. Figs 4 and 5 and Table 3 show escape mortality percentages and size distribution of red mullet. Mean mortalities were 26.3%±12.67, 46.3%±2.38 and 27.4%±8.37 for red mullet escaping from 40-mm square-mesh and 44- and 50-mm diamond-mesh codends into the codend covers, respectively. Mean mortality for open codend cages was 51.5%±7.24.

A total of 10630 individuals and 54 (40 teleost) species were sampled in September 2012. Red mullet (3170) was the most abundant species, followed by anchovy (1122) (*Engraulis encrasicolus*, Engraulidae), brown comber (1103), black goby (814), red bandfish (778), blotched picarel (593) and solenette (421). Mean water temperature was 25°C around the cages. A total of 1964 red mullet individuals ranging from 6.0 to 18.5 cm TL were caught by the test codends, while a total of 779 individuals ranging from 6.5 to 19.0 cm TL were caught in open codend hauls. Mean mortalities were 22.2%±8.49, 35.4%±30.67 and 21.3%±3.06 for red mullet escaping from 40-mm square-mesh and 44- and 50-mm diamond-mesh codends, respectively (Figs 4 and 5, and Table 3). Open codend cages had a high mean mortality of 49.1%±16.18.

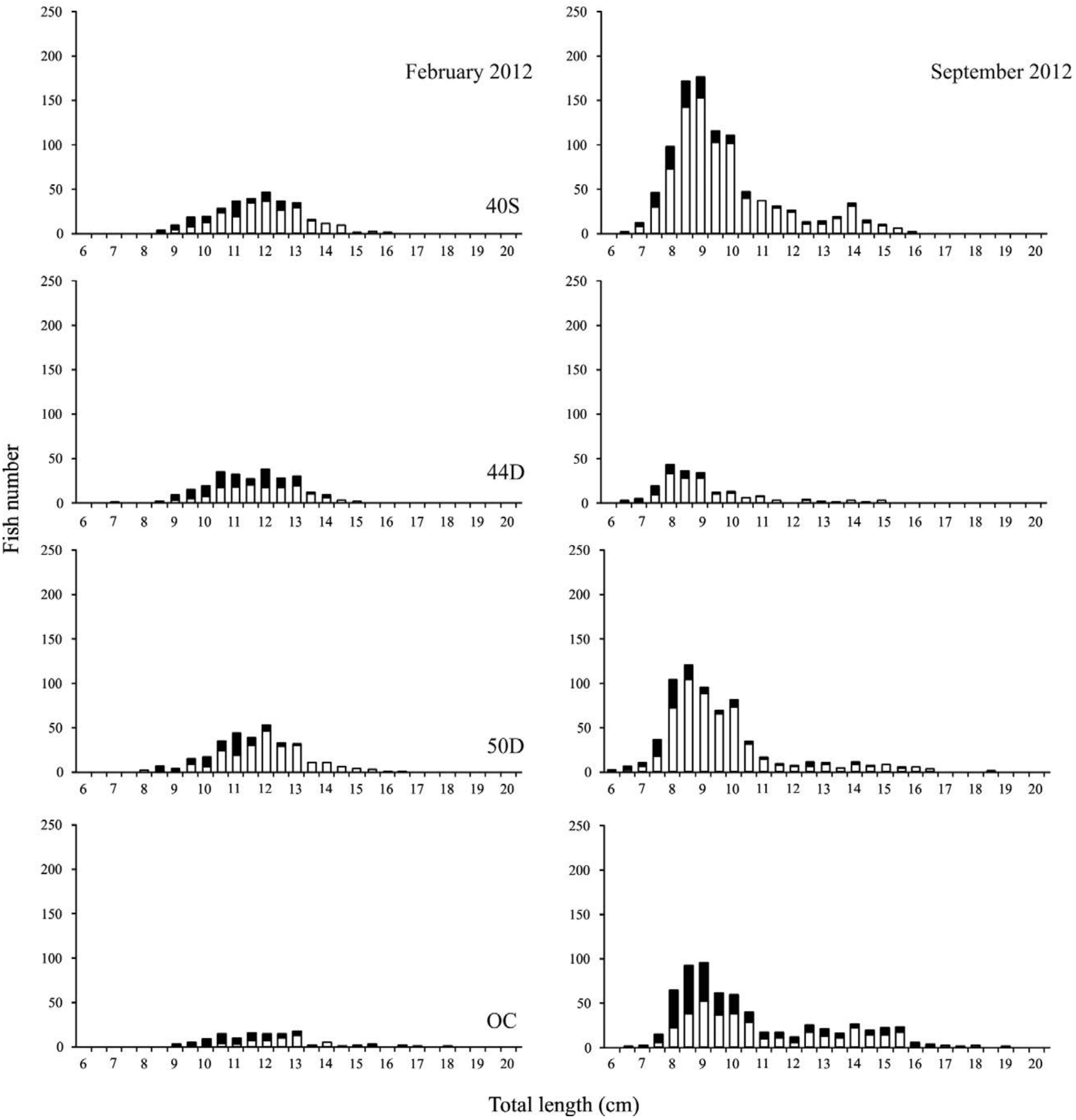

Fig. 4. – Red mullet. Number of dead fish (black) and survivors (white) in each length class for test and open codend cages in winter and summer of 2012.

