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Controlled Ghost Fishing: Effects of Soaking Times and Mesh Sizes on Catchability in Trammel Net Fisheries

Yusuf Şen[1] | Uğur Özekinci[2]

[1]Department of Marine Biology, Faculty of Marine Science and Technology, Çanakkale Onsekiz Mart University, Çanakkale, Turkiye | [2]Department of Fisheries and Fish Processing, Faculty of Marine Science and Technology, Çanakkale Onsekiz Mart University, Çanakkale, Turkiye

Correspondence: Yusuf Şen (yusuf.sen@comu.edu.tr)

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ABSTRACT

Trammel nets are used with extended soaking times to increase the catching efficiency for demersal fish in commercial fishing. Long soaking time causes deterioration or damage to species caught in the first days. Effects of soaking time were investigated with 36-mm, 42-mm, and 46-mm mesh sizes soaked over 1, 3, 5, and 7 days on target, non-target, and other species. Only 26.3% (293 individual fish) of 1113 individual fish were not damaged of the target species. Total weight of non-damaged individuals was 247.6 kg, of which 150.6 kg (60.8%) was the target species. Critically endangered and endangered Chondrichthyes species were negatively affected by soaking time and mesh size. Current and previous regulations did not restrict soaking time or mesh size of trammel-net fisheries in Türkiye. Extended soaking times of trammel nets may cause more negative ecosystem effects than ghost fishing. Consequently, 42-mm mesh-size trammel nets soaked for 1 day should be used by fishers. If used for more than 1 day, 42-mm or 46-mm mesh sizes should be used.

1 | Introduction

Ghost fishing is undesirable fishing in ocean and inland waters where abandoned, lost, discarded, or derelict fishing gear continues to cause adverse effects and death on aquatic organisms through uncontrolled catching (Breen 1990; Beneli et al. 2020). Controlled ghost fishing occurs when fishing gear, such as trammel nets (called "marya nets"), is used with extended soaking time to catch demersal fish, to increase fishing efficiency under the control of fishers. Species caught earlier during controlled ghost fishing are subject to deterioration or damage when sacrificed to catch high economic value species in trammel nets with soaking times longer than 3 days (Cilasın 2014). Marya net fisheries that are fished an average of 5 days in the Marmara Sea, Türkiye, could have negative consequences for species and Türkiye's commercial fisheries (Şen and Özekinci 2022). Some scavenger crustaceans can negatively affect local fishing activities with long soaking times of trammel nets (Mülayim et al. 2022). Soaking time of gillnets should be short and not exceed 24 h to avoid degrading the quality of fish caught (Dickson 1989; Engas 1994; Cilasın, Öztekin, et al. 2015). Other fishing methods should be tried instead of controlled ghost fishing with long soaking times to catch species with high economic value, such as lobster (*Homarus gammarus* (Linnaeus, 1758)) in trammel net fisheries, although extended soak times appear to be profitable for fishers, due to catching efficiency for target species (Cilasın, Adnan, et al. 2015). Unwanted species or individuals can be caught with long soak times, such as fish that are too small, damaged, inedible, and have little or no market value. Long soak times also increase discards and mortality in many species. Moreover, injury and exhaustion of captured fish due to stress depend on soaking times and mesh

