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RESEARCH PAPER

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A Variation in the Mortality of European Anchovy and European Pilchard After Sieving and Discarding from a Purse Seine Fishery in the Eastern Mediterranean

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Abstract

Discard mortality of European anchovy (*Engraulis encrasicolus*) and European pilchard (*Sardina pilchardus*) was investigated during commercial purse seine fishing operations off İzmir Bay, Turkey. In total, 6703 anchovy and 2545 sardine individuals were observed for seven days in five survival experiments carried out from March to October 2019. Only in March, fish cages were used and observed by divers. In the other trials, fish were observed in holding tanks; dead fish were collected and any surviving fish were fed. In the study, we compared the mortality of sorted and unsorted fish. The GLM model for European anchovy demonstrated a highly significant category effect ($p<0.0001$) and a highly significant interaction between length-related mortality and season (CL: season; $p<0.0001$). There were also significant differences in length-related mortality ratio according to the different categories in both seasons ($p<0.0001$). However, there was a highly significant interaction between mortality ratio, length, uncrowded category, and spring ($p<0.005$) for European pilchard. The observations showed that high mortalities occurred in the sorted fish categories of both pelagic species during the experiments.

Introduction

On the global scale, trawls and purse seines are responsible for the estimated fishing mortality including escape and discard mortality (Suuronen et al., 1995; Marçalo et al., 2006; Ingolfsson et al., 2007; Huse & Vold, 2010). The catch of purse seine fishery represents the vast majority of small pelagic, resulting in a discard rate of 3.9% and 1.02 million tons of discards (Slipped catches and post-release mortalities were not included) in global fishery catch records (Pérez Roda et al., 2019). Tsagarakis et al. (2012) reported that weighted discard rates (proportion of the catch discarded) of purse seines were 4.6% in the Aegean Sea.

It has been widely studied to find effective methods to decrease the mortality of escaped fish (Misund & Beltestad, 2000; Stratoudakis & Marçalo, 2002; Marçalo et al., 2010, 2018; Olsen et al., 2012; Handegard et al., 2017). To decrease fishing mortality of purse seine nets, which are poor or non-selective fishing gears, meshes, or sorting grids to help undersize fish escaping through panel meshes and separating grids. A fundamental restriction for the application of selection devices is the survival of the fish that escape from fishing gears. Similarly, discarded fish in the catch until the net is pulled aboard the purse seiner with a power block is a critical factor in fishing mortality as the escape mortality (Misund & Beltestad, 2000; Kelleher, 2005; Gonçalves et al., 2008; Olsen et al., 2012; Tenningen et al., 2012).

Over 80 percent of global marine fish stocks identified by FAO are now fully exploited or overfished and depleted (FAO, 2020). It was reported that almost European pilchard (*Sardina pilchardus*) and European anchovy (*Engraulis encrasicolus*) were overfished in the Mediterranean Sea and Black Sea (FAO, 2020). On the Aegean coast of Turkey, the most captured fish was European anchovy (~13% of total anchovy production) followed by European pilchard (~65% of total European pilchard production), bogue (*Boops boops*), mackerel and grey mullet (*Mugil* sp.) in purse seine fishery (Tosunoğlu et al., 2018).

Fishery statistics between 2006 and 2018 showed that the total catch of European anchovy decreased by 30% (96,452 tons in 2018) while the declining capture of European pilchard was 18,854 tonnes (TUIK, 2018) in Turkey. The overfishing forced the local fishers (Aegean fishermen) to use a sieve system for sorting and grading fish by size and species to release undersized individuals for obtaining the likelihood that released fish will survive (Misund & Beltestad, 2000; Tenningen et al., 2012). The vibrating sieve system with two or three grids, which is developed from a tea sieving machine, had been used for 5-6 years in all purse seiners that have sufficient space on their deck in the Aegean Sea. The system is used to move the mixture of undersized live fishes into the sea after sieving, and separate the captured fish into different sizes and species. Although the primer purpose of the local fisherman is to separate the small fish and increase their income, the fate of the fish sieved and then discarded has been undetermined until now.

In this study, we aimed to investigate the discard mortality of purse-seined anchovy and pilchard individuals that passed through a two-grid-sieve and discarded.

Material and Methods

Five trials were done with a commercial purse seiner, F/V AFALA (23.4 m LOA and 420 kW) in March, April, and October 2019 in İzmir Bay (Figure 1). The work schedule was determined from March to October because the commercial fisheries season begins on September 1 and finishes on April 15 in the Aegean Sea. To investigate the discard mortality of pelagic fishes, fishing operations were conducted between the depths of 36.6 and 52.5 meters. The purse seine net was 750 m in length and 164 m in depth. The fish pump with the capacity of 400 tons.h^{-1} is typically used in the Turkish purse seine fleet. Additionally, catch data of commercial purse seiner were systematically recorded to calculate the discard rate (weight of discards to the weight of one-year total catch) for one year. Dissolved oxygen and seawater temperature were measured with a probe in the field experiments.

In this study, we used a two-grid sieve system to be used for sorting fish by size and species. Undersized fish that passed through the grids are discarded. In the operation, a submersible pump was lowered into the net and moved fish to a two-grid-sieve for sorting and grading or throwing undersized individuals, which is called the selected/sorted fish category, overboard via a flexible hose in 10 min at the most (Figure 2). The other

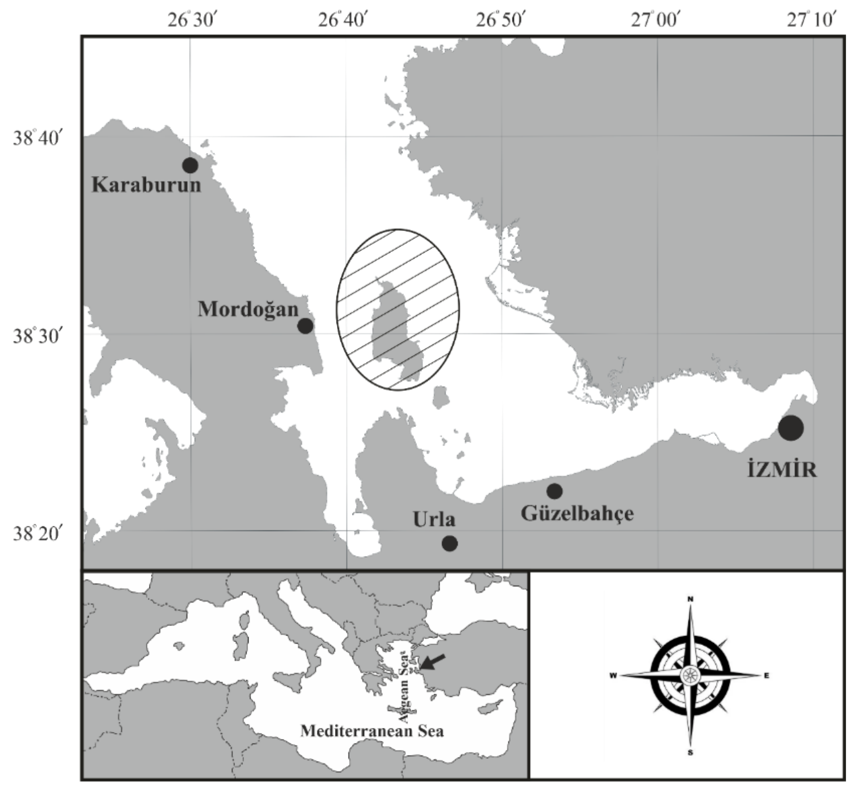

Figure 1. Study site (between latitude 38°27′-38°34′N and longitude 26°38′-26°46′E).