Length-related mortality, and seasonal- and mesh-type effects on mortality

There was a clear length-related mortality in most treatments, with smaller fish having an increased likelihood of dying after escaping (Fig. 5, Tables 4 and 5). The only exception was the 44-mm diamond-mesh treatment in summer 2011, but this had small sample sizes (Fig. 3, Tables 3 and 6).

A seasonal effect on the length-related mortality was observed in both 2011 and 2012, with smaller fish (<13 cm TL) showing lower mortality in summer than in winter (Fig. 5 and Table 6). For larger fish, this seasonal effect seems less apparent. Although the mean size of escaping fish was smaller in summer than in winter (Figs 3 and 4, Table 3), the mean mortality of red mullet was generally higher in each treatment in winter (2011, 33.0%; 2012, 33.3%) than in summer (2011, 26.8%; 2012, 26.3%). Furthermore, the GLM demonstrated a highly significant seasonal effect ($p<0.0001$), as well as a highly significant interaction between length-related mortality and season (Length:Season $p<0.0001$) in both years (Tables 4 and 5).

There were also significant differences in mortality according to the different mesh sizes in both years ($p<0.0001$) (Tables 4 and 5). Generally, the 40-mm square-mesh and 50-mm diamond-mesh codends showed the lowest mortality, irrespective of fish size.

