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Evaluating the Sustainability of an Eastern Mediterranean Gillnet Fishery Based on the Catches of Undersized Individuals and the Reproductive Period of Targeted Species

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Abstract: The catch composition of a coastal gillnet fishery in the Eastern Mediterranean Sea was analyzed through a two-year experimental fishing survey. Seven fish species occurred regularly in the hauls. Surmullet, *Mullus surmuletus*, which is the most valuable demersal fish in Greek waters and the intended target of the gillnets in small-scale fisheries, was the most abundant and systematically caught species. Almost all surmullets were larger than their minimum conservation reference size. However, three commercially exploited species (*Diplodus annularis*, *Pagellus acarne*, and *P. erythrinus*) were caught systematically as undersized individuals. In addition, these three species were caught mostly as immature individuals. Moreover, the operational season of the surveyed métier overlapped completely with the reproductive period of five commercially exploited species (*D. annularis*, *M. barbatus*, *M. surmuletus*, *Sphyraena sphyraena*, and *Trachurus trachurus*). Improvements and the establishment of additional technical measurements should be considered for the small-scale gillnet fisheries in the studied area to attenuate their detrimental effects and achieve a better compromise between sustainable exploitation of the local multi-species fish resources and the need for an economically sustainable practice.

Keywords: coastal fisheries; gillnets; minimum conservation reference size; reproductive period; Aegean Sea

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1. Introduction

Small-scale fisheries (SSFs) provide more than a quarter of the global marine fisheries catch and supply almost half of the landings intended for human consumption [1]. SSFs in the Mediterranean Sea are of great socioeconomic and cultural significance for both the fishing sector and coastal communities [2,3]. The importance of Greek SSFs as a source of food and income and as part of the local heritage and tradition is reflected in the size of their fleet, which is the largest in Europe, with over 13,000 vessels under 12 m operating static gear [4–6].

The fishing gears of SSFs are characterized by lower discard rates [7] and are considered more size- and species-selective and with less detrimental effects than the gears employed in large-scale fisheries [8,9]. However, their contribution to fisheries overexploitation and total discards should not be overlooked [10,11].

Passive (or fixed) nets (gillnets and trammel nets) are the main fishing gears used in SSFs in the Mediterranean Sea. In Greek coastal fisheries, fixed nets target a variety of demersal, benthic, and pelagic fish species, like surmullet (*Mullus surmuletus*), the most valuable demersal species in Greek waters [12], red mullet (*M. barbatus*), common sole (*Solea solea*), and common pandora (*Pagellus erythrinus*), or molluscs (e.g., common

cuttlefish, *Sepia officinalis*) and crustacea (e.g., caramote prawn, *Penaeus kerathurus*). The target species are mainly dictated by season, market demand, and availability [13,14]. Interactions between fishing gear and marine megafauna might also coerce fishermen into shifting their strategies. In the Mediterranean Sea, most of the assessed fish stocks (83%) are characterized as overexploited [15], while the state of non-target species stocks is often not evaluated. Moreover, the landing size composition and the potential overlap between fixed nets' operation period and fishes' reproductive period are still largely unknown in this region.

In that context, the present study focused on the coastal gillnet fishery targeting surmullet in the inner Thermaikos Gulf in the northern Aegean Sea, Greece, typically operating between spring and early fall. The aims were to analyze (a) the catch and size composition relative to the established minimum conservation reference sizes (MCRSs) and (b) the temporal overlap between the gear operation period and the reproductive period of commercially exploited species. The results of the present study will be useful for the management of Greek SSF resources, which largely relies on technical measures such as minimum mesh sizes, gear dimensions, fishing effort limitations, temporal and/or spatial closures, and MCRSs.

2. Materials and Methods

A two-year experimental fishing survey was conducted in the inner Thermaikos Gulf in the northern Aegean Sea, Greece (Figure 1), a shallow (<100 m), semi-enclosed basin of high productivity that constitutes a significant spawning habitat for several fish species [16]. It is also one of the two most productive fishing grounds for both large- and small-scale fisheries (24.6% of the yield nationwide) in Greece and hosts the largest commercial fishing fleet in the country [16].