category was the uncrowded fish (unsorted fish) group which was composed before forming a concentrated pocket of pelagic fish. The third category was the crowded (unsorted fish) category that collected from the captured fish become more densely packed.

To sample the fish, R/V EGESÜF (23.2 m LOA and 550 kW) was positioned and moored alongside the purse seiner, and fish were transferred to holding tanks on the deck of R/V. The crowded and uncrowded fish were taken from the purse seine net with the help of plastic bins (~50 liters) transferred into pre-filled tanks with seawater in a maximum of 10 seconds. The mixture of selected undersized fish (35-40% fish) and seawater (60-65% water) was put into FRP (Fibre-reinforced plastic) tanks (2x2x1 m^3) for a maximum of 15 seconds by a flexible hose after being sieved (Figure 3a).

In the first experiment (in March), all fish in tanks were transferred into floating cages placed in the sea at the observation site. The cages were secured by attaching to the R/V EGESÜF and observed by divers thrice a day. As this method did not work well (fish samples transferring into the cages), in the following experiments (from April to October) fish were only kept in holding tanks and observed thrice a day over 7 days on the deck of R/V EGESÜF (Table 1).

All fish tanks with a depth of 1 m were supplied with seawater up to ~0.9-m depth by 3 submersible pumps and aerated by two portable compressors using air-stone diffusers. When air and water circulation systems were installed, fish were transferred to holding tanks on the deck. After transporting fish, the layer caused by fish scale and oil at the surface of fish tanks

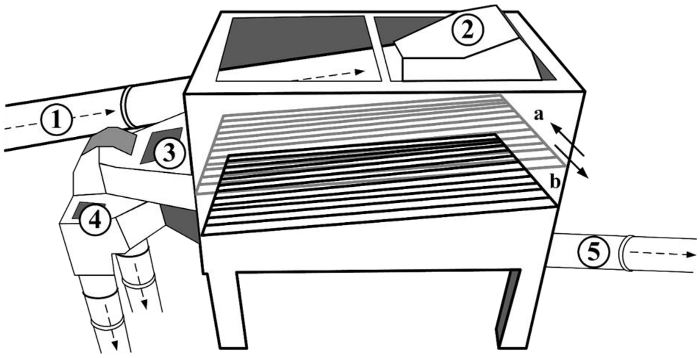

Figure 2. Two-grid-sieve system (a. grid with 13-14 mm b. grid with 8-9 mm) for sorted undersized pelagic fish: 1. Pumped fish and water through the two-grid-sieve 2. Routing fish 3. Fish being graded for size (13-14 mm grid) 4. Fish being graded for size (7-8-9 mm grid) 5. Discarded fish after sieving.

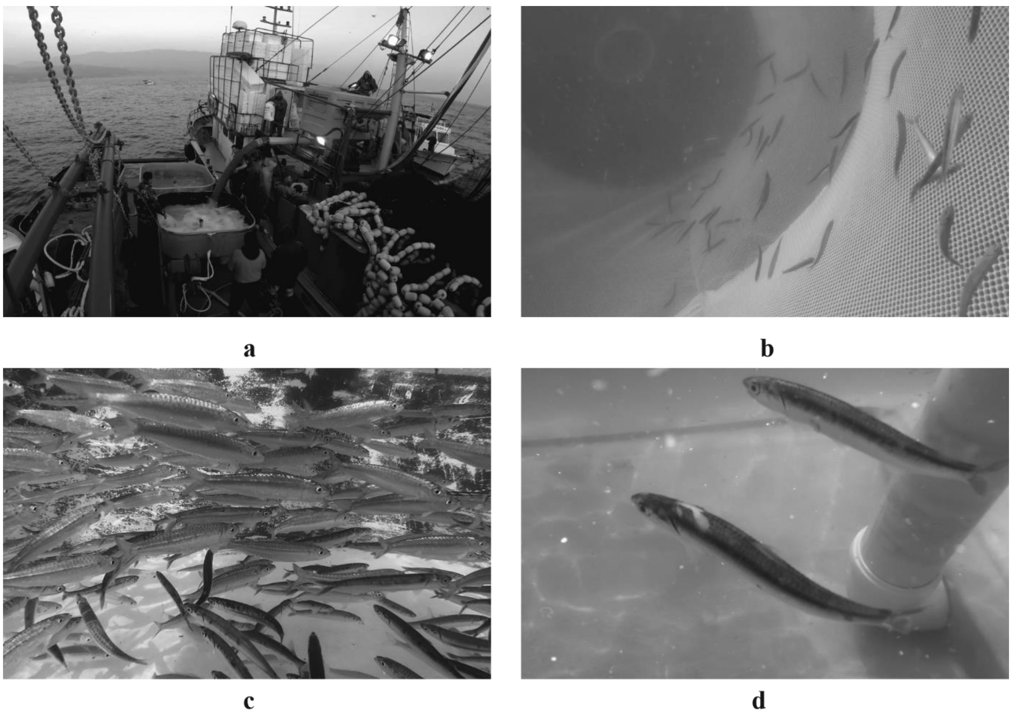

Figure 3. a: Fish are put into fish tanks by a flexible hose after sieving, b: Anchovy individuals swim along to the knotless mesh panel of the fish cage, c: Pilchard individuals swim in groups in an observation tank., d: Injured anchovy prefers to be apart from the other fish in a tank.

was simultaneously removed by fish scoops. The fish samples in observation cages and tanks were dominated by the individuals of anchovy and pilchard. During the experiments, we used a digital handheld video camera (GoPro Hero 2018 and GoPro Hero 7 Black) to record the behavior of the fish in the cages and tanks. Dissolved oxygen and seawater temperature in fish tanks were measured using a dissolved oxygen meter (YSI EcoSense DO200A) three times a day. For the next seven days, divers/staff observed the fish cages/tanks thrice a day; dead fish were collected and any surviving fish were fed with pellets. During the monitoring period, dead fish were removed and measured to the nearest mm for total (TL) and standard (SL) lengths. Discard mortality (F_D) was estimated as

$$F_D = \frac{n_m}{\Sigma(n_m+n_s)}$$

where n_m is the number of dead individuals of discarded and sampled fish and n_s is the total number of survived fish in observation cages or tanks. A total of five experiments were conducted from March to October 2019. All data were obtained from the fish captured by a commercial purse seiner in a legal fishing area. The fish were transferred to fish tanks on the deck of R/V EGESÜF and the vessel returned to the observation site. Excluding experiments performed in march, fish remained in tanks at the end of the observation period of the trail. Only in that experiment, fish were transported to the fish cages.