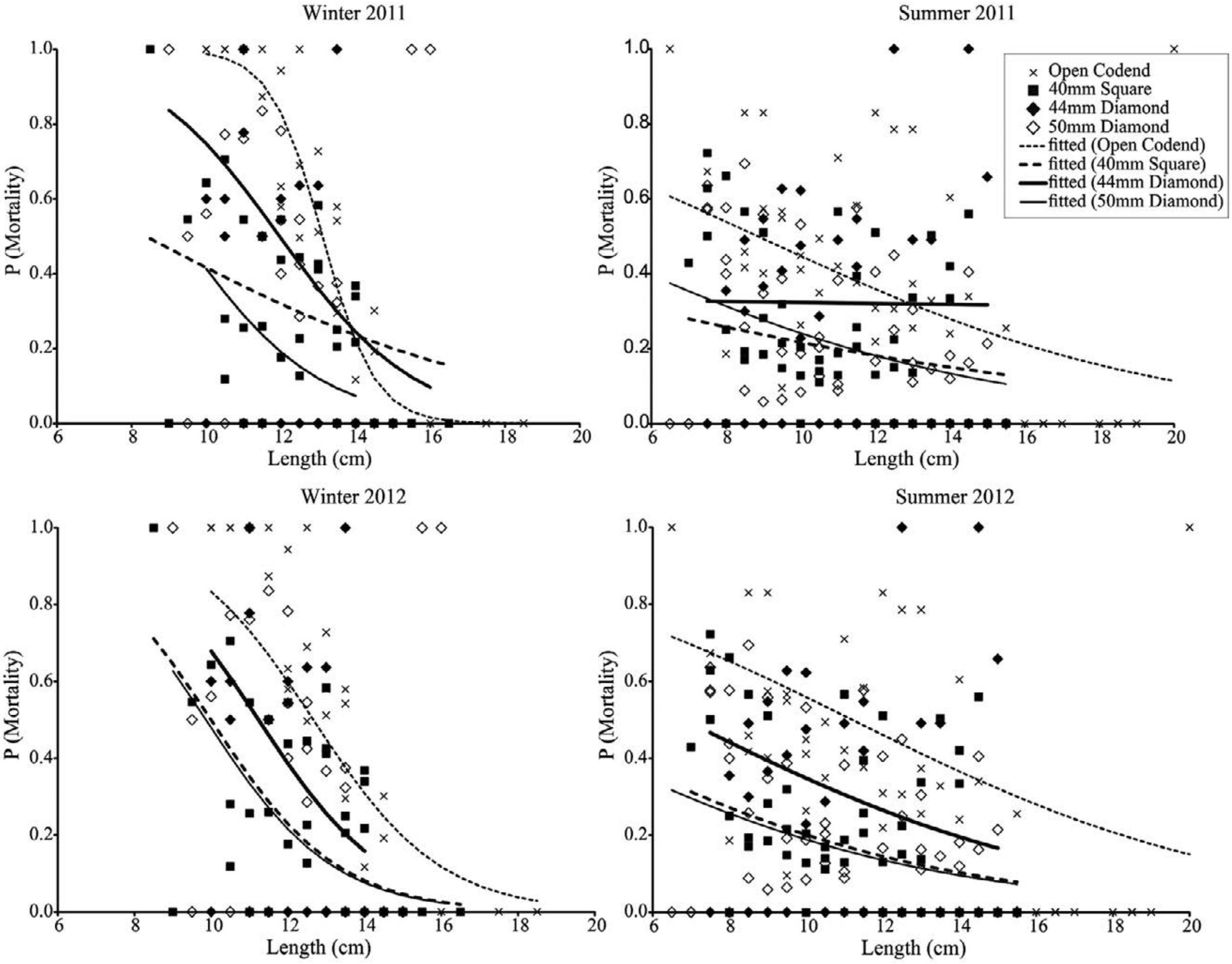

Fig. 5. – Proportions of mortality of red mullet that escaped from open codend and test cages in 2011 and 2012 along with fitted values from the GLM model.

Table 4. – Results of GLM analysis of red mullet mortality in 2011. Note: as dispersion was estimated, parameter significance was assessed by an F Test.

Model coefficients	Estimate	Std. Error	t value	p
Intercept	–0.156	0.756	–0.206	0.8368
Length	–0.112	0.074	–1.525	0.1283
Season (winter)	1.912	1.857	1.029	0.3041
Mesh (44 mm, diamond)	–0.518	1.641	–0.316	0.7524
Mesh (50 mm, diamond)	0.817	1.128	0.724	0.4694
Mesh (open codend)	1.785	1.026	1.739	0.0830
Length : season (winter)	–0.097	0.155	–0.624	0.5329
Length : mesh (44 mm, diamond)	0.106	0.161	0.659	0.5103
Length : mesh (50 mm, diamond)	–0.068	0.111	–0.611	0.5418
Length : mesh (open codend)	–0.072	0.098	–0.733	0.4643
Season (winter) : mesh (44 mm, diamond)	3.875	6.436	0.602	0.5475
Season (winter) : mesh (50 mm, diamond)	4.051	3.219	1.258	0.2092
Season (winter) : mesh (open codend)	15.231	4.026	3.783	0.0002
Length : season (winter): mesh (44 mm, diamond)	–0.443	0.554	–0.800	0.4243
Length : season (winter): mesh (50 mm, diamond)	–0.276	0.270	–1.025	0.3063
Length : season (winter): mesh (open codend)	–1.151	0.317	–3.630	0.0003