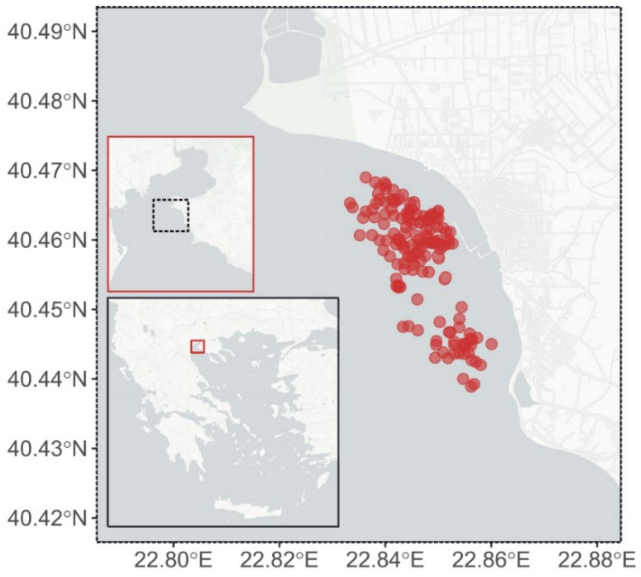

Figure 1. Sampling area with insets showing Greece and the inner Thermaikos Gulf (outlined in red). Dashed outline in the smallest inset indicates the surveyed area. Gillnets were deployed within the 20-m isobath.

The sampling surveys were carried out between March and November in 2020 and 2021 using a chartered coastal fishing vessel (8 m-long, 2.3 GT, 43 hp). The sampling effort was spread out as evenly as possible across the surveyed area throughout the study, given the circumstantial weather conditions and the presence of other fishing gear. The fishing gear had the same characteristics and was deployed in the exact same manner as local fishing practices. Thus, our findings represent the impact of gillnets on actual fishing conditions. In specific, nylon gillnets with a 36-mm mesh size were used and deployed

within the 20-m isobath, aligning with the predominant mullet-fishing tactics in the area and in Beaufort Sea State 0–3. Three fleets, 300-m-long each, were deployed on every sampling survey between 06:00 and 07:00 a.m. and left to soak for ~1.5 h. Each fleet consisted of three connected net panels, with each panel measuring 100 m × 1.8 m attached to a head rope equipped with floaters and a ground rope with a lead core. Prior to redeployment, nets were visually inspected for damage upon hauling and repaired if needed. In total, 80 sampling surveys were conducted (36 in 2020 and 44 in 2021; Figure 1; Table 1) under permit from the Fisheries Department of the Region of Central Macedonia, Greece.

Table 1. Number of sampling surveys and of fish belonging to the seven studied species (*Diplodus annularis*, *Mullus barbatus*, *M. surmuletus*, *Pagellus acarne*, *P. erythrinus*, *Sphyraena sphyraena*, and *Trachurus trachurus*) caught per year.

	2020		2021	
	Sampling Surveys	**Fish Samples**	**Sampling Surveys**	**Fish Samples**
March	1	74		
April	3	240	1	22
May	6	310	7	285
June	2	168	8	325
July	3	60	9	222
August	8	219	8	301
September	8	305	6	313
October	4	286	5	382
November	1	49		
Total	36	1711	44	1850

All fish caught were placed on ice and transported to a wet lab for further processing. Fish damaged by predation from cetaceans and other predators [17,18] that could not be identified to the taxonomic species level were not included in the analyses. The analyses focused on seven commercially exploited fish species: *Diplodus annularis*, *M. barbatus*, *M. surmuletus*, *P. acarne*, *P. erythrinus*, *Sphyraena sphyraena*, and *Trachurus trachurus*. Sex and reproductive stage (using a 5-point grading scale based on [19]) were determined. Total length (TL in mm), total weight (TW in g), eviscerated weight (Wev in g), and gonad weight (Wg in g) were measured, and the gonadosomatic index was estimated (GSI = Wg/Wev × 100). The length at maturity (Lmat) values used in the analyses were extracted from the current bibliography for the Mediterranean Sea (Table 2). Specifically, Lmat values for *D. annularis*, *M. barbatus*, *M. surmuletus*, *P. acarne*, and *P. erythrinus* were obtained from [3], who performed a literature review for many species of the SSFs in the Mediterranean Sea. Lmat values for *S. sphyraena* and *T. trachurus* were obtained from other sources (Table 2). For the latter two species, when more than one value was available in the literature, the average Lmat was calculated. If Lmat was available for both sexes, the more conservative average value was used, as in [3].