The relationships between discard mortality ratios (F_D) and other explanatory variables were analysed with generalized linear modelling (GLM) techniques with the binomial error distribution and logit-link function for European anchovy and pilchard (McCullagh & Nelder, 1999). The models included the main effects of fish length, category, season, and the interactions between them. Thus, the form of the GLM was used:

$$F_D \sim a + TL + C + S + TL{:}C + TL{:}S + C{:}S + e$$

where a is the intercept, TL is total length, C is the category (sorted, uncrowded, and crowded fish), S is season and e is a random error term. Model fitting was accomplished in the R language environment (R Development Core Team, 2019). The “dplyr” (Wickham et al., 2020) and “broom” (Robinson & Hayes, 2020) libraries were also required. Statistical inference was based on the 95% confidence level.

Results

In total, 9248 individuals were observed in the experiments. European anchovy (6703) was the most abundant fish species, followed by European pilchard (2545). In total, 136 days were active fisheries performed by a commercial purse seiner, F/V AFALA in a fishing season, resulting in a weighted discard rate of 2.9% (discarded fish rate after sieving).

Behavior of Captive Fish in the Cages and Tanks

During the experiment period, divers observed all the fish cages and collected mortalities from the sea surface or along the water column after opening the cage zipper. It was observed that individuals of both fish species responded to the divers when the cage zipper was opened to remove dead fish. Survivors escaped from the divers, moved to other parts of the fish cage, and continued to swim around and explore their new surroundings (Figure 3b). In tank experiments, dead fishes were collected by fish scoops. It was observed that fish samples swam in groups at all levels of fish tanks continually (Figure 3c). Some injured individuals preferred to stay apart from the fish school in the observation tank (Figure 3d). When specimens of dying or dead fish individuals were examined, it was observed that the occurrence of scale loss was very high. Fish were fed with pellets during the capture, although they initially showed no interest, survivors reacted to pellets positively at the end of 48 hours. In the hauling process, the crowding in the purse seine net is associated with increases in physical activity causes to abrasion and resulting in fish injury (scale, skin, tissue losses, etc.). We examined the skin and fin deformations among the injured fish that die in the following hours. In particular, fish that were affected by physical impacts in the capture suffered head, abdomen, and fin damages (Figure 3d).

Table 1. Details of the experimental trials

Season	Date	Coordinates	Depth (m)	Wind force (Beaufort)	Fishing operation	Grid size (mm)	Seawater temperature (°C)	Dissolved oxygen (mgL^{-1})
Spring	14 Mar.	38°27′020″N 26°44′000″E	36.9	1	17.40-18.40	9-8	14.4	7.1
	15 Mar.	38°32′370″N 26°46′150″E	36.6	3	03.15-04.20			
	4 Apr.	38°32′420″N 26°38′590″E	46.7	3-5	06.00-07.15	14-8	14.9	7.0
Autumn	10 Oct.	38°32′430″N 26°46′420″E	39.0	1-3	06.35-07.42	13-7	22.0	6.7
	18 Oct.	38°34′530″N 26°44′470″E	52.5	1	06.00-07.18	13-7	21.0	6.8
	25 Oct.	38°32′390″N 26°45′450″E	50.1	3	06.45-07.56	13-7	20.0	6.7

Experiments in March (Exp. 1) – Fish Held in Cages

In March 2019, 1449 individuals were moved to the tanks and then transferred to the sea cages (10 fish cages) for monitoring (Table 2). Sorted (discarded) fish after sieving was pumped to tanks and then transferred via plastic bins to cages. Uncrowded fish were collected after closing the bottom of the net and crowded fish were collected from concentrated fish of the net that decrease in volume during hauling. Of these, 1374 anchovy, ranging in total length (TL) from 8.6 to 12.1 cm (TL_{mean}=10.2, SD=0.6), had the highest proportion of fish in the 10.0 cm length group (n=407). In total, 240 anchovies ranging from 8.6 to 11.6 cm TL were observed in sorted fish cages. 301 and 833 anchovies ranging from 8.8 to 12.1 cm TL were in uncrowded and crowded fish cages, respectively. All categories of anchovy died at the end of the 7th day (Figure 4). Only 75 pilchards, ranging in total length from 11.2 to 13.9 cm were captured (TL_{mean}=12.2 cm, SD=0.5) (Table 2). The highest proportion of pilchard was in the 12 cm length group (n=29). All fish died in the sorted fish category. Only two and seven fish survived in uncrowded and crowded fish categories, respectively (Figure 5).

Experiments in April (Exp. 2) - Fish Held in Tanks

A total of 878 individuals were collected from the capture in April 2019 (Table 2). Of these, 466 anchovies ranging from 9.7 to 14.0 cm TL (TL_{mean}=12.1 cm, SD=0.6) were captured in all categories. The highest proportion of anchovy was observed in the 12 cm length group (n=135). The percentage of pooled mortality in sorted two fish tanks and uncrowded two fish tanks were 93.6 (TL_{dead}=9.7–14.0 cm) and 82.7 (TL_{dead}=10.8–13.4 cm), respectively. The crowded fish could not collect in April 2019 (Figure 4). The total number of pilchards ranging from 10.8 to 17.2 cm TL (TL_{mean}=13.1 cm, SD=0.7) in the tanks was 328. The highest proportion of pilchard was obtained in 13.5 cm (n=95) length groups for pilchard. The pooled mortality rates of pilchard were 76.4% and 64.7% in two sorted and two uncrowded fish tanks, respectively (Table 2 and Figure 5).