Analysis of deviance	df	Deviance	Res. df	Res. Dev	F	p
NULL			334	796.18		
Length	1	4.78	333	791.39	2.77	0.0970
Season	1	70.63	332	720.76	40.91	<0.0001
Mesh	3	110.43	329	610.32	21.32	<0.0001
Length : Season	1	29.60	328	580.72	17.14	<0.0001
Length : Mesh	3	4.80	325	575.92	0.93	0.4282
Season : Mesh	3	27.05	322	548.87	5.22	0.0016
Length : Season : Mesh	3	27.80	319	521.07	5.37	0.0013

Table 5. – Results of GLM analysis of red mullet mortality in 2012. Note: as dispersion was estimated, parameter significance was assessed by an F Test.

Model coefficients	Estimate	Std. Error	t value	p
Intercept	0.591	0.327	1.804	0.0721
Length	–0.197	0.033	–5.888	<0.0001
Season (Winter)	5.450	0.868	6.281	<0.0001
Mesh (44 mm, diamond)	0.751	0.163	4.600	<0.0001
Mesh (50 mm, diamond)	–0.079	0.138	–0.576	0.5648
Mesh (Open Codend)	1.614	0.137	11.779	<0.0001
Length : Season (Winter)	–0.408	0.078	–5.239	<0.0001

Analysis of deviance	df	Deviance	Res. df	Res. Dev	F	p
NULL			369	1014.71		
Length	1	46.04	368	968.67	30.35	<0.0001
Season	1	52.40	367	916.27	34.55	<0.0001
Mesh	3	302.29	364	613.98	66.43	<0.0001
Length : Season	1	45.01	363	568.97	29.67	<0.0001

Table 6. – Red mullet. Percentage mortality of fish in 2011 and 2012, in winter and summer, for each treatment (Control, 40-mm square mesh, 44- and 50-mm diamond mesh), with respect to three different length classes (10, 13 and 16 cm TL).

Length (cm)	Winter				Summer			
	Control	40 mm	44 mm	50 mm	Control	40 mm	44 mm	50 mm
2011								
10	98.9	41.7	41.3	74.8	44.8	21.8	32.4	24.2
13	54.0	27.6	12.0	36.0	31.8	16.6	32.0	15.7
16	1.6	16.9	2.6	9.7	21.2	12.4	31.6	9.8
2012								
10	83.3	49.9	67.8	47.9	55.9	20.1	34.8	18.9
13	44.9	14.0	25.6	13.0	41.2	12.3	22.9	11.4
16	11.7	2.6	5.3	2.4	28.0	7.2	14.1	6.7

The exception to this was observed in winter 2011, when the 44-mm diamond-mesh codend showed the lowest mortality across all length classes. However, we highlight that sample sizes were small for this treatment in that season, so it may not be truly representative. In all size cases, the open codend control treatments showed the highest observed mortality, particularly for the smallest fish.

Cumulative mortality during the monitoring period

Most of the mortality occurred in the first 48 hours of the observation period (Fig. 6). In winter 2011, 45%, 62%, and 48% of the mortality for the 40-mm square-mesh and the 44- and 50-mm diamond-mesh codends, respectively, were observed on the first day. In summer 2011, the mean percentage mortalities were 72%, 87% and 80% for the 40-mm square-mesh and the 44- and 50-mm diamond-mesh codends, respectively, in the first 24 hours. In winter 2012, 62%, 67%, and 53%, and in summer 2012, 80%, 88%, and 85% of mortalities for the 40-mm square-mesh and the 44- and 50-mm diamond-mesh codends, respectively, occurred on the first day.

The relationship between escape mortality and Fulton's K factor

K factors for dead fish (mean 0.9360) and survivors (mean 0.9569) (K<1) escaping from codends were significantly different from those of the fish retained in the codend (mean 1.0980) (K>1; p<0.01) for all experiments (Table 7). On the other hand, in terms of K factor, there was no significant difference between dead fish and survivors (p>0.01) of the escapees for all the hauls.

