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Habitat loss and small-scale fishery: A controversial issue

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Abstract

Fishery is one of the most impacting human activities and is responsible for habitat loss in marine systems. While the effects of large-scale fisheries have been largely investigated, impacts of small-scale fisheries (SSF) on seafloor integrity are more often assumed than quantitatively investigated. We carried out a literature review at global scale, resulting in 19 studies with quantitative data on sessile benthic bycatch and only one documenting habitat loss driven by SSF. We also conducted a fine-scale assessment within a Mediterranean partially protected area (PPA). Results showed that 513 m^2 of the *Posidonia oceanica* meadow are removed annually by local SSF within the PPA, considering bycatch, fishing effort, and shoot density. Knowledge on fishing effort and fine-scale mapping is critical to assess habitat loss, suggesting the need for specific recommendations for eco-sustainable local fisheries.

KEYWORDS
benthos, bycatch, discard, habitat loss, *Posidonia oceanica*, small-scale fisheries

1 | INTRODUCTION

Pristine habitats support biodiversity and provide essential ecosystem services. Human stressors on marine ecosystems, such as pollution (Cabral & Sousa, 2019), urbanization (Airoldi & Beck, 2007; Ding et al., 2020; Montefalcone et al., 2010), ocean warming (Layton et al., 2020; Micheli et al., 2013), and industrial fisheries are responsible for a large portion of habitat loss and fragmentation. As a consequence of multiple pressures, in the last century, seagrass meadows and mangrove forests have suffered

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a global loss (Duarte et al., 2020; Dunic et al., 2021; Goldberg et al., 2020) and a decline of 50% occurred in coral reefs (Eddy et al., 2021).

Fishing activities can cause severe impacts on the structure and functioning of marine ecosystems (Bevilacqua et al., 2018; Halpern et al., 2019; Kaiser et al., 2006; Mazaris et al., 2019). Studies on bycatch highlighted that large-scale bottom-contact fisheries (e.g. otter trawls, dredges, and beam trawls) are responsible for habitat destruction and can cause dramatic shifts in benthic assemblages (Amoroso et al., 2018; Mangano et al., 2013, 2014; Pusceddu et al., 2014). Even worse, bottom trawling activities are still conducted in 59% of the EU marine protected areas (MPAs), depleting vulnerable species within their boundaries (Dureuil et al., 2018). Recently, a declaration of support for the prohibition of bottom trawling inside protected areas has been submitted by several marine scientists with the aim to "help restoring European marine biodiversity, replenishing European fisheries, resuscitating exhausted small-scale coastal fisheries and the livelihoods they support, and be easily financed by redirecting EU's harmful fisheries subsidies" (https://www.enricsala.com/).

The effects on seabed habitats driven by small-scale fisheries (SSF), representing 90% of world fisheries, contributing about half of global fish catches and operating mostly in coastal areas, are poorly investigated (Calò et al., 2022; Di Lorenzo et al., 2022; FAO, 2015; Grati et al., 2022), with direct and indirect ecological and economic consequences (Hoagland et al., 2013; Ofiara & Seneca, 2006) still largely unknown. Indeed, fixed gears, the most used gear in SSF, have been generally acknowledged as potentially less impacting on marine ecosystems compared to other forms of fishing (e.g. large-scale fisheries, Catanese et al., 2018; Jacquet & Pauly, 2008). SSF is characterized by relatively small vessels (<12 m total length, with low-power engine) fishing on the continental shelf (0–200 m deep) not using towed gear and exploiting areas located within a few hours from the ports or where the fishers are based (Colloca et al., 2003; Guyader et al., 2013). They are highly multi-specific and multi-métier, using a broad range of gears and techniques selected according to seasonal availability of target species to optimize the catch and maximize profitability (Calò et al., 2022; Grati et al., 2022; Tzanatos et al., 2006). These characteristics increase the heterogeneity of the fisheries, making the assessment, monitoring, and management of the sector challenging. Few attempts have been carried out to increase the selectivity and reduce fish discard by developing experimental bottom nets for SSF (Briggs, 2010; Kalayci & Yeşilçiçek, 2014; Lucchetti et al., 2020; Priester et al., 2021). However, the very limited evidences focusing on bycatch composition of unmarketable invertebrates show that fishing activities can determine significant impacts on the benthic communities (FAO, 2018) directly removing habitat-forming species (Enrichetti et al., 2019; Eryasar et al., 2020; Gil et al., 2018; Gonçalves et al., 2008; Montseny et al., 2021) or losing the nets and fishing gears on the bottom (i.e., ghost net: Bo et al., 2014; Ferrigno et al., 2018; Betti et al., 2020) mainly due to bad weather conditions (Ozyurt et al., 2012).