Table 2. Summary data of European anchovy and European pilchard in 5 experiments conducted in 2019 (T; seawater temperature and DO; dissolved oxygen)

			Anchovy			Pilchard				
			Number of fish	Mortalities		Number of fish	Mortalities		T (°C)	DO (mgL^{-1})
	Category	No		Mean Length (cm)	% mortality		Mean Length (cm)	% mortality		
Spring	*March experiments*									
	Sorted	1	47	10.1±0.5	100.0	2	12.3±0.3	100.0		
		2	69	10.2±0.5	100.0	4	12.7±0.7	100.0	14.2	6.9
		3	36	10.0±0.4	100.0	2	11.7±0.2	100.0		
		4	88	10.0±0.5	100.0	0	-	n/a		
	Uncrowded	1	120	10.2±0.6	100.0	6	12.7±0.7	66.7		
		2	73	10.2±0.5	100.0	2	n/a	100.0	14.2	6.9
		3	108	10.2±0.5	100.0	5	n/a	60.0		
	Crowded	1	314	10.2±0.6	100.0	24	12.3±0.4	79.2		
		2	277	10.2±0.6	100.0	15	12.1±0.3	86.7	14.3	6.8
		3	242	10.1±0.5	100.0	15	12.1±0.4	100.0		
	April experiments									
	Sorted	1	155	12.1±0.6	92.3	54	13.2±0.6	70.4	15.0	6.9
		2	143	12.1±0.7	95.1	56	13.2±0.7	82.1	14.8	6.7
	Uncrowded	1	109	12.0±0.6	99.1	131	13.0±0.8	84.6	14.8	6.5
		2	59	11.8±0.5	52.5	87	13.0±0.5	34.5	14.8	6.8
Autumn	*10th October experiments*									
	Sorted	1	372	9.2±0.7	100.0	336	10.7±0.9	100.0	21.6	5.9
		2	393	9.7±0.6	100.0	119	11.1±0.6	100.0	21.5	6.0
		3	178	9.4±0.8	100.0	65	11.1±0.8	100.0	22.1	5.6
	Uncrowded	1	23	9.1±0.7	69.6	272	11.4±0.9	68.8	21.4	5.5
	Crowded	1	186	9.6±0.7	98.9	551	11.4±0.7	97.1	21.6	5.8
	18th October experiments									
	Sorted	1	767	9.9±0.8	99.9	70	11.4±0.6	100.0	21.3	5.9
		2	283	9.9±0.6	100.0	29	11.4±0.6	100.0	22.2	5.4
		3	406	9.5±0.8	99.8	168	11.3±0.6	100.0	20.3	6.1
	Uncrowded	1	11	9.8±1.2	45.5	100	11.7±0.9	66.0	21.7	5.5
	Crowded	1	58	9.5±0.8	86.2	275	11.3±0.7	66.9	21.4	5.5
	25th October experiments									
	Sorted	1	334	9.5±0.5	99.7	2	n/a	100.0	20.3	6.2
		2	986	9.5±0.6	99.1	11	11.8±0.7	100.0	20.0	6.2
		3	188	9.7±0.5	99.5	2	n/a	100.0	18.3	6.8
	Uncrowded	1	291	9.5±0.6	63.6	43	12.1±0.7	34.9	19.9	5.9
	Crowded	1	387	9.3±0.6	82.2	99	12.1±0.8	65.7	20.1	5.9

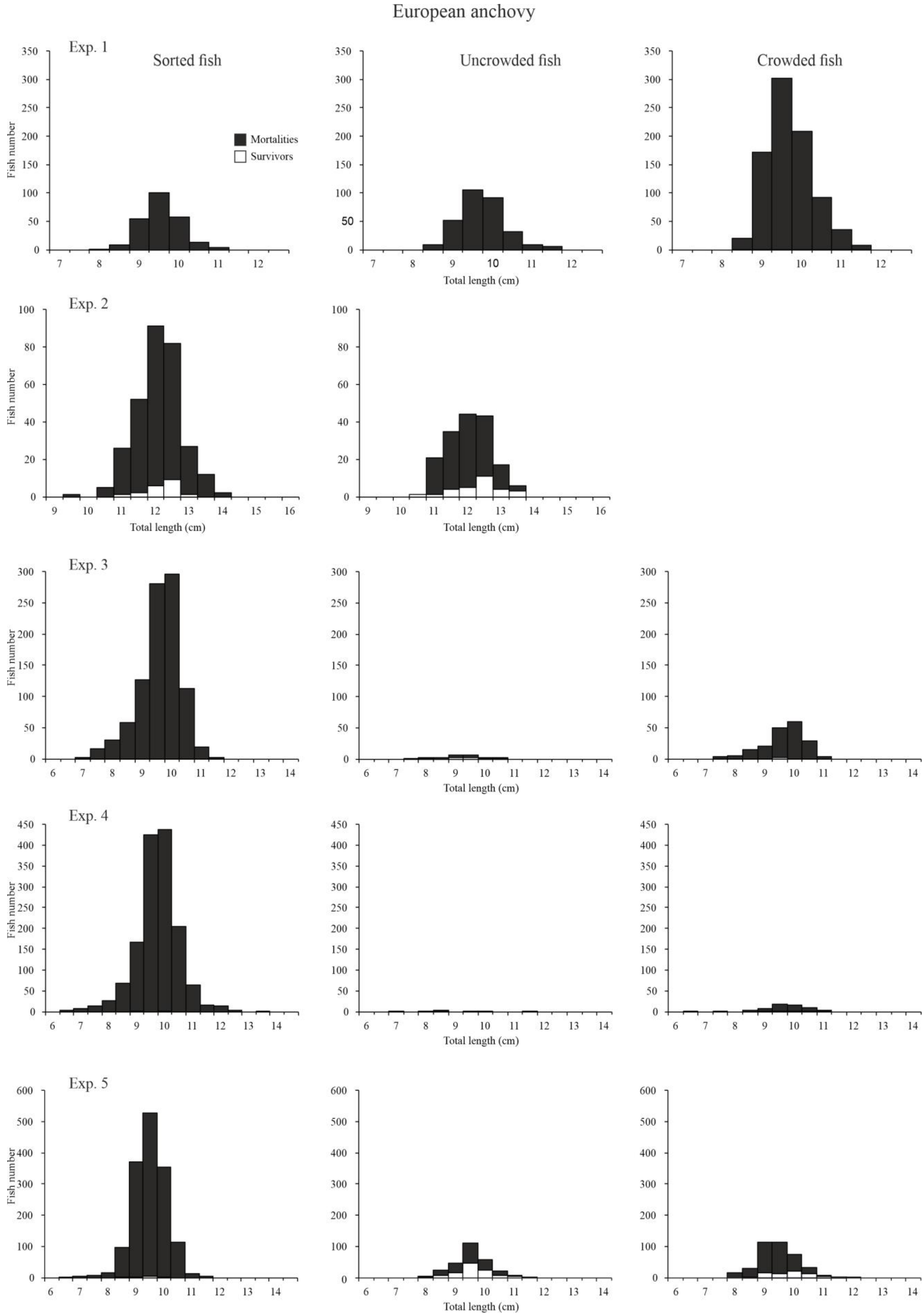

Figure 4. European anchovy: Number of dead fish (black) and survivors (white) in each length class for sorted, crowded, and uncrowded fish in the experiments of 2019.