In all experiments, the mean weight of dead fish was 24% lower than that of the survivors. Mean

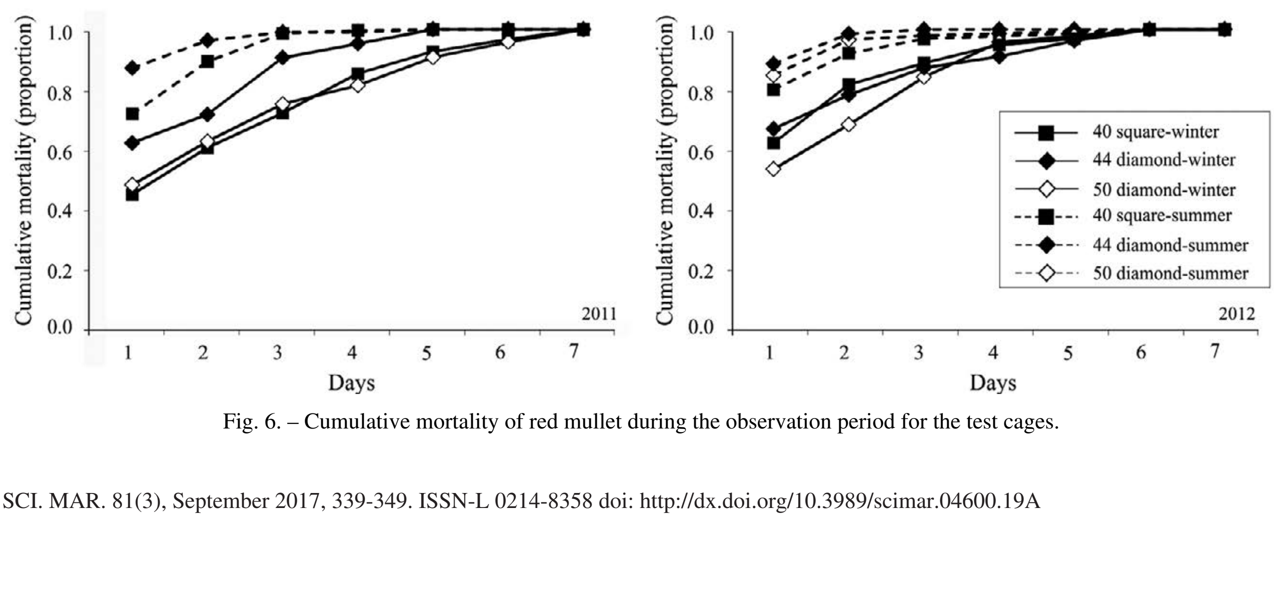

Fig. 6. – Cumulative mortality of red mullet during the observation period for the test cages.

Table 7. – Red mullet. Mean values of coefficients (a, b), condition factor, Fulton's K factor and mean lengths (TL_{mean}) in the test cages and codends.

	Winter (2011-2012)					Summer (2011-2012)				
	a	b	Condition factor	Fulton's K factor	TL_{mean}	a	b	Condition factor	Fulton's K factor	TL_{mean}
Dead	0.0049	3.2613	0.4879	0.8929	11.5	0.0083	3.0830	0.8360	0.9791	9.4
Survivors	0.0048	3.2998	0.4774	0.9749	11.9	0.0050	3.3055	0.4901	0.9389	9.9
Codend	0.0052	3.3284	0.5170	1.0818	12.8	0.0075	3.1875	0.7391	1.1142	12.5

Table 8. – Sex data of red mullet caught from test and open codend hauls.

	January, 2011			September, 2011			February, 2012			September, 2012		
	Immature	♀	♂	Immature	♀	♂	Immature	♀	♂	Immature	♀	♂
Number of fishes	160	323	578	313	479	424	75	261	682	806	464	365
Mortality (%)	90.0	29.1	29.1	52.1	2.9	3.3	94.7	27.6	29.9	30.8	2.3	2.4