Table 2. Length at maturity (Lmat) values per species used in the analyses.

Species	**Lmat (mm)**	**Reference**
Diplodus annularis	105	[3] and references within
Mullus barbatus	128	[3] and references within
Mullus surmuletus	155	[3] and references within
Pagellus acarne	142	[3] and references within
Pagellus erythrinus	140	[3] and references within
Sphyraena sphyraena	251	[20,21]
Trachurus trachurus	188	References in [22]

All plots and statistical analyses were performed in R [23]. For plot preparation, the R packages ggplot2 and ggridges were used. The data from the two sampling seasons were analyzed together.

3. Results

In total, 3561 fish were sampled from the seven targeted species. Surmullet was the most abundant species (accounting for 14% of the abundance and 27.2% of the biomass in the total catch, respectively) (Table 3) and was caught consistently throughout the samplings. *Diplodus annularis* was the second most abundant catch, representing 10.6% of the total catch, while *S. sphyraena* had the second highest total biomass at 12.4% (Table 3).

Table 3. Descriptive statistics of abundance and total biomass (in kg). *n* = number of fish; %RF = relative abundance.

Species	*n*	%RF	TL Min–Max (Mean)	Total Biomass	%Total Biomass
Diplodus annularis	862	10.6	73–156 (102.3)	15.3	8
Mullus barbatus	315	3.9	115–213 (147.7)	11.9	6.2
Mullus surmuletus	1137	14	94–231 (153.5)	52.1	27.2
Pagellus acarne	199	2.4	87–159 (134.5)	6.1	3.2
Pagellus erythrinus	620	7.6	78–229 (129.6)	18.2	9.5
Sphyraena sphyraena	205	2.5	177–400 (307.1)	23.8	12.4
Trachurus trachurus	223	2.7	138–244 (184.8)	11.5	6

MCRS has been established for only six of the seven fish species included in this study (*D. annularis*: 120 mm, *M. barbatus*: 110 mm, *M. surmuletus*: 110 mm, *P. acarne*: 170 mm, *P. erythrinus*: 150 mm, and *T. trachurus*: 150 mm; [3,24]; MCRS has not been established for *S. sphyraena*. Three of those species were caught solely (*M. barbatus*) or almost exclusively (*M. surmuletus*, *T. trachurus*) at sizes above their MCRSs (Figures 2 and 3). On the contrary, all *P. acarne* and most of *D. annularis* and *P. erythrinus* caught were smaller than their MCRSs (Figures 2 and 3).