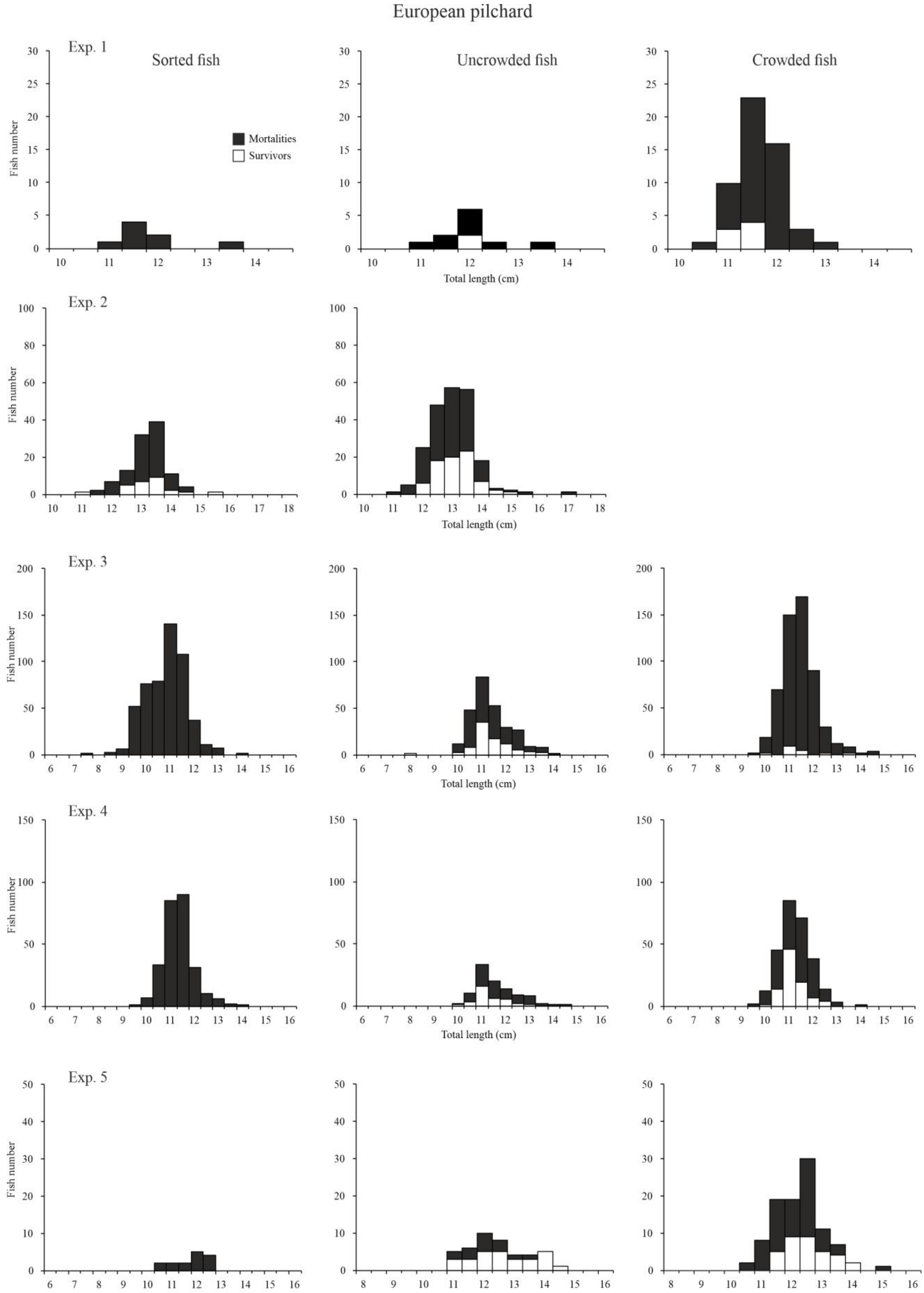

Figure 5. European pilchard: Number of dead fish (black) and survivors (white) in each length class for sorted, crowded, and uncrowded fish in the experiments of 2019.

Experiments on 10th October (Exp. 3) - Fish Held in Tanks

Three experiments were carried out in October 2019. Of these, 1206 European anchovy and 1343 European pilchards were captured on 10th October 2019 (Table 2). Anchovy individuals ranging from 6.8 to 11.7 cm TL (TL_{mean}=9.6, SD=0.7), had the highest proportion of anchovy in the 10.0 cm length group (n=358) (Figure 4). All anchovy fish died in the three sorted fish tanks. The observed uncrowded mortality rate was 69.6% in an observation tank. Only two fish of 186 individuals survived in the crowded tank, resulting in a mortality rate of 98.9%. In all fish tanks, 1343 European pilchards, representing 52.7% of the total individuals and ranging in total length from 7.7 to 14.6 cm (TL_{mean}=11.2 cm, SD=0.8), were caught. Pilchards had the highest proportion in the 11 cm length group (n=374). All fish died in three sorted fish tanks (Table 2 and Figure 5). A total of 85 fish survived in the uncrowded fish tank (F_D<69%). Sixteen individuals of pilchard died in the crowded fish tank, resulting in a mortality rate of 97.1%.

Experiments on 18th October (Exp. 4) - Fish Held in Tanks

A total of 2167 individuals were caught on 18th October 2019. Of these, 1525 anchovy, ranging in total length from 6.5 to 13.4 cm (TL_{mean}=9.7 cm, SD=0.8), was captured in all fish tanks (Table 2 and Figure 4). The highest proportion of anchovy was in the 10 cm length group (n=455). All fish died in three sorted fish tanks, whereas mortality percentages were 45.5 and 86.2 in the uncrowded and the crowded fish tank, respectively. In total, 642 pilchards ranging from 9.5 to 14.3 cm TL (TL_{mean}=11.3 cm, SD=0.7) were captured in all fish tanks. The highest number of pilchard individuals was in the 11.0 cm length group (n=203). Mortality rates of pilchards were 100.0, 66.0, and 66.9% in sorted (3 tanks), uncrowded (one tank), and crowded (one tank) fish tanks, respectively (Figure 5).