Understanding the potential impact of SSF on the structure and functioning of coastal ecosystems is crucial for improving the efficacy of biodiversity management and protection. Here, we combined a literature review on the effects of SSF on benthic habitats at the global scale, with in situ quantitative assessments in a Mediterranean partially protected area (PPA) to shed new light on the role of SSF as a driver of habitat loss.

2 | MATERIALS AND METHODS

2.1 | Literature review

We conducted a literature search to collect all scientific papers assessing the effects of SSF on marine habitats. A search string was run on the Web of Science (https://www.webofscience.com/) and Scopus (https://www.scopus.com) literature databases without applying any temporal- or spatial-scale restriction (1985–2022). The final search was run on 13/04/22.

Search string:

(("artisanal fish" OR "small-scale fish*" OR "Small Scale Fish*" OR "Small-Scale Fish*") AND ("habitat*" OR "discard*" OR "bycatch*" OR "by-catch"))*

The search resulted in 1042 studies on Web of Science and 960 on Scopus, which were further screened, leading to a total of 19 eligible studies (Table S1; Figure S1 reporting the adapted PRISMA flow diagram; Moher, 2009) reflecting the settled selection criteria: studies that included quantitative data on sessile benthic bycatch taxa (i.e., habitat-forming algae, seagrasses, and invertebrates) or on the interaction between sessile benthic species and fishing gears.

We excluded studies that (i) were not related with SSF; (ii) did not include the bycatch analysis; (iii) did not include sessile taxa in the bycatch analysis; (iv) did not include quantitative data in the bycatch analysis; (v) did not provide species discrimination in the bycatch analysis (Figure S1).

Details of the suitable studies are reported in Table S2, while the excluded studies, with exclusion reasons, in Table S3.

Trammel nets, gill nets, traps (pots, creels, baskets), beach seines, and bottom long-lines were considered during the screening. For each eligible study we reported the following: study area, fishing gears employed, habitat (assumed from the study area and species list if not specified in the text), spatial scale of the survey, response variable (abundance, biomass, and frequency and interactions with gears), habitat characterization, and estimation of habitat loss (when available) (Table 1).

2.2 | Study area and fisher's interviews

The survey was carried out within the Santa Maria di Castellabate MPA (40°16′ N, 14°55′ E), in the Campania region (Southern Tyrrhenian Sea, Italy). Established in 2009, the MPA extends over a surface area of about 70.95 km^2 from Punta Tresino to Punta

TABLE 1 List of eligible studies that provided quantitative data on bycatch composition of sessile species or their interaction with fishing gears.

Area	Fishing gear	Habitat	Spatial scale	Habitat loss estimation	References
Thoothukudi (India)	Trammel nets	Seagrass meadow and coral reef	10's km	No	Anirudh et al., 2014
Algarve (Portugal)	Trammel nets	Soft bottom	10's km	No	Borges et al., 2001
Florida Keys (USA)	Long poles with hooks	Coral reef	10's km	Yes	Butler et al., 2017
Mallorca Island (Spain)	Trammel net	Hard and soft bottom	10's km	No	Catanese et al., 2018
Lundy Island (UK)	Pots	Hard bottom	km's	No	Coleman et al., 2013
Sagres (Portugal)	Bottom-set gill nets	Deep coral gardens	10's km	No	Dias et al., 2020
England, Scotland and Wales (UK)	Pots and creels	Hard and soft bottom	10's km	No	Eno et al., 2001
Maledetti Shoal, Ligurian Sea (Italy)	Trammel nets	Coralligenous	10's km	No	Enrichetti et al., 2019
Mallorca Island (Spain)	Trammel nets	Seagrassmeadow	10's km	No	Gil et al., 2018
Izmir Bay (Turkey)	Trammel nets	Soft bottom	10's km	No	Gökçe & Metin, 2007
Florida Keys (USA)	Traps	Coral reef	km's	No	Lewis et al., 2009
Diani and Mombasa (Kenya)	Gill nets, beach seines and traps	Coral reef	100's km	No	Mangi & Roberts, 2006
North-West Adriatic Sea (Italy)	Pots, baskets, traps, trammel nets, and gill nets	Hard and soft bottom	10's km	No	Pranovi et al., 2016
Central and Southern Chile	Gill nets	Hard and soft bottom	100's km	No	Queirolo et al., 2014
Azores (Portugal)	Bottom longlines	Seamounts	100's km	No	Sampaio et al., 2012
Baja California (Mexico)	Traps and gill nets	Kelp forests and hard bottom	10's km	No	Shester& Micheli, 2011
Algarve (Portugal)	Trammel nets	Soft bottom	10's km	No	Szynaka et al., 2018
Florida Keys (USA)	Traps	Seagrassmeadow	10's km	No	Uhrin et al., 2005
ThermaikosGulf (Greece)	Trammel nets and gillnets	Soft bottom	10's km	No	Voultsiadou et al., 2011