weights of retained fish were 54.1% and 43.1% higher than those of the dead fish and survivors, respectively. There were significant differences in the LWR parameters ($p<0.001$) between the individuals retained in the codend and the escapees in the cover. On the other hand, no significant differences were observed between the LWR parameters of the dead individuals and the survivors in any of the experiments ($p>0.01$). The exponents (b) of the LWR for dead, surviving and retained fish (means; 3.292, 3.288, and 3.241, respectively) indicated that relative growth of red mullet followed a positive allometry (the change in weight in relation to proportional changes in body size). In winter (2011 and 2012), Fulton's K factor was significantly different among the dead (0.9266 and 0.8591), surviving (1.0260 and 0.9239) and retained fish (1.1320 and 1.0317) ($p<0.001$). In summer 2011 and 2012, K factors of dead (0.9508 and 1.0073) and surviving (0.9461 and 0.9317) fish were significantly different from those of the retained fish (1.1368 and 1.0917) ($p<0.001$).

The relationship between escape mortality and sex

A total of 4930 dead and surviving red mullet were examined to determine sex (Table 8). The mortality of immature fish (mean 67%) was greater than that of mature fish (mean 15% females and 16% males) for all experiments. There was no significant difference ($p>0.01$) between the escape mortality of females and males; on the other hand, there was a significant difference ($p<0.01$) between mortality of immature specimens and that of males and females.

DISCUSSION

The main aim of this study was to compare the survival of escapees of red mullet from square- and diamond-mesh codends of otter bottom trawl. We used hauls with open codends in an attempt to have methodological controls for the experiment, according to ICES (2014), as this was the only method available to catch red mullet as control fish in a size range comparable to the test subjects. Specimens caught with this method showed a significantly higher mortality than the treatments. Similarly, Metin et al. (2004), who also collected control fish using an open codend, reported a significantly higher mortality of red mullet in the control than in the tested codend cages. In the same area, the Aegean Sea, similar controls were abandoned by Düzbastılar et al. (2010b) due to a higher density of fish and the presence of predators in the control cage. This approach only controls for escape through the codend meshes, while the fish are subjected to other stresses (e.g. exhaustion, physical contact with the net and catch), so it should not be considered as a valid methodological control. The higher mortality in the open codend may have been induced by the forced swimming and the injuries, through skin abrasion, in the codend cover, as a result of the excessive water flow (Suuronen et al. 1996b, Breen 2004). Future studies should aim to develop methods for the collection of more valid methodological controls. However, where this is unavoidable, the use of a lined codend and/or codend cover may reduce exhaustion and the risk of physical injuries (Breen et al. 2007).

The experimental hauls used in this study have different characteristics from those of the commercial fishing hauls, as they were shallower (10-30 m, compared with 50-150 m) and shorter (15 min, compared with 1-6 hours) than commercial trawl hauls. The shallow depth was chosen to enable the divers to operate at safe depths. The short hauling time was necessary to avoid over-filling the sampling cages with fish. Moreover, the limited resources available for this project did not allow the use of more technologically advanced sampling techniques, which would allow short sampling times following long fishing tows (e.g. Lehtonen et al. 1998 and Breen et al. 2007). Finally, extending the towing duration to 3 to 6 hours in this experiment would have meant that fish were collected over a much wider depth range, and would have exposed them to higher decompression stress.

The lack of valid methodological controls and the deviance from standard commercial fishing practices may undermine our confidence in the absolute estimates of the magnitude of the escape mortality, as the methodology may have induced some of the observed mortality in the treatment cages (ICES 2014). However, the consistent and highly significant effects observed between treatments (i.e. season, as well as mesh size and shape) may provide strong evidence that these effects influence the survival of red mullet escaping from trawl codends, although the magnitude of these effects remains uncertain. Furthermore, this experiment observed a length-related mortality, which is consistent with other escape mortality studies (Suuronen 2005).

A size-related mortality has previously been described for red mullet (Lök et al. 2002), as well as for other species (Sangster et al. 1996, Wileman et al. 1999, Breen 2004). Likewise, many studies have shown an inverse relationship between physical injury and fish length (Suuronen et al. 1996a). This study has shown that length-related mortality was significantly more pronounced in winter, particularly for the smallest specimens. This finding suggests that the observed mortality may be related to the physical condition of the fish: the fish less nourished during winter months may be physically less able to avoid and/or recover from exhaustion and physical injuries during the catching process (Chopin and Arimoto 1995, Breen 2004).