Experiments on 25th October (Exp. 5) - Fish Held in Tanks

In total, 2342 individuals were captured on the 25th of October 2019. Of these, 2186 anchovy ranging from 6.7 to 12.0 cm TL (TL_{mean}=9.5, SD=0.6) and 156 pilchard ranging from 10.4 to 15.2 cm TL (TL_{mean}=12.3 cm, SD=0.9) were observed (Table 2 and Figure 4). The greatest number of anchovy was in the 9.5 cm length class (n=753), but the highest proportion of fish was recorded at 12.5 cm for pilchard (n=42). The pooled discard mortality rate of anchovy ranging in total length from 6.7 to 11.7 cm was 99.3% in three sorted fish tanks, whereas mortality rates in uncrowded fish ranging from 8.0 to 11.3 cm TL and crowded fish ranging from 7.8 to 12.0 cm TL was 63.6% and 82.2% in fish tanks, respectively. All pilchards ranging from 10.4 to 12.7 cm TL died in three replicate tanks of the sorted fish category. The observed mortality rates of pilchards were 34.9% and 65.7% in uncrowded fish ranging from 11.0 to 13.6 cm TL and crowded fish ranging from 10.5 to 15.2 cm TL in fish tanks, respectively (Table 2 and Figure 5).

Length-Related Mortality, and Seasonal- Effect on Mortality

In the experiments, anchovy individuals in the sorted fish category had high discard mortality, resulting in 96.8% (mean) and 99.7% (mean) in observation cages/tanks for the seasons (Figure 6). Anchovy in crowded fish cages/tanks in spring had higher mean mortality than in the autumn experiments ($FD_{[spring]}$=100.0%; $FD_{[autumn]}$=89.1%). It was observed that the mean mortality rates of anchovy for uncrowded

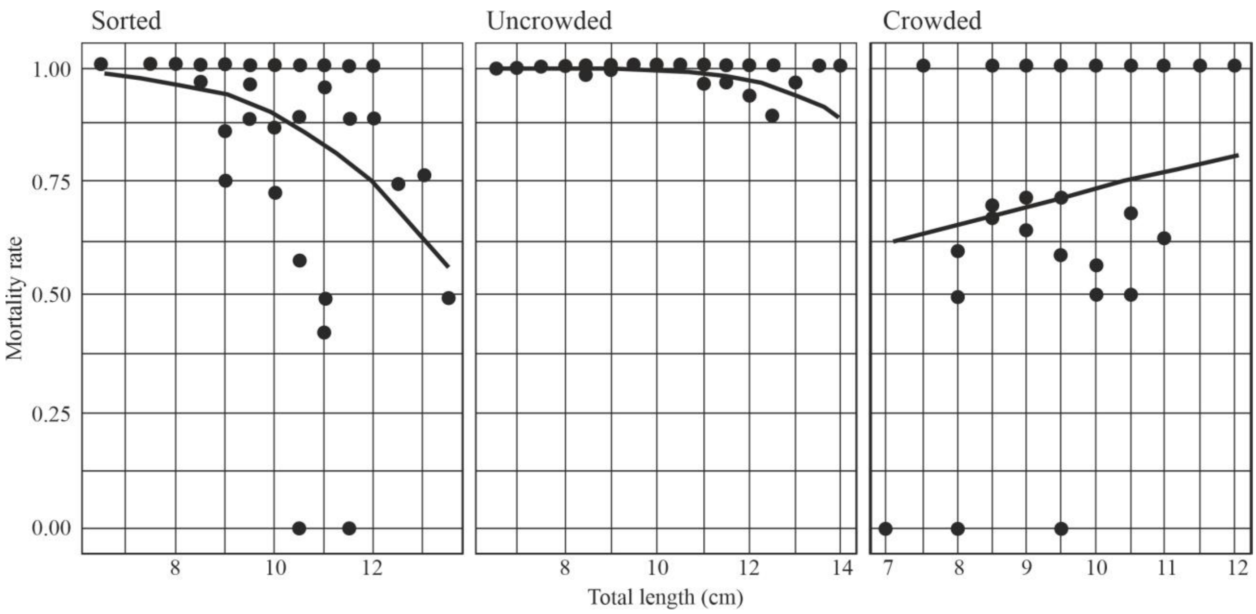

Figure 6. Proportions of mortality of European anchovy from the GLM model.

fish cages/tanks (91.3%) in the spring experiments were significantly higher ($p<0.001$) than that in the autumn experiments (59.6%). The model for anchovy demonstrated a highly significant category effect ($p<0.0001$) and a highly significant interaction between length-related mortality and season (TL: season; $p<0.0001$). There were also significant differences in length-related mortality ratio according to the different categories in both seasons ($p<0.0001$) (Table 3). It was observed that there was clear length-related mortality in selected and crowded categories, excepting the uncrowded group, with smaller anchovies having an increased likelihood of dying after discarding.

Discarded pilchards in sorted fish cages/tanks had lower mortality in spring (88.2%, mean) than in autumn (100%, mean). European pilchards had higher mean mortality in spring (87.0% and 67.0%) than in autumn (56.6% and 76.6%) for both uncrowded and crowded fish tanks. Except for the mortality of pilchards in sorted fish tanks observed in the spring experiments, the mean mortality of fish was generally higher in spring than in autumn. Moreover, there was a highly significant interaction between mortality ratio, length, uncrowded category, and spring (Figure 7 and Table 4, $p<0.005$) for pilchard species.

Cumulative Discard Mortality During the Monitoring Period

Most of the mortality occurred in the first 48 h of the observation period. However, a lower cumulative ratio for uncrowded fish in autumn was observed. For the anchovy, 81.4%, 70.4%, and 95.6% of the mortality for the sorted, uncrowded and crowded fish, respectively, were observed on the first 2 days in the spring. In autumn, 96.0%, 20.9%, and 58.0% of the pooled mortality occurred for the sorted, uncrowded and crowded anchovies, respectively, in the first 48 h. In spring, 40.7%, 9.5%, and 35.2% of the mortality for the sorted, uncrowded and crowded categories of pilchard, respectively, were observed in the first 48 h. In the autumn experiments, the pooled mortality of pilchard was 99.4%, 33.7%, and 56.4% for the sorted, uncrowded and crowded categories, respectively, in the first two days.

Discussion

To determine the mortality of discarded fish after sieving, anchovy and pilchard individuals were kept in cages and tanks for a week. Additionally, the uncrowded fish, which were collected from the net before forming a concentrated pocket of pelagic fish, and the crowded fish, which were sampled from captured fish that become more densely packed in the purse seine fishing were other fish categories of the study to determine whether crowding contributed to discard mortality. Contrary to previous investigations on the mortality of small pelagic (Misund & Beltestad, 2000; Tenningen et al., 2012), there were more deaths occurred than we expected in the uncrowded and crowded groups of our study.