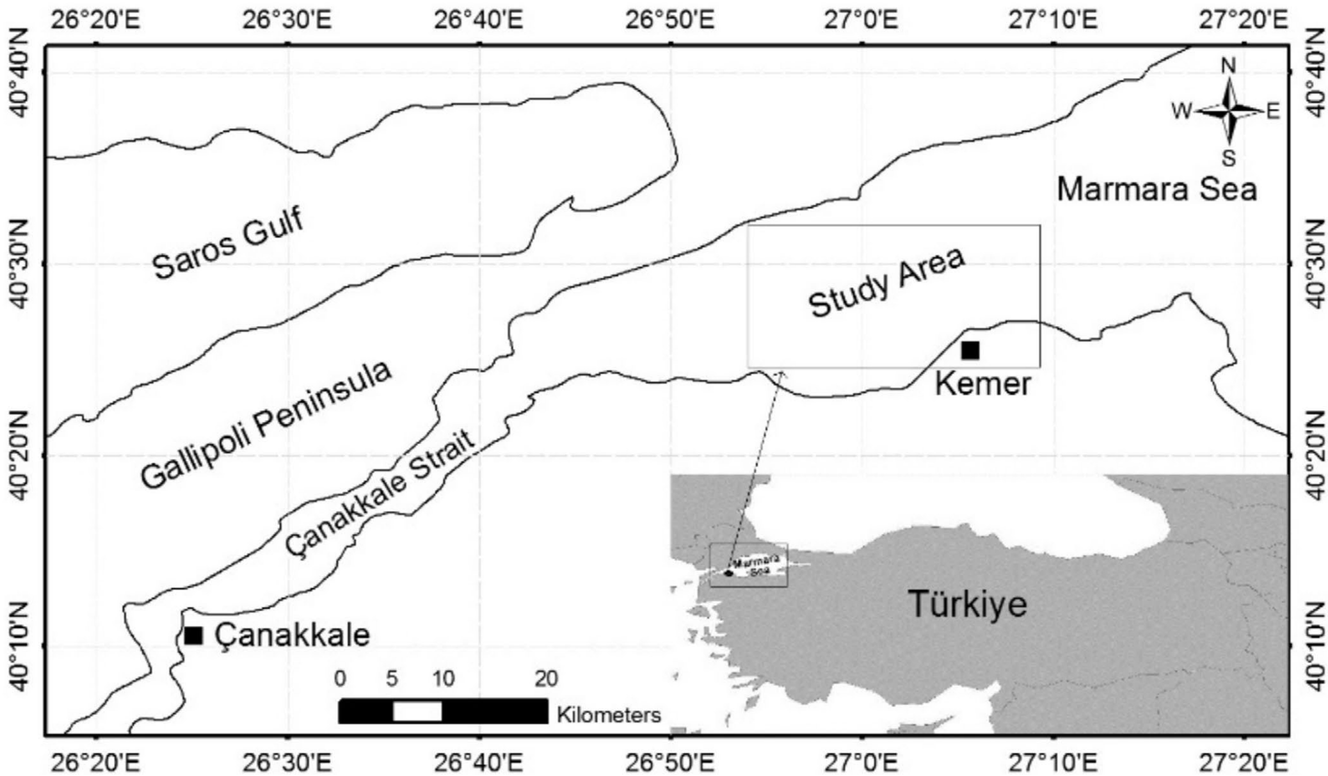

FIGURE 1 | Study area where effects of mesh size and soaking time of trammel-net fisheries were evaluated in the southwestern Sea of Marmara, Türkiye, between December 2020 and December 2021.

sizes (Ganias, Malioufa, et al. 2023). However, soaking times of trammel nets in commercial fisheries are not regulated in Türkiye (GDFA 2024).

In gillnets, soaking time is related to catch efficiency (Acosta 1994; Engas 1994; Akiyama et al. 2007; Savina et al. 2016). For example, increasing the soaking time of gillnets does not increase catch efficiency, but rather sometimes decreases catch efficiency (Alverson et al. 1994; Kelleher 2005; Zeller and Pauly 2005; Davies et al. 2009). Most studies have focused on the catch efficiency of trammel nets with long soaking times, but not detailed effects on species or individuals. Also, catch composition is affected by the mesh size of fishing gear (Pouladi et al. 2020; Cheng et al. 2023). Although trammel nets of different mesh sizes are used to catch demersal fish with different soaking times in the Marmara Sea (Şen and Özekinci 2022), 36-mm, 42-mm, and 46-mm mesh sizes were used in the present study to investigate the effects of controlled ghost fishing on species composition caused by soaking times and mesh sizes in trammel net fisheries.

In this study, trammel nets of fishers were not abandoned, lost, discarded, or derelict during ghost fishing, so the effects of trammel nets with extended soaking times and mesh sizes under the control of fishers were investigated. Trammel nets used with extended soaking times acted as controlled ghost fishing, with catch not removed from until nets were hauled. This study aimed to determine soaking times and mesh sizes for trammel net fisheries that caused the least negative effects on catchability.

2 | Material and Methods

This study was conducted monthly between December 2020 and December 2021 in the Kemer region of the southwestern Sea of Marmara, Türkiye (Figure 1). Twelve catch operations were conducted each month with the assistance of local fishers. Multifilament trammel nets with three different nominal mesh sizes (36-, 42-, and 46-mm) and outer panels of 180-mm (bar length) mesh size were used in catch operations similar to those used by commercial fishers. Each trammel net was 33-m long, 33 meshes deep, a 0.50 hanging ratio, and 210d/6 mesh thickness, with lead weighing 50 g (Pb) as sinker and plastic material (PL) number 3 as buoyant material.

Each of 36 trammel nets consisted of three mesh sizes and four soaking times, with three repetitions. All nets were operated simultaneously and deployed at depths ranging 20–70 m, similar to commercial fishers. For each trammel net, one mesh size of 36-mm, 42-mm, and 46-mm was joined together end-to-end. Nets were fished passively from early morning until retrieval in the morning 1, 3, 5, and 7 days later. Nets were retrieved after different soaking times, so one operation was completed in 4 days.

Catch composition was classified for each mesh size and soaking time. Species were identified using Whitehead et al. (1986) and Bilecenoğlu et al. (2014), and WoRMS Editorial Board (2025). Target, non-target, and other species identified by Alverson et al. (1994) were used as references. Species targeted by fishers (T) included *Homarus gammarus*, *Sepia officinalis*, *Octopus vulgaris*, *Solea solea*, *Chelidonichthys lucerna*, *Chelidonichthys* sp.,

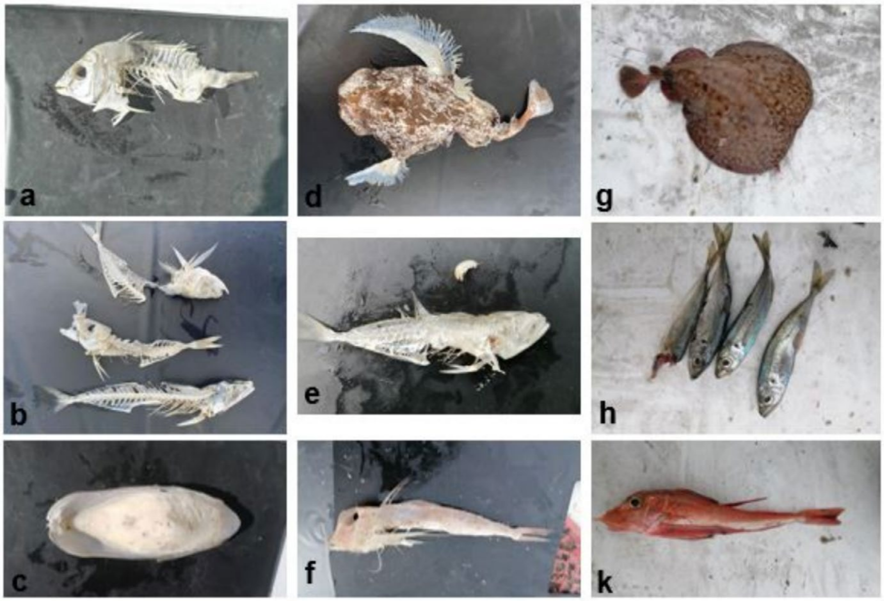

FIGURE 2 | Illustrations of damaged (a–f) and non-damaged individuals (g, h, k) of target and non-target species in trammel-net fisheries in the southwestern Sea of Marmara, Türkiye, between December 2020 and December 2021.