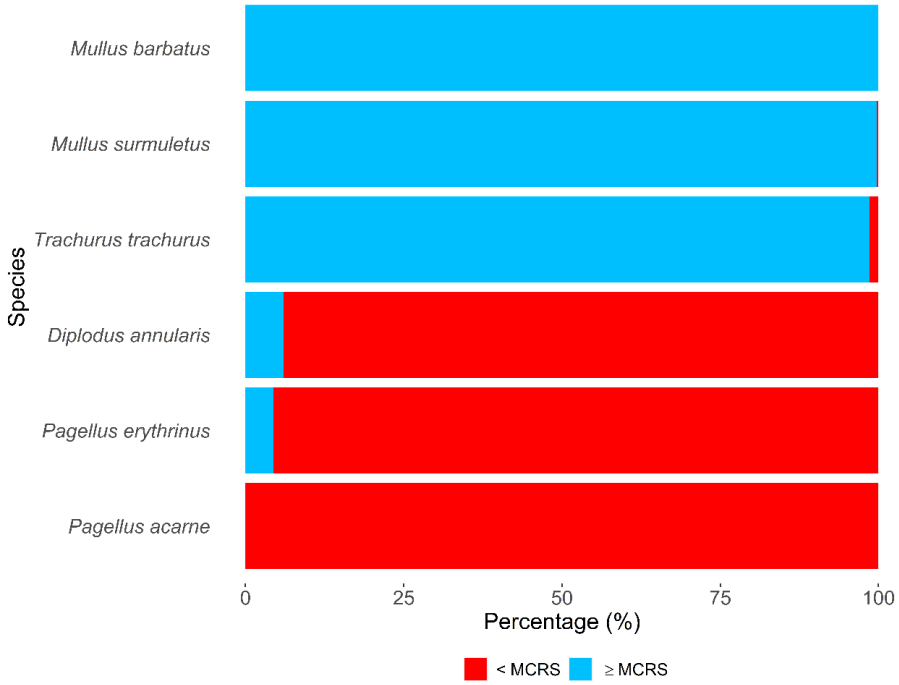

Figure 2. Percentage of fish caught below and above the minimum conservation reference size (MCRS) for the fish species included in this study with such thresholds in European legislation.

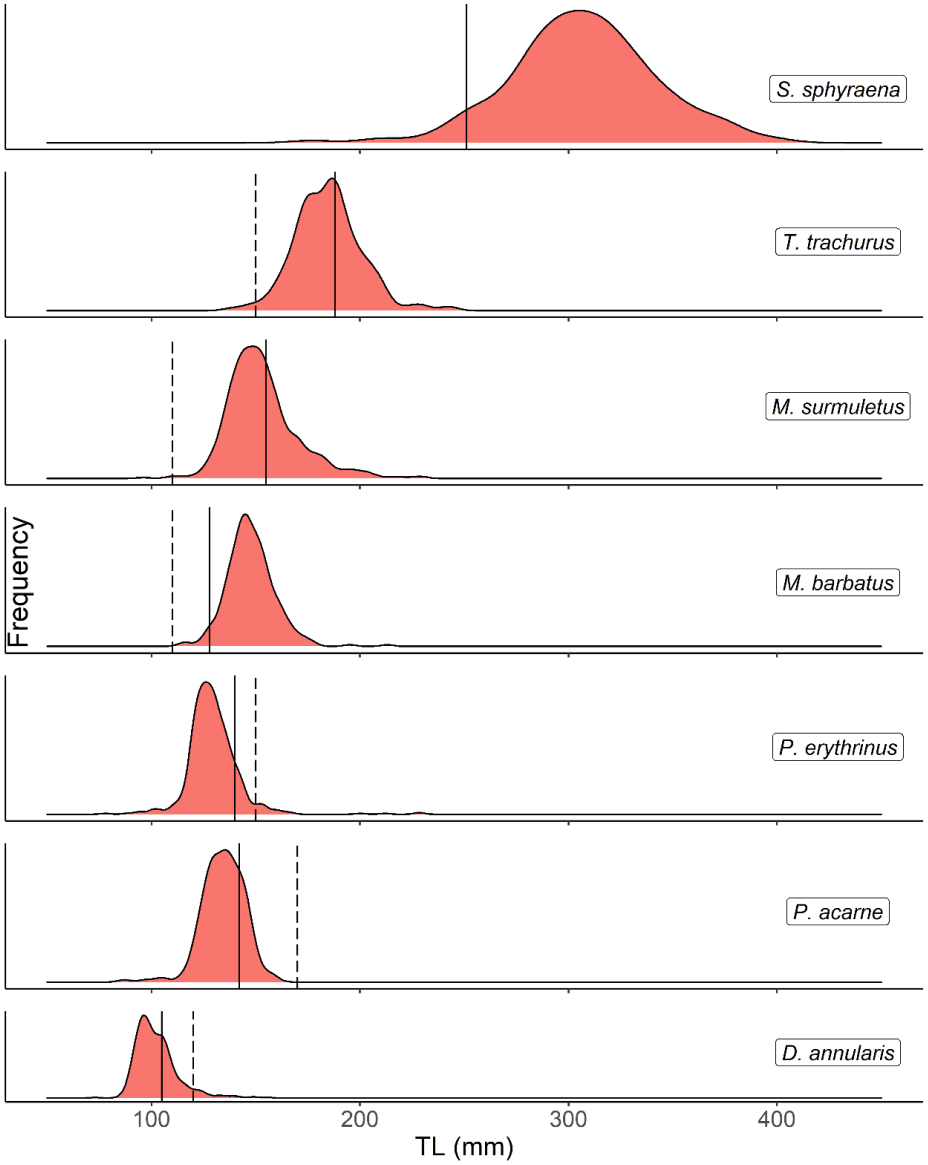

Figure 3. Total length (TL) frequency distributions per species. Vertical lines and vertical dashed lines correspond to the length at maturity (cf. Table 2) and the minimum conservation reference size (MCRS) per species, respectively. Note: MCRS has not been established for *Sphyraena sphyraena*.