Holding cages or tanks cause many problems in estimating post-release survival rates due to having artificial conditions to hold fish during the observation period. Even there were some manipulations (water temperature, dissolved oxygen, bait, light, etc.) to keep the fish alive (Gilman et al., 2013). In previous studies, the different types of cages and tanks had been used successfully to investigate escape/post-release mortality associated with numerous fishing gears (bottom trawl, purse seine, hand-line, etc.) (Mitchell et al., 2002; Palsson et al., 2003; Ingolfsson et al., 2007). In the first sea trial, the fish were transferred to holding tanks on the R/V, and then, on the cage site, live fish were transferred from tanks to floating cages with plastic bins, manually. As the method did not work well, anchovy and pilchard individuals were only kept in holding tanks for the next experiments.

Estimation of unaccounted mortality rates has been difficult to obtain due to operational limitations in the study site and difficulties of keeping the pelagic fish in captivity (Marçalo et al., 2013). Purse seine fishing is an important stressor for fish individuals causing fish mortality due to decreasing seawater volume and increasing fish density related to the fishing activity (Marçalo et al., 2006). However, as in previous studies, we had to use holding tanks to determine the mortality rates of anchovy and pilchard under adjustable water parameters that must meet all the requirements of the captured fish in the experiments (Marçalo et al., 2008).

Table 3. Results of GLM analysis of European anchovy

Model coefficients	Estimate	Std. Error	z value	p
(Intercept)	95.078	18.550	5.125	< 0.001
TL	-0.7851	0.1896	-4.140	< 0.001
Category Crowded	-79.739	40.272	-1.980	< 0.001
Category Uncrowded	-82.869	25.512	-3.248	< 0.001
Season Spring	151.119	34.677	4.358	< 0.001
TL: Category Crowded	12.325	0.4247	2.902	< 0.001
TL: Category Uncrowded	0.7082	0.2639	2.684	< 0.001
TL: Season Spring	-10.702	0.3065	-3.492	< 0.001
Category Crowded: Season Spring	-33.575	58.076	-0.578	0.563177
Category Uncrowded: Season Spring	90.443	231.105.490	0.000	0.999688
TL: Category Crowded: Season Spring	-0.2304	0.5463	-0.422	0.673246
TL: Category Uncrowded: Season Spring	0.7348	22.258.155	0.000	0.999737

Although this study was the first experiment to investigate the mortality of fish discarded via a fish pump into the sea after sieving, there were many studies have been conducted on purse seine fishing. Of these, Misund and Beltestad (2000) conducted full-scale experiments on survival mackerel and saithe that escape through sorting grids in purse seine in 1993, 1994, and 1995. In the field experiments, they observed that a maximum of 60% of the experimental groups survived one month after the experiments whereas the control group had a very low mortality rate (<5%). However, there was a variation in the mortality of escaped mackerel individuals in the experiment groups, resulting in mortality rates of 64% in 1993, 100%, 38% in 1994, and 82% in 1995. They explained that the fish in the catch were injured due to worse sea conditions and all the fish died in both the experimental and control groups in six day-period. In another study to determine the effects of crowding in purse seines on the mortality of mackerel after pursing and slipping from a purse seine, five fishing operations were performed, slipped fishes were kept in net pens, which were left to drift at the sea for 3-6 days and finally observed high mortality in crowded fish (80%-100%) (Huse & Vold, 2010). Studies on the effect of crowding in purse seine nets on the mortality of the fish showed that the high fish density in purse seine caused increasing mortality of small pelagic fish the same as herring (52%) (Tenningen et al., 2012). Although the species between this study and the other studies as different, our results show similarities with these arguments. The mortality ratios of uncrowded fish for both species are lower than the other categories and the cumulative death ratio of uncrowded fish in the observation period has progressed lowly.

In the experiments, we observed high discard mortality for sorted and discarded anchovy individuals for all seasons (>96%). Contrary to expectations, very high mortalities of uncrowded anchovy were observed in the spring (91.3%) whereas lower mortality occurred in the autumn (59.6%). In the same season, none of the anchovies in the crowded category could survive whereas only 10.9% of fish survived in autumn experiments.

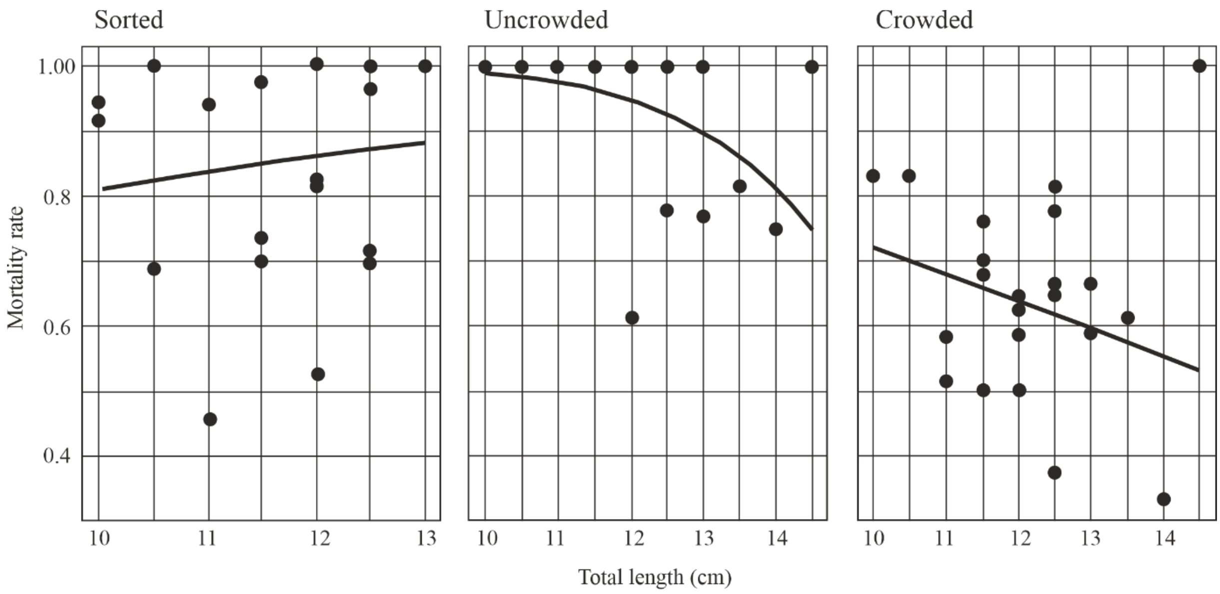

Figure 7. Proportions of mortality of European pilchard from the GLM model.