Merluccius sp., *Lophius* sp., *Scorpaena scrofa*, and *Platichthys flesus*. Non-target species (NT) included Osteichthyes and Chondrichthyes groups and non-commercial octopus species that cannot be commercially evaluated. Other species (O) included Macrobenthic organisms in the Arthropoda, Mollusca, Echinodermata, Cnidaria, and Annelida groups that cannot be commercially evaluated.

Based on knowledge and observations from earlier fishing, two stages of "Non-damaged or damaged" were identified from target and non-target species to determine effects of soaking time and mesh size. Stages were adapted from Humborstad et al. (2003). Non-damaged (*F*) fish included alive or dead fish with no signs of morphological damage, such as faded gills, glossy eyes, or rigor. Damaged (*D*) fish included damage indicators, such as faded gills, glossy eyes, or rigor, and also small holes in the flesh caused by scavenger organisms (amphipods and isopods), partially exposed bones, missing intestines, bacterial decay, and only skeleton or parts remaining (Figure 2).

Body weight of non-damaged target and non-target species was measured to the nearest 1 g with a digital scale. Non-damaged and damaged *S. officinalis*, non-damaged and damaged Chondrichthyes species, and individual discard species were compared among mesh sizes and soaking times. A two-way Permutational Multivariate Analysis of Variance (PERMANOVA) was used to test for differences in non-damaged and damaged target and non-target species, non-damaged weight of target and non-target species, non-damaged and damaged *S. officinalis*, non-damaged and damaged *Chondrichthyes* species, and discard species between soaking time, mesh size, and the interaction between soaking time and mesh size. The Bray–Curtis similarity index and 9999 permutations were performed in Past (Ver. 4.04) software (Hammer et al. 2001). This test performs an ANOVA experimental design on the dissimilarity measure. The multivariate normality test of skewness and Box's *M* test for equal variance–covariance (Monte Carlo Permutation method) showed these variables were not normally distributed ($p < 0.05$), so a PERMANOVA test was used to compare soaking times, mesh sizes, and their interaction, with Tamhane's T2 post hoc pairwise comparisons and sequential Bonferroni correction (Anderson 2014).

3 | Results

In 12 catch operations, 1113 individuals of 58 species were caught with various mesh sizes and soaking times, including 489 individuals (43.9%) of 10 target species, 251 individuals (22.6%) of 31 non-target species, and 373 individuals (33.5%) of 17 other species, including 293 non-damaged and 196 damaged individuals of target species (Table 1). The total weight of non-damaged individuals was 247.6 kg, of which 150.6 kg (60.8%) was target species and 97 kg (39.2%) was non-target species. The total weight of the target species was 36.2 kg (24.0%) in the 36-mm mesh size, 50.1 kg (33.3%) in the 42-mm mesh size, and 64.3 kg (42.7%) in the 46-mm mesh size. The total weight of non-target species was 36.5 kg (37.6%) in the 36-mm mesh size, 37.1 kg (38.2%) in the 42-mm mesh size, and 23.4 kg (24.2%) in the 46-mm mesh size.

Non-damaged and damaged target species were minimized in the 46-mm mesh size and maximized in the 36-mm mesh size, and minimized with a 1-day soak time and maximized with a 7-day soaking time. *S. officinalis* was the most abundant target species (241 individuals). Damaged *S. officinalis* increased with soaking time. The most non-damaged *S. officinalis* were caught in 5 days (71 individuals) and the most damaged *S. officinalis* were caught in 7 days (19 individuals). The fewest non-damaged and damaged *S. officinalis* were caught in 1 day, including 78 non-damaged *S. officinalis* in the 36-mm mesh size and 52 non-damaged *S. officinalis* in the 46-mm mesh size. Non-damaged and damaged *S. officinalis* decreased as mesh size increased (Table 1; Figure 3).

TABLE 1 | Non-damaged (*F*) and damaged (*D*) individuals of target species in relation to mesh size and soaking time (TT: Total) in trammel-net fisheries in the southwestern Sea of Marmara, Türkiye, between December 2020 and December 2021.

Targeted species	1 day						3 days						5 days						7 days								
	36		42		46		36		42		46		36		42		46		36		42		46				
	F	*D*	*F*	*D*	*F*	*D*	*F*	*D*	*F*	*D*	*F*	*D*	*F*	*D*	*F*	*D*	*F*	*D*	*F*	*D*	*F*	*D*	*F*	*D*	*F*	*D*	TT
Mollusca																											
S. officinalis	13	0	9	0	11	1	12	4	16	4	11	2	30	5	22	6	19	6	23	9	17	5	11	5	194	47	241
O. vulgaris					1	0																			1	0	1
Arthropoda																											
H. gammarus									2	0															2	0	2
Osteichthyes																											
S. solea	6	4	5	1	3	0	7	15	4	5	3	1	10	9	4	3	3	4	9	9	4	3	3	0	61	54	115
C. lucerna	3	0	4	0	2	0	3	2	1	2	5	0	3	1	0	1	1	2	2	8	0	3	4	1	28	20	48
Chelidonichthys sp.	0	4	0	1	0	1	0	5	0	7	0	2	0	7	0	8			0	7	0	6	0	5	0	53	53
Merluccius sp.	0	4					0	2	0	4					0	1			0	4	0	4	0	2	0	21	21
Lophius sp.															1	0	1	0			1	0			3	0	3
S. scrofa			1	0	0	1			1	0															2	1	3
P. flesus																	1	0					1	0	2	0	2
TT	22	12	19	2	18	3	22	28	24	22	19	5	43	22	27	19	25	12	34	37	22	21	18	13	293	196	489

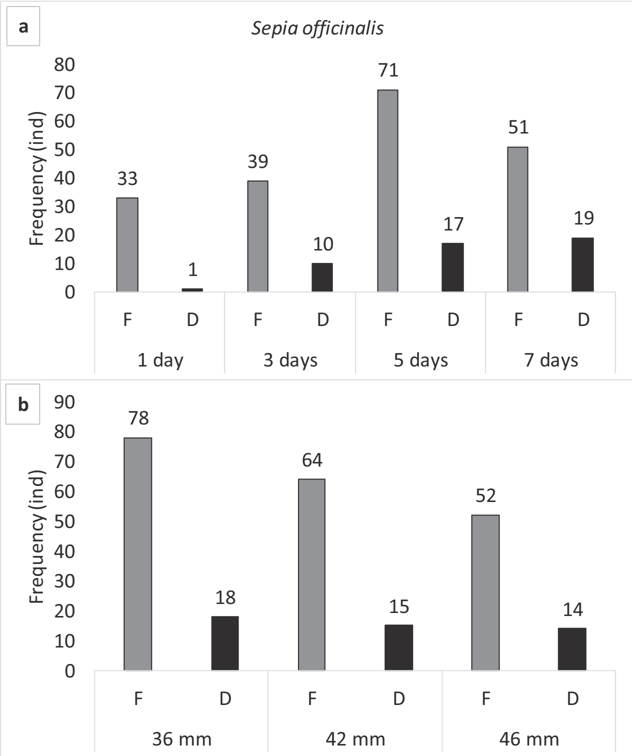

FIGURE 3 | Number of non-damaged (*F*) and damaged (*D*) individuals of *S. officinalis* in relation to soaking time (a) and mesh size (b) in trammel-net fisheries in the southwestern Sea of Marmara, Türkiye, between December 2020 and December 2021.

S. solea was the most frequently caught fish species (115 individuals), including 61 non-damaged and 54 damaged individuals. While 48 *C. lucerna* were identified, 53 *Chelidonichthys* sp. could not be identified due to damage. As soaking time increased, the number of damaged *Chelidonichthys* sp. increased. As mesh size increased, damaged *Chelidonichthys* sp. decreased. All *Merluccius* sp. were damaged. All *Lophius* sp. were non-damaged, including two in the 42-mm mesh size and one in the 46-mm mesh size, and two in 5 days and one in 7 days. *H. gammarus* was the primary target of trammel nets fisheries with very high economic value, but only two non-damaged *H. gammarus* were caught in the 42-mm mesh size in 3 days (Table 1).

Of non-target species, 117 were non-damaged and 134 were damaged, including *C. lastoviza*, *Trachinus* sp., *Z. faber*, *E. encrasicolus*, *Mullus* sp., *D. dentex*, Scombridae, *Pagellus* sp., *S. maena, S. sarda, S. pilchardus, S. canicula, S. acanthias, O. centrina, M. mustelus*; *E. moschata, S. oculata, S. squatina, T. marmorata, R. miraletus, R. radula, and M. aquila* (Table 2). The number of non-damaged and damaged individuals of non-target species was lowest in the 46-mm mesh size and highest in the 36-mm mesh size, and lowest for 5 days soaking time and highest for 3 days soaking time. Non-damaged individuals were lowest for 7 days soaking time and highest for 1 day soaking time. *Trachurus* sp. was the non-target species most frequently caught (64 individuals). Only five individual *Trachurus* sp. were non-damaged. As mesh size increased, the number of damaged and non-damaged *Trachurus* sp. decreased, and the fewest were caught in 5 and 7 days of soaking time (Table 2).

Non-target shark species included *S. stellaris*, *S. canicula*, *O. centrina*, *M. mustelus, S. acanthias, S. oculata* and non-target stingray species included *S. squatina*, *R. clavata*, *T. marmorata*, *M. aquila*, *R. miraletus, R. miraletus, R. radula* and *D. pastinaca* (114 individuals), of which 83 were non-damaged and 31 were damaged. The fewest Chondrichthyes species (23 individuals) were caught in 1 and 3 days, and the most (18 individuals) were caught in 7 days, with the fewest damaged (1 individual) in 1 day. The most were caught in the 36-mm mesh size (41 individuals), including the most damaged (12 individuals) in the same mesh size (Table 2; Figure 4).

R. clavata was the most common Chondrichthyes species (59 individuals), including 44 non-damaged and 15 damaged, six of which were damaged in 3 and 7 days, and all non-damaged in 1 day soaking time. The most non-damaged *R. clavata* (14 individuals) were caught in 5 days of soaking time. As mesh size increased, the number of damaged *R. clavata* decreased. All *T. marmorata* were non-damaged, nearly equally among mesh sizes, with four caught in 1 and 3 days, and seven caught in 5 and 7 days (Table 2).

L. depurator was the most frequently caught other species (83 individuals), including one caught in the 42-mm and 46-mm mesh sizes in 1 day of soaking time (Table 3). None were caught in the 36-mm mesh size in 1 day of soaking time. As soaking time increased, the number of *L. depurator* increased. Also, *Alcyonium* sp. (82 individuals) and *Bolinus brandaris* (61 individuals) were the most commonly caught other species (Table 3).

The number of discarded individuals decreased as mesh size increased for all soaking times (Figure 5). The number of discarded individuals increased only at 46 mm as soaking times increased (Figure 5).

Catches of damaged *Chondrichthyes* species differed significantly among soaking times and mesh sizes (PERMANOVA test, $p < 0.05$), including differences between 1 and 7 days of soaking times ($p < 0.001$). Catches of damaged target species, non-damaged *S. officinalis*, and discarded species differed significantly ($p < 0.05$) among soaking times and mesh sizes, whereas interactions were not significant ($p > 0.05$). Catches of damaged target species differed significantly with Tamhane's T2 test between 1 and 3 days of soaking time ($p < 0.001$), 1 and 5 days of soaking time ($p < 0.001$), and 1 and 7 days of soaking time ($p < 0.001$) for 36-mm and 46-mm mesh sizes ($p < 0.001$). Catches of non-damaged *S. officinalis* differed significantly with Tamhane's T2 test between 1 and 5 days of soaking time ($p = 0.011$). Catches of discarded individuals differed significantly with Tamhane's T2 test between 1 and 3 days of soaking time ($p = 0.021$), 1 and 5 days of soaking time ($p < 0.001$), and 1 and 7 days of soaking time ($p = 0.026$) in 36-mm and 46-mm mesh sizes ($p < 0.001$) (Table 4).

TABLE 2 | Non-damaged (*F*) and damaged (*D*) individuals of non-target species in relation to mesh size and soaking time (TT:Total) in trammel-net fisheries in the southwestern Sea of Marmara, Türkiye, between December 2020 and December 2021.

Non-target species	1 day						3 days						5 days						7 days								
	36		42		46		36		42		46		36		42		46		36		42		46				
	F	*D*	*F*	*D*	*F*	*D*	*F*	*D*	*F*	*D*	*F*	*D*	*F*	*D*	*F*	*D*	*F*	*D*	*F*	*D*	*F*	*D*	*F*	*D*	*S*	*B*	TT
Osteichthyes																											
Chelidonichthys lastoviza											0	1					0	1	0	1					0	3	3
Trachinus sp.	0	2			0	1	0	1	0	4	0	1					0	1	0	1					0	11	11
Trachurus sp.	2	7	1	8	0	6	1	14	0	9	0	2	0	3	0	3	0	1	1	3	0	1	0	2	5	59	64
Zeus faber													0	1											0	1	1
Engraulis encrasicolus	0	1							0	1															0	2	2
Citharus linguatula	0	1									1	0			1	0	0	1	1	3	0	1	0	2	3	8	11
Mullus sp.													0	1											0	1	1
Mullus surmuletus							0	1	1	0					1	0									2	1	3
Dentex dentex							0	1																	0	1	1
Scombridae					0	1																			0	1	1
Pagellus sp.					0	1																			0	1	1
Spicara maena							0	1																	0	1	1
Sarda sarda									0	1															0	1	1
Sardina pilchardus									0	1							0	1							0	2	2
Uranoscopus scaber	1	0																	0	1	1	0			2	1	3
Scorpaena porcus	4	0	2	0	3	0							1	1	1	0			2	0					13	1	14
Scomber scombrus	1	0	0	2	1		1	1	2	3	2	1							0	1					7	8	15

(Continues)

TABLE 2 | (Continued)

Non-target species	1 day						3 days						5 days						7 days								
	36		42		46		36		42		46		36		42		46		36		42		46				
	F	***D***	***F***	***D***	***F***	***D***	***F***	***D***	***F***	***D***	***F***	***D***	***F***	***D***	***F***	***D***	***F***	***D***	***F***	***D***	***F***	***D***	***F***	***D***	***S***	***B***	**TT**
Mollusca																											
Eledone moschata			1	0			1	0																	2	0	2
Chondrichthyes																											
Scyliorhinus stellaris	0	1													1	0			0	1					1	2	3
Scyliorhinus canicula																			0	1			0	1	0	2	2
Squalus acanthias							0	1													0	1	0	2	0	4	4
Raja clavata	4	0	3	0	1	0	3	4	5	2	3	0	5	1	3	2	6	0	2	1	5	1	4	4	44	15	59
Oxynotus centrina																					0	1			0	1	1
Mustelus mustelus																							0	2	0	2	2
Squatina oculata													1	0											1	0	1
Squatina squatina			1	0			1	0																	2	0	2
Torpedo marmorata			3	0	1	0	3	0			1	0	2	0	1	0	4	0	3	0	2	0	2	0	22	0	22
Raja miraletus	2	0																							2	0	2
Raja radula			1	0																	1	0			2	0	2
Myliobatis aquila	1	0																							1	0	1
Dasyatis pastinaca	2	0	2	0	1	0									3	1	0	1	0	2			0	1	8	5	13
TT	17	12	14	10	7	9	10	24	8	21	7	5	9	7	11	6	10	6	9	15	9	5	6	14	117	134	251

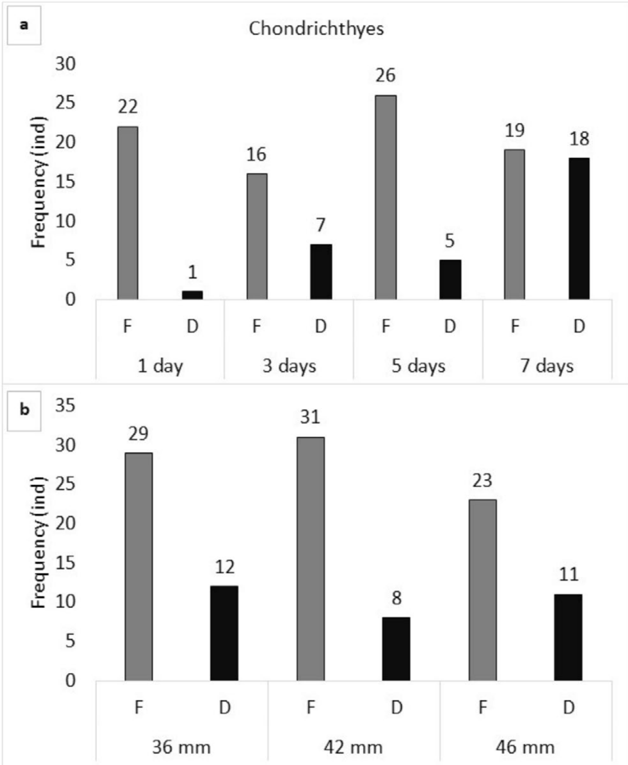

FIGURE 4 | Number of non-damaged (*F*) and damaged (*D*) individuals of Chondrichthyes species in relation to soaking time (a) and mesh size (b) in trammel-net fisheries in the southwestern Sea of Marmara, Türkiye, between December 2020 and December 2021.

4 | Discussion

In our study, 293 non-damaged individuals of target species comprised only 26.3% of the total catch (1113 individuals), including 251 (34%) damaged individuals of target and non-target species (740 individuals) caught in a range of mesh sizes and soaking times. We were unable to identify damaged individuals of all caught species, so their weight could not be measured because isopods and amphipods scavenged both target and non-target species. These scavenger organisms, called "sea lice" by fishers in the study area, feed on blood and enter the body through the mouth and gill lamella, causing economic loss to commercial fisheries, especially due to damage, death, and weight loss of bony fish (Rameshkumar and Ravichandran 2014; Şen and Özekinci 2024). Some Crustacean species damage fish in trammel nets in the Turkish Straits (Mülayim et al. 2022). These scavenger organisms play an important role in the food chain and ecology of marine environments, as they surround living and dead aquatic organisms (Keable 1995). *Natatolana neglecta* poses an increasing threat to Aegean Sea fisheries (Kırkım et al. 2019). Some isopods cause problems in small-scale fisheries in the Aegean Sea (Öndes 2019). A significant number of target and non-target species feed on species caught in trammel nets due to the smell emitted during the decomposition of caught fish (Erzini et al. 1997). In Norwegian gillnets, 60% of *Reinhardtius hippoglossoides* were caught non-damaged after 7 days, although amphipod and isopod "sea lice" were on all caught fish after more than 24 h of soaking time, although it is not known when these fish were caught (Humborstad et al. 2003). However, interactions between habitat and fishing gear can affect long-term dynamics of benthic ecosystems (Catanese et al. 2018). Effects of immobility, drowning, water parameters, physicochemical and mechanical factors, and stress can trigger damage to species. Moreover, injury and exhaustion in captured individuals due to stress depend on long-term entanglement of species in trammel nets (Ganias, Malioufa, et al. 2023). Therefore, effects of stress factors on species quality should be investigated.

Only two individuals of *H. gammarus* with the highest commercial value among target species in our study were caught after 3 days of soak time. The soaking time of trammel nets was nearly 3 days in Gökçeada, Türkiye, when *H. gammarus* and *Palinurus elephas* fed on dead fish caught in nets (Yıldız et al. 2012). *P. elephas* was the target species of highest economic value caught in trammel nets, and non-target species caught in nets ranged from habitat-dependent species to sharks (Catanese et al. 2018). Arthropod species of high economic importance were caught in nets due to the attractiveness of fish caught within 1–2 days, although the catch efficiency of nets decreased within a few days (Kaiser et al. 1996). The soaking time of nets can increase as visibility increases, whereas net height decreases with effective catch areas, which affects catch efficiency, so individuals of target and non-target species may not increase in relation to the closure of the mesh of trammel nets and the increase in visibility of nets due to marine activities (Erzini et al. 1997). The visibility of trammel nets may be related to the fact that fishers used an average of 5 days of soaking time (Şen and Özekinci 2022).

Of 1216 individuals, 353 were alive in 160-mm trammel nets after 48 h of soaking time in Spain, including more than 60% of *P. elephas*, so nets should not be left for more than 48 h soaking time, the legal limit for catching this species (Breen and Nin Morales 2017). Trammel nets with 44-, 50-, 56-, and 60-mm mesh sizes caught 43.38% of target scorpion fishes and 56.62% of non-target species in Ordu, Türkiye, including 54.56% of economic species (Aydın et al. 2015). The bycatch rate was 79.7% in trammel nets on the coast of Spain (Gonçalves et al. 2007). Approximately 10 million tons of marine species were damaged and discarded around the world annually (Zeller et al. 2018). *Carcinus aestuarii* and *Liocarcinus depurator* were caught most among non-target crab species in trammel nets of 32-mm, 36-mm, and 40-mm mesh sizes in the Black Sea, Türkiye, and crabs were caught more in coastal areas, and very rare at 15–30 m (Özdemir et al. 2017). Differences in target species catch rates among studies may be due to structural characteristics of trammel nets and species caught due to operational differences, in addition to the presence of non-target species that may be affected by habitat, catch area, depth, and predator species in areas fished.

Discard species catches were highest with 7 days of soaking time in this study, likely because such species were attracted to trammel nets to consume caught and damaged individuals (Coston-Guarini et al. 2018; Ganias, Karatza, et al. 2023). *L. depurator and B. brandaris* were the most commonly caught species in our study, with *L. depurator* typically inhabiting muddy habitats at 0–40 m depths (Onay and Bilgin 2021). *B. brandaris* is

TABLE 3 | Numbers of non-damaged (*F*) and damaged (*D*) individuals of other species in relation to mesh size and soaking time (TT:Total) in trammel-net fisheries in the southwestern Sea of Marmara, Türkiye, between December 2020 and December 2021.

	1 day			**3 days**			**5 days**			**7 days**			
Other species	**36**	**42**	**46**	**36**	**42**	**46**	**36**	**42**	**46**	**36**	**42**	**46**	**TT**
Arthropoda													
Squilla mantis				4	4	3	1	3		2	2	1	20
Liocarcinus depurator		1	1	2	4	3	16	5	2	21	20	8	83
Medorippe lanata								1					1
Dromia personata							1						1
Goneplax rhomboides						1		1				1	3
Mollusca													
Galeodea echinophora				1									1
Tonna galea				2	1			1					4
Bolinus brandaris	4	4	1	6	7	3	16	10	4	2	3	1	61
Cnidaria													
Alcyonium sp.	7	5	4	11	9	7	4	11	6	7	7	4	82
Pennatula sp.	4	3		1	4	1		2	2	2	1	3	23
Annelida													
Laetmonice hystrix										1			1
Echinodermata													
Asteroidea	1	1	1	1		1	7	1	2	3	1		19
Ophiura albida				1									1
Astropecten irregularis		2				1							3
Holothuria tubulosa				1						1			2
Marthasterias glcialis	3		2	2	2	1	5	3	3	7	5	2	35
Parastichopus regalis	5	1	3	5	1	3	2	1	3	6	2	1	33
TT	24	17	12	37	32	24	52	39	22	52	41	21	373

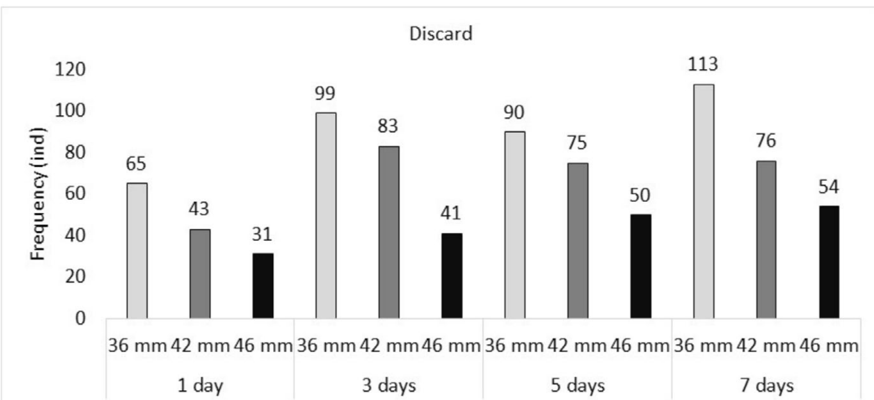

FIGURE 5 | Number of discarded individuals in relation to soaking time and mesh size in trammel-net fisheries in the southwestern Sea of Marmara, Türkiye, between December 2020 and December 2021.

TABLE 4 | Two-way PERMANOVA results with interaction for non-damaged and damaged individuals of target and non-target species, non-damaged weight of target and non-target species, non-damaged and damaged individuals of *S. officinalis* and Chondrichthyes species, discarded individuals of species as main factors (d.f. = degrees of freedom; *F* = Test value; *p*(BC) = Bray-Curtis asymptotic *p*-value; *$p < 0.05$ significant) in trammel-net fisheries in the southwestern Sea of Marmara, Türkiye, between December 2020 and December 2021.

	Soaking times			Mesh sizes			Interaction		
Source of variation	**d.f.**	***F***	***p*(BC)**	**d.f.**	***F***	***p*(BC)**	**d.f.**	***F***	***p*(BC)**
Non-damaged ind of target species	3	0.715	0.607	2	1.063	0.358	6	0.990	0.445
Damage ind of target species	3	9.102	*0.000	2	6.218	*0.000	6	1.501	0.150
Non-damaged ind of non-target species	3	1.915	0.121	2	1.412	0.245	6	0.763	0.621
Damage ind of non-target species	3	1.434	0.219	2	0.661	0.531	6	1.102	0.356
Non-damaged weight of target species	3	1.252	0.260	2	1.152	0.329	6	0.588	0.896
Non-damaged weight of non-target species	3	1.338	0.236	2	1.302	0.248	6	0.872	0.559
Non-damaged ind of *S. officinalis*	3	5.082	*0.002	2	0.270	0.756	6	0.409	0.883
Damaged ind of *S. officinalis*	3	0.151	0.323	2	0.161	0.949	6	0.681	0.711
Non-damaged ind of Chondrichthyes	3	0.948	0.414	2	0.849	0.431	6	1.510	0.169
Damaged ind of Chondrichthyes	3	7.439	*0.000	2	0.823	0.443	6	4.327	*0.000
Discard ind of species	3	3.351	*0.005	2	4.801	*0.002	6	1.029	0.407

a macrobenthic scavenger fish that is attracted to fishing gears that entangle prey (Ganias et al. 2021), so the extended soaking times in our study may have led to increased recruitment of these scavenger species into trammel nets due to damage to caught species. This causes the number of *B. brandaris* in the trammel nets to increase and the quality of the target species to decrease in the process until trammel nets are hauled. Another discard species, *Alcyonium* sp., was also commonly caught in our study, a species that is found in cold-water and rocky habitats (Bruning et al. 2024). Their presence may be explained by rock fragments in some seabeds and the depth where trammel nets are located. In order to reduce the bycatch of these macrobenthic species, soaking times can be reduced as well as adding a guarding net to trammel nets.

Reducing bycatch is a common goal for fisheries, so the survival of bycatch species in fishing gear is a potential problem. Chondrichthyes species are especially vulnerable to bycatch mortality because they are slow-growing, late-maturing, low-fertility species that are therefore protected by regulations to avoid population decreases (Dulvy et al. 2017). Despite protective regulations, 50% of stingray and 54% of shark Chondrichthyes species are in danger of extinction in the Mediterranean Sea (Dulvy et al. 2017). Chondrichthyes species in our study included 114 of 740 (15%) individual target and non-target species, of which 83 (73%) were non-damaged and 31 (27%) were damaged, including critically endangered *S. squatina*, *S. oculata*, *O. centrina*, *M. aquila*, and endangered *M. mustelus*, *R. radula*, and *S. squatina*, *S. oculata*, *O. centrina*, and *R. clavata* that were prohibited from being caught by commercial fisheries regulations in Türkiye (GDFA 2024). All Chondrichthyes species caught were damaged in our study, except for *T. marmorata*, which produces electricity from an electrical organ that repels scavenger organisms (Jawad 2018). Catch rates of non-target Chondrichthyes species in trammel nets can reach 97% of the total catch (Ceyhan et al. 2010). For example, 541 individual *R. radula*, *D.pastinaca, T. marmorata*, and *T. torpedo* were caught among non-target species in trammel nets targeting *S. officinalis*, including 256 individual *T. torpedo* (Tiralongo et al. 2018). Similarly, a large number of sharks were caught in a few hours of fishing with gillnets and trammel nets (Kaiser et al. 1996).

In our study, fewer target and non-target fish (96 individuals, 29.4 kg, 17 species) were caught than in an earlier study (680 individuals, 422.4 kg, 43 species) with 1 day of soaking time using the same 36-mm, 42-mm, and 46-mm trammel nets (Cilasın, Öztekin, et al. 2015). Differences in catches between the two studies are likely related to the distance between the two study areas and differences in population density between the two study areas. The highest number of non-damaged *S. officinalis* were caught after 5 days of soaking time in our study, whereas the most commonly caught fish in the earlier study was *Scorpaena porcus* (Cilasın, Öztekin, et al. 2015), likely because the most commonly caught species differed between study areas. In another earlier study, 6084 individuals (701.14 kg) of 34 species were caught when 32-mm mesh-size trammel nets targeted *S. officinalis* (285 individuals and 522.1 kg = 37% of the total catch) in Mersin, Mediterranean Sea (Bozaoğlu et al. 2022). In our study, 26.3% of the total catch (1113 individuals) was non-damaged individuals of the target species caught with 36-mm, 42-mm, and 46-mm trammel nets. Differences in catches may be due to the outer panel of mesh size (180 mm in our study and 160 mm in the earlier study; Cilasın, Öztekin, et al. 2015). The diversity and catch rates of species in the two study areas and the size of individuals affect catches in different mesh sizes.

The discard ratio was highest with 1200 m of trammel nets in our study, whereas 82,400 m and 5 days of average soaking time were used for trammel nets in the Kemer region, Marmara Sea, Türkiye (Şen and Özekinci 2022). Such long trammel nets can adversely affect target, non-target, and other species in the Marmara Sea, so they will likely have negative consequences for sustainable stocks and the ecosystem. Fishers have ignored discarded species because they believed catches of target species would increase as the soaking time increases in trammel nets. This is an important issue to consider when fishers set trammel nets back with discarded species acting as bait because trammel nets fished with extended soaking times damage many species, thereby causing unaccountable, unknown, and valueless fishing. Also, the Marmara Sea has become more sensitive in recent years due to mucilage events (Topçu and Öztürk 2021; Karadurmuş and Sarı 2022). To prevent further damage to the ecosystem and sensitive species in this area, the discard ratio and use of trammel nets should be reduced.

Problems may arise in commercial fisheries when a reduction in soaking time reduces catches of a target species (Erickson and Berkeley 2008). Many fishers used extended soaking time, while ignoring negative effects, as a "piggy bank" that accumulates catches in marya nets in the Marmara Sea. The aim of this method is to attract high-value species like lobster to trammel nets, regardless of ecological and environmental impacts. But, when these nets are fished with long soaking times, dolphins, a marine mammal, may damage these nets to increase costs of additional time and repair of trammel nets. For example, cetaceans and fishers were both negatively affected by interactions between dolphins and trammel nets (Feliu-Tena et al. 2023). Extended soaking times can result in injury or death of marine mammals that come towards trammel nets to consume species entangled in these nets. Deaths of these species by entangling in nets have been reported by commercial fishermen, but without evidence. Similarly, gillnets negatively affect aquatic ecosystems (Cochrane 2002). Tangled nets used in angler fish fishing continued fishing up to 224 days after being lost, and 18.1 tons of angler fish caught in Spain annually were caught in lost nets (Sancho et al. 2003). Despite potential negative effects of long soaking time, the Notification of Regulation of Commercial Fisheries in Türkiye (Regulation No: 2020/20) and earlier regulations do not regulate soaking times (GDFA 2024). As a result, new methods and designs should be developed for trammel net fishing with short soaking times or by preventing trammel net fishing in sensitive areas.

5 | Conclusions

The purpose of the present study was to assess effects on catchability of trammel nets related to soaking time and mesh size. Damage to target and non-target species was related to soaking time and mesh size, so discard was higher at long soaking times. Consequently, negative effects of soaking time of trammel nets can be reduced by reducing soaking time. Trammel nets of all mesh sizes should be soaked for no more than 1 day or fished every day to minimize damage to target and non-target species. In addition, 42-mm trammel nets are preferred. Although many species are targeted by trammel nets, *S. officinalis* was the primary target species, so the effectiveness of other fishing gears, such as traps and longlines, that can catch more *S. officinalis* should be investigated, along with effects on other species. Controlled ghost fishing caused by use of long soaking times of trammel nets may cause more negative effects on the ecosystem than ghost fishing, so effects of controlled ghost fishing should be studied to improve management. To increase the catch of other species, detailed scientific studies are needed to examine habitats of these species and their reactions to fishing gear.

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Ethics Statement

The authors have nothing to report.

Conflicts of Interest

The authors declare no conflicts of interest.

Data Availability Statement

The data that support the findings of this study are available from the corresponding author upon reasonable request.

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