Ogliastro (Figure 1). The MPA is divided into areas with different protection regimes, where human activities are strictly regulated: the integral reserve (zone A, 1.69 km^2), the partial reserve (zone B, 32.26 km^2), and the general reserve (zone C, 37 km^2). Zone A is a fully protected area (FPA) where extractive activities are banned, while Zones B and C are partially protected areas (PPAs) where some human uses (including SSF) are allowed but more strictly regulated than in unprotected areas. In the MPA, three main benthic habitats have been identified: *Posidonia oceanica* meadows, extending for about 28 km^2 and occurring both on the hard and soft substrate down to about 35 m depth (Flagella, 2010); coralligenous assemblages, covering about 9.5 km^2; and frondose algae, covering about 2.5 km^2 (https://amare.interreg-med.eu/). Overall, 21 small-scale vessels, harbored within the port of San Marco di Castellabate, are authorized to operate within the PPA. Interviews were administered to 14 fishers to characterize the SSF fleet (number, size and engine power of vessels) and to assess the mean days of fishing operations per year. These set of questions were embedded in a larger survey carried out with fishers, in which a wide number of questions concerning their background, the characteristics of fishing operations, and their perceptions about different socio-ecological issue were included. Here, only the elements specifically related to our study aims were reported.

2.3 | Bycatch and quantitative estimates of habitat loss

The bycatch collection was performed between June and November 2021, in the framework of a participatory project engaging fishers, MPA managers, and researchers (https://pofeamp.politicheagricole.it/en/il-programma/). In particular, fishers have been involved through all the stages of the entire process in the definition of the objectives, methods, and data collection. We distributed coastal trammel nets, gill nets, and red mullet trammel nets, respectively, 1500, 480, and 240 m long to six different vessels which operated according to their fishing behavior. The nylon multifilament nets were rigged and sized in length by the fishers to adapt them to the local fishing spots and environmental conditions. The gears provided to fishers and adopted in this study were designed based on the features of the fishing gears regularly used by local fishers (assessed during an initial phase of the project) and differed from the normally used ones only by the mesh size. More specifically, the mesh size used in this study is larger than the average used in the study area, despite falling in the entire range of the mesh size adopted. Based on this, we are confident that the estimates generated in this study are representative of the standard practices carried out in the study area.

Fishers were asked to land all benthic bycatch fraction from each fishing trip, subsequently collected by observers on the dock in the fishing harbor. Relevant data on the fishing trip (e.g., position, soak time, and depth) were also registered. In the laboratory, the benthic bycatch was analyzed for a total of 48 fishing trips (16 with trammel nets, 16 with gill nets, and 16 with red mullet trammel nets). All non-target specimens, including algae, seagrasses, and invertebrates, have been photographed, identified at the lowest possible taxonomic level, measured, and weighted.

The only habitat-forming species (sensu Ingrosso et al., 2018) that was found trapped in the gears during the survey was *P. oceanica* (conservation priority habitat under the Habitats Directive (Dir 92/43/CEE)).

Therefore, we used the bycatch of this species to estimate the loss of habitat in the study area (HL) in relation to the SSF fishing effort by the equation:

$$HL = \frac{s \times fe}{d}$$

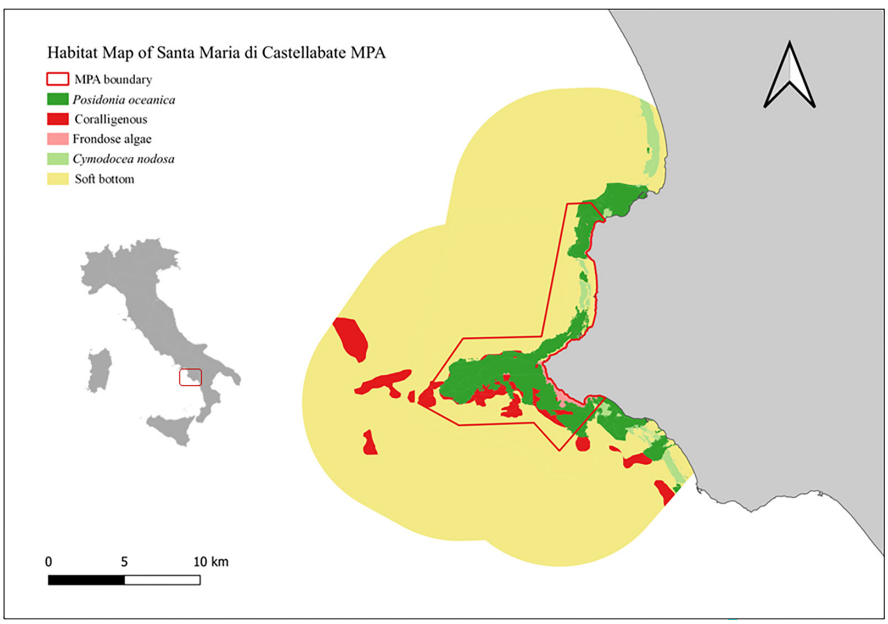

FIGURE 1 Map of the habitat distribution inside the Santa Maria di Castellabate MPA (https://amare.interreg-med.eu/) (Print in color).

where *s* is the mean number of shoots collected in the survey standardized per meter of net; *fe* (fishing effort) is calculated as the product of the mean net length per fishing operation and the total number of fishing operations per year; *d* is the mean shoot density within the study area (163.6 ± 6.57 shoots/m^2; Flagella, 2010).

3 | RESULTS

3.1 | Literature search on habitat loss

The 19 eligible studies were distributed worldwide, most of them occurring in European seas (Figure 2). Among the fishing gears considered in the screening, the studies mainly focused on trammel nets and traps (nine and seven studies, respectively), followed by gillnets (six studies) (Figure 3a). The main response variables measured were abundance and biomass (12 and seven studies) (Figure 3b). When considering fishing gears and response variables, the overall number of studies exceeds the number of eligible studies (19) because some studies addressed multiple types of gears and more than one response variable. The spatial scale of surveys was mostly of 10's km (14 studies) with few exceptions of studies carried out at km's and at 100s km (two and three studies) (Figure 3c). We found a total of six habitats assessed among the eligible studies, with soft bottom (eight studies), hard bottom (six studies), and coralligenous (five studies, coralligenous and coral reef) being the most represented (Figure 3d). The habitat characterization was provided in six articles, while one study carried out an estimation of habitat loss due to SSF activity.

3.2 | Small-scale fleet and fishing effort

Fishers' interviews revealed that the size of the SSF vessels operating inside the Santa Maria Castellabate MPA ranges between 6.5 and 9 m in length and the engine power between 13 and 70 kW (kilowatt). The main deployed small-scale gears are trammel net, gill nets (fixed nets), and traps, with an average net length per fishing operation of 2000 m. On average, each vessel operates 125 days per year. To estimate the habitat loss, we assume the scenario where all the 21 SSF fishing vessels deploy fixed nets for the average number of yearly working days, resulting in 2625 fishing operations per year.

3.3 | Total bycatch and estimates of habitat loss

All fishing activities were carried out inside the PPA, on sandbanks and *P. oceanica* meadows, within a depth range between 5 and 40 m. The nets were soaked for an average time of 15 h. The total catch consisted of 154 invertebrate specimens, encompassing 25 taxa and 260 shoots of *P. oceanica*, which represented 62.8% of the total catch (expressed as number of shoots). Crustaceans included eight species/taxa out of 86 individuals, while Echinoderms included seven species/taxa from 35 individuals. Other taxa included Gastropods with five species/taxa out of 19 individuals and four taxa of algae from 14 thalli. The list of benthic bycatch species/taxa is available in the Table S4. The average number of *P. oceanica* shoots collected during the survey was 0.016 (±0.0039) per meter of net. We estimated that a total of 84,000 shoots (0.016 shoots/m net × 2000 m net × 21 fishers × 125 fishing operations/year) are potentially extirpated every year by the entire small-scale fleet inside the Santa Maria di Castellabate PPA. Based on the shoot density in the study area (163.6 ± 6.57 shoots/m^2), we calculated that about 513 m^2 of *P. oceanica* could be removed each year (HL).

4 | DISCUSSION

Our literature analysis pointed out a general lack of quantitative information about the impact of SSF on benthic habitats. The only study quantifying habitat loss reported that artisanal sponge fishery removed sponge species of commercial interest at a rate of 3.5% per month and non-commercial large sponges at a rate of 4.3% per month (i.e., Butler et al., 2017). SSF are generally considered more sustainable than other forms