Table 4. Results of GLM analysis of European pilchard

Model coefficients	Estimate	Std. Error	z value	p
(Intercept)	0.3157	1.6850	0.187	0.8514
TL	0.1263	0.1484	0.851	0.3948
Category Crowded	279.374	161.531.052	0.002	0.9986
Category Uncrowded	17.705	24.399	0.726	0.4680
Season Spring	-309.608	158.139	-1.958	0.0503
TL: Category Crowded	-0.7447	14.159.929	-0.001	0.9996
TL: Category Uncrowded	-0.2520	0.2144	-1.175	0.2399
TL: Season Spring	25.898	13.362	1.938	0.0526
Category Crowded: Season Spring	65.806	161.531.136	0.000	0.9997
Category Uncrowded: Season Spring	351.460	161.861	2.171	0.0299
TL: Category Crowded: Season Spring	-21.682	14.159.935	-0.002	0.9988
TL: Category Uncrowded: Season Spring	-29.021	13.642	-2.127	0.0334

The relationship between mortality and fish length has not been propounded clearly by the studies, especially focused on escape mortality. However, there was a significant number of experiments that have argued that mortality decreases with increasing fish size (Suuronen et al., 1996; Suuronen, 2005; Ingolfsson et al., 2007; Düzbastılar et al., 2017). For instance, Tenningen et al. (2012), reported that small individuals of herring were more vulnerable to the effects of crowding. In the study, the smallest individuals showed the highest injury rates and died. For instance; mortality for crowded anchovy was 97% in the 8.5 cm length group, 88% in the 9.5 cm length group, and 58% in the 10.5 cm length group in the experiments on 25th October 2019. In both seasons, it was observed that there was length-related mortality in sorted and crowded categories for anchovy, however, there was a highly significant interaction between mortality ratio, length, uncrowded category, and spring. In particular, small pelagic fish as in this study are open to physical damages such as scale loss and caudal fin erosion in fishing, crowding, pumping, and holding stages resulting in death during the experiments. The deformation may cause accuracy problems and requires more attention to obtain mortality data when measuring fish length as reported by Tenningen et al. (2012).

The mortality of anchovy was affected by the seasonal variation in terms of water temperature for the uncrowded and crowded categories. However, the seasonal effect on mortality of pilchard was observed only for the uncrowded category. The mean mortality rates of anchovy and pilchard for uncrowded fish cages/tanks in the spring experiments (~15°C) were significantly higher than that in the autumn experiments (~20°C). Düzbastılar et al. (2017), reported that a seasonal effect on the length-related mortality of red mullet (*Mullus barbatus*) escaping from different codends of bottom trawl was observed, with smaller fish (<13 cm TL) showing lower mortality in summer (25°C) than in winter (13°C). However, particularly among smaller fish individuals, low water temperatures may cause decreasing swimming ability, which may cause higher mortality (Özbilgin & Wardle, 2002). Suuronen et al. (2005), observed lower mortality of cod at lower water temperatures (<10°C compared with >15°C). The difference in the effects of water temperature influences the physiological processes and behaviour of fish may affect the probability of mortality that needs to be studied comprehensively under commercial fishing conditions (Özbilgin & Wardle, 2002; Suuronen, 2005).

In the survival studies, the captured fish being held in holding cages or tanks are monitored for a certain period varies from 4 to 5 days to over 30 days (Misund & Beltestad 2000; Huse & Vold, 2010; Tenningen et al., 2012; Marçalo et al., 2018). We observed anchovy and pilchard individuals in holding cages and tanks for a period of 7-day and terminated the experiment following the last sampling of the seventh day. It was reported that the deaths of captive fish under experimental conditions could continue to occur even after 4-5 days due to physical damages such as skin and scale loss, and fin injuries (Düzbastılar et al., 2015). However, survival studies have shown that most of the mortality of fish species occurred in the first 48 h of the observation period whereas the duration extended up to 5 days for small pelagic. In the experiments, most of the injured anchovy and pilchard died in the first two days. We observed the highest mortality of sorted anchovies in the first 48 h, resulting in between 81.4% and 96.0% of mortality for spring and autumn, respectively. For pilchard, the mortality was between 40.7% and 99.4% for the sorted categories in the spring and autumn seasons, respectively.

In conclusion, this study has demonstrated that discarded mortality of anchovy (>96%) and pilchard (>88%) are very high in both seasons. Excepting sorted fish category for anchovy and pilchard, the mortality of these pelagic fishes was higher, particularly for the smallest fish, in spring months. The mean lengths of anchovy and pilchard in the sorted category were the same or higher than the minimum landing sizes (MLS) of that fish (9 cm and 11 cm, respectively) in the experiments (Official Gazette, 2016). Even so, the sieve method was used by fishers for sorting and grading fish into groups of similar individual sizes close to MLS to increase the commercial value of catch and save their own time without selecting fish manually. In terms of fishery management, at least 88% of discarded fish could not survive, resulting in an approximate weighted discard rate of 2.5%-2.7%, which was recorded during a period of 136 active fishing days in legal fishing areas.

At least initially, while Aegean fishermen have come forward to use the sieve system, purse seiners in the Sea of Marmara and the Black Sea were unwilling to take advantage of the sieve system because the mostly dead undersized fish that were returned after sieving to the sea. The argument of Aegean fishers was not possible for effective fishing without a sieve system if they used a fish pump to transfer the fish from the purse seine net because the sieve system provided both selecting and grading anchovy and pilchard in the catch. However, specific structural improvements must be applied to the sieve system such as submerging the output of the flexible hose to decrease the impact effect on discarded fish and increasing the surface area of sieves which makes a positive contribution to fish length selectivity, and relatively high survival rate. The sieve system may give fish a chance to survive in the multispecies fisheries, otherwise, the selecting species and grading of undersized fish on the deck of a fishing boat and discarding of the fish cause considerable fishing mortality upon exploited fish stocks. The use of a sieve system is particularly essential in April for electing the juveniles of Atlantic mackerel (*Scomber scombrus*) and Mediterranean horse mackerel (*Trachurus mediterraneus*) recruited to the exploited stock, and during the hauling process, the bunt should not be denser to avoid abrasion and crushing of the catch. In addition, towards to end of the summer, the gathering of juveniles under an artificial light depending on seawater temperature together with target species leads to an undersized catch, for this reason, fishermen must show a great effort not to surround and capture the school of juvenile fish.

Authors know that several restrictions of this study such as working with commercial purse seiners and obtaining alive, homogenous, and sufficient fish specimens to compare the discard mortality for two commercial species, anchovy, and pilchard. Therefore, we planned that further studies to be developed on the current methodology to keep fish alive particularly for the uncrowded category by eliminating certain methodical lacks and increasing the number of replicates.

Ethical Statement

Not applicable

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Author Contribution

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T.C. (Third author): Writing – review & editing, Conceptualization, Investigation.

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C.A. (Fifth author): Methodology, Conceptualization, Investigation.

Ö.G. (Sixth author): Methodology, Conceptualization, Investigation

G.M. (Seventh author): Methodology, Conceptualization, Investigation

Conflict of Interest

The author(s) declare that they have no known competing financial or non-financial, professional, or personal conflicts that could have appeared to influence the work reported in this paper.

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