Most *D. annularis*, *P. acarne*, and *P. erythrinus* were caught at sizes smaller than their respective Lmat (Figure 3). On the contrary, most *M. barbatus* and *S. sphyraena* were considered sexually mature, as they were larger than their Lmat values (Figure 3). *Mullus surmuletus* and *T. trachurus* were somewhat equally distributed above and below their respective Lmat thresholds (Figure 3). Monthly TL frequency distributions were analyzed for each species, and no statistically significant differences were found.

The operational period of the surveyed métier (spring to early fall) overlapped completely with the reproductive periods of *D. annularis*, *M. barbatus*, *M. surmuletus*, *S. sphyraena*, and *T. trachurus* (Figure 4). Based on the temporal distribution of mean GSI values, the spawning activity of these species occurs within a three-month period, from April to June, following a pattern of succession: the maximum monthly GSI of female *M. surmuletus* in April, of *D. annularis* and *T. trachurus* in May, and of *M. barbatus* and *S. sphyraena* in June (Figure 4). On the contrary, all the *P. acarne* and *P. erythrinus* individuals were reproductively inactive and probably immature, as most were smaller than their respective Lmat values (cf. Figure 3).

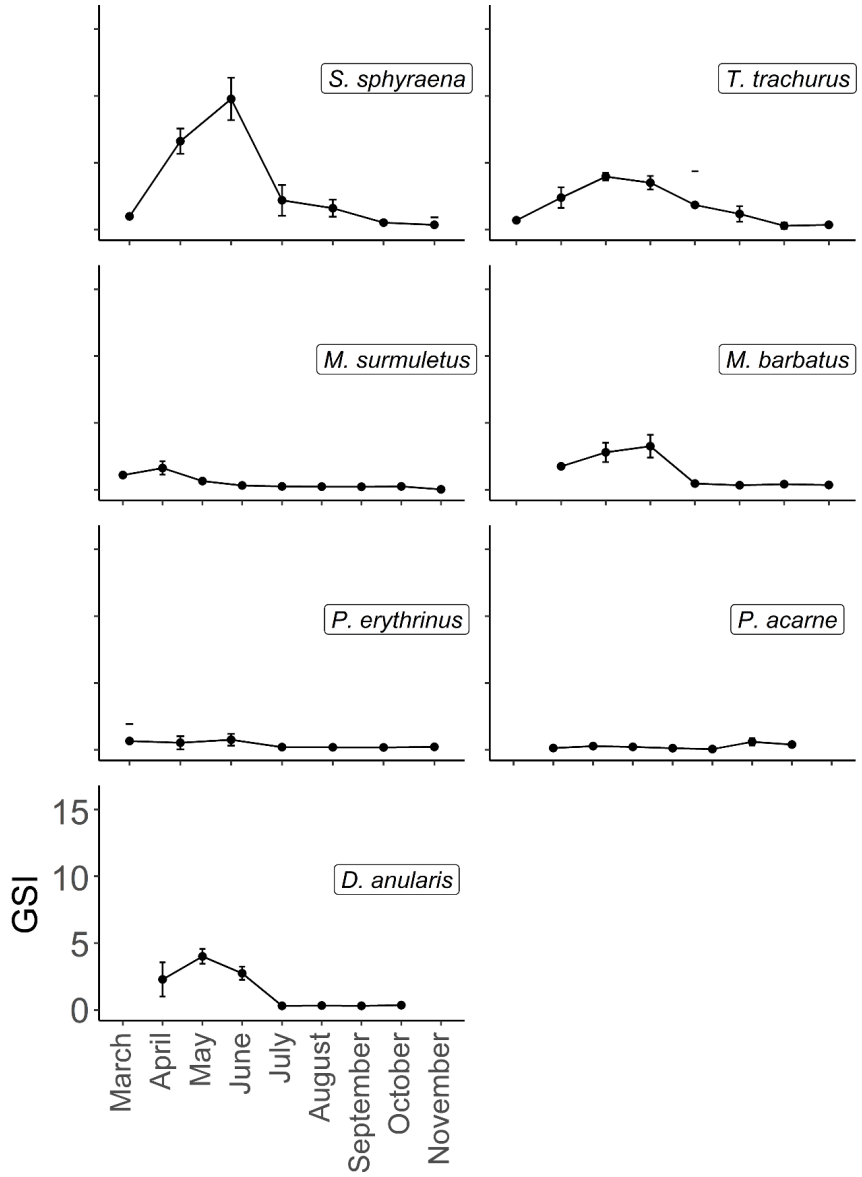

Figure 4. Monthly mean gonadosomatic index (GSI) values per species. Note: the scale is the same on all y axes; females and males were analyzed together.

4. Discussion

This study was focused on seven commercially exploited species (*D. annularis*, *M. barbatus*, *M. surmuletus*, *P. acarne*, *P. erythrinus*, *S. sphyraena*, and *T. trachurus*) of the coastal gillnet fishery in the inner Thermaikos Gulf, Aegean Sea, which is a multispecies métier that mainly targets surmullet, the most valuable demersal fish in Greek waters. Given that the main catch was *M. surmuletus*, the surveyed métier can be characterized as an efficient practice. Additionally, almost all the surmullets were larger than the established MCRS for the species, suggesting a sustainable exploitation of this particular fish population, despite the considerable catch of immature individuals and the overlap between the métier's operational period and the reproductive period of the species in the surveyed area. On the other hand, this métier has