Fulton's K factor (Ricker 1973) can give an indication of the condition of fish. It varies with, and is strongly affected by, age, sex, environment, water temperature, feeding pattern and stress factors (Barton and Schreck 1987, Carscadden and Frank 2002). This study demonstrated that K values in September were generally higher than those in winter for all the specimens. Özbilgin et al. (2011) reported that the condition factors at minimum landing size of red mullet were 1.0187 (January), 1.0555 (April), 1.0710 (July) and 1.0765 (September).

Water temperatures in İzmir Bay were substantially lower in winter (13°C) than in summer (25°C). Thus, an alternative explanation of the lower survival rates in winter months, particularly among smaller fish, is the lower swimming ability due to lower water temperatures (He and Wardle 1988, Özbilgin and Wardle 2002). There is some controversy about this aspect: Düzbastılar et al. (2010a) found that the mortality of brown comber escaping from diamond-mesh codends was not affected by water temperature (13°C and 25°C); conversely, Suuronen et al. (2005) observed lower mortality of cod at lower water temperatures (<10°C compared with >15°C).

The seasonal differences in abundance and size distribution of red mullet agree with the characteristics of the ecology of the species. Red mullet is a warm-water fish (18°C) that is homogenously distributed around the Mediterranean Sea (Cheung et al. 2013). The species shows a discrete recruitment concentrated in late summer; Kınacıgil et al. (2001) reported the first recruitment of red mullet in August in İzmir Bay, which explains the small mean size of the specimens caught in this study in September. In winter, the species moves to deeper waters to avoid lower temperatures.

The results of this study demonstrate that escape mortality is also affected by mesh size, with increasing mesh size from 44 mm to 50 mm generally reducing escape mortality. It has been hypothesized that increasing codend mesh size may reduce mortality, because larger meshes reduce the risk of abrasive injury when escaping fish pass through them (Lowry et al. 1996, Suuronen 2005). Other studies have reported that codend mesh size is not related to fish mortality and has only small effects on the survival of escaping fish (Sangster et al. 1996, Suuronen et al. 1996a, Wileman et al. 1999).

The mesh shape also appears to play a role in reducing escape mortality (Main and Sangster 1990, Suuronen 2005), because round fish may escape more easily through square-mesh than through diamond-mesh codends (Suuronen 2005). Moreover, Düzbastılar et al. (2010b) found that the 40-mm square-mesh codend produced a higher mean survival rate for red mullet than the 44-mm diamond-mesh codend. In the present study, though the mesh size of the square-mesh codend was smaller than that of the other test codends, it showed lower mortality than the 44-mm diamond-mesh codend and comparable mortality to the 50-mm diamond-mesh codend.

The overall mortality of red mullet escaping from codends (21.3-35.4%) was greater than those reported in previous experiments performed at the same site in summer (<7%, Metin et al. 2004; 5-9%, Düzbastılar et al. 2010b). This difference may be due to a larger number of replicates (48 hauls), the trawl net characteristics (mesh size and number of meshes), the presence of predators (e.g. rays) in the cages and the trawling conditions (e.g. weather).

To date, few studies have been done to quantify the effect of sex and sexual maturity on the mortality of escaping fish. Wileman et al. (1999) reported no effects of sex on the escape mortality of sexually immature haddock and whiting. In the present study, we determined that there was no significant difference in escape mortality due to sex. The significantly higher escape mortality found in immature fish corresponds to the inverse length-related mortality.

In conclusion, this study has demonstrated that codend escapee mortality for red mullet is higher, particularly for the smallest fish, in winter months, which coincide with low water temperature and poorer physical condition. Codend mesh size and shape and fish condition and size (fish length) are also factors significantly affecting escape mortality. However, due to a lack of valid methodological controls, there is some uncertainty about the absolute magnitude of the mortality estimates. For fishery management purposes, escape mortality investigations should be carried out together with selectivity studies to consider the likely factors affecting mortality.

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