detrimental effects on three other commercially exploited species (*D. annularis*, *P. acarne*, and *P. erythrinus*), which were caught systematically as undersized individuals, with the majority of them being immature. In addition, the biomass of actively spawning individuals of four species (*D. annularis*, *M. barbatus*, *S. sphyraena*, and *T. trachurus*) was systematically removed from the ecosystem between April and June.

In total, 48 different fish species were sampled in the present study. Similar fish species compositions (50 species) of gillnets have been previously reported in the Aegean Sea (e.g., [25]). *Mullus surmuletus* was systematically caught from mid-spring to mid-autumn and was the most abundant fish species in the hauls, followed by *D. annularis*, *P. erythrinus*, and *M. barbatus*. Surmullet was also the main fish species in the catch in terms of biomass, followed by *S. sphyraena*, *P. erythrinus*, and *D. annularis*. *Mullus surmuletus* and *D. annularis* have been reported as the main catch of coastal gillnet fisheries in the Aegean Sea in previous studies as well [26]. Most of the non-targeted species were caught sporadically and in very low numbers. The discards ratio was low, and there was a low prevalence and capture intensity of endangered or threatened species [27].

MCRS has been established for six of the seven species analyzed in this study: *D. annularis*, *M. barbatus*, *M. surmuletus*, *P. acarne*, *P. erythrinus*, and *T. trachurus*, while there is no such regulation for *S. sphyraena*. Even though most *S. sphyraena* individuals were larger than the Lmat for the species in the Mediterranean Sea, its systematic exploitation and its medium to high commercial value justify the establishment of an MCRS and appropriate mesh sizes for its Mediterranean stocks.

Mullus barbatus, *M. surmuletus*, and *T. trachurus* were caught (almost exclusively) at sizes above their MCRSs. *Mullus barbatus* and *T. trachurus* were fished systematically above these thresholds, probably due to the large mesh size used, which was larger than the suggested ones for their Mediterranean stocks (28.8 and 30 mm, respectively; [3]). The used mesh size was also highly selective for appropriately sized *M. surmuletus*, even though the suggested mesh length for the species in the Mediterranean Sea is 38.5 mm [3].

In contrast, all *P. acarne*, most *P. erythrinus*, and *D. annularis* were caught as undersized individuals. *Diplodus annularis*, despite its low commercial value, is one of the main catches of Greek SSFs, and it is usually sold mixed with other sparids. The suggested mesh size for the species is 37.8 mm for the Mediterranean Sea [3]. The 36 mm mesh gillnets used in this study resulted in sampling almost exclusively undersized fish. Based on their GSI values, a significant proportion of these fish were sexually mature. The latter result indicates that the specific population is lacking larger individuals and perhaps undergoing an adaptive shift in size/age at maturity towards smaller/younger individuals, probably due to overexploitation, making management actions imperative.

Management of the valuable resources of *P. acarne* and *P. erythrinus* in the studied area should also be considered. Both species have a medium commercial value and were systematically fished as undersized individuals. The fact that most of those fish were immature is also alarming. These results may be attributed to the mesh size used (36 mm), which is smaller than the suggested ones for the Mediterranean stocks of the two species (40.5 and 41.6 mm, respectively; [3]), the lack of large individuals in the surveyed populations, or a combination of the two.

The surveyed métier catches its main target species, *M. surmuletus*, mostly after the completion of its spawning activity, which peaks in mid-spring. However, the gear's operation period overlaps with the reproductive period of four other commercially exploited species in the studied area (*D. annularis*, *M. barbatus*, *S. sphyraena*, and *T. trachurus*). A pattern of succession of the maximum GSI was observed among these species. *Diplodus annularis* mean GSI peaked in May, which aligns with previous results from other stocks of the species in the Aegean Sea [28]. *Trachurus trachurus* highest mean GSI was also observed in May, later than previously found in the central Aegean Sea (February) [29]. *Mullus barbatus* mean GSI peak was found in June (similar to results previously reported from Thermaikos Gulf by [30]), as it was for *S. sphyraena*, for which there are no previous estimations from the Aegean Sea. Inferentially, the spawning activity of these species occurred right in the middle of the gillnet operation period. The latter result raises concerns regarding the degree of spawning success for these stocks. Unsuccessful or limited spawning—in terms of the number of spawners or number of spawning events per fish—may hamper the replenishment of the removed biomass from the local SSFs through juvenile recruitment to the adult population.

Implementation of additional technical measurements might need to be considered during May–June to ensure the sustainability of both the commercially valuable species and the discards, which are also critical in sustaining a balanced ecosystem. Certainly, Lmat values need to be estimated for the commercially exploited species, especially for *D. annularis*, *P. acarne*, and *P. erythrinus* in Thermaikos Gulf, and—if necessary—the current MCRSs might need to be readjusted, as size at maturity is the basis for setting the MCRSs in fisheries management.

5. Conclusions

Gillnets employed in SSFs, like any other fishing gear, are not selective for any given species or size range [31,32]. In the Thermaikos Gulf, gillnets: (i) fail to spare undesired species with no commercial value in the Greek market, but with a low discard ratio and prevalence/capture intensity of endangered or threatened species [27], (ii) they catch undersized individuals of species whose management is under regulation, and (iii) their operation period overlaps with the GSI peak of several exploited species. On the contrary, the surveyed métier catches its main target species, *M. surmuletus*, almost exclusively above the established MCRS and after the peak of its spawning activity, rendering its exploitation sustainable. In parallel, *M. surmuletus* remains the primary catch of gillnet SSF in the studied area, which ensures the economic sustainability of the sector.

Technical measures, such as MCRS and mesh size, often aim to achieve a compromise between a sustainable exploitation of the multi-species fish resources exploited by SSFs and the need to maintain the economic sustainability of the sector. Compromises are not always ideal, resulting in incidental catches of undesired, undersized individuals or mature fish during their reproductive period. In any case, technical measures are justifiable, and they provide the framework for fisheries management and a basis that can and should constantly be evaluated and revised if needed. Such improvements and the possible establishment of additional technical measures should be considered for the gillnet SSF in Thermaikos Gulf, which in general is a highly efficient métier.

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Institutional Review Board Statement: The study is approved by the Fisheries Department of the Region of Central Macedonia, Greece. Approval code: 221937(1417); Date: 21 April 2021.

Data Availability Statement: The data supporting the conclusions of this article will be made available by the authors on request.

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Conflicts of Interest: The authors declare that they have no conflicts of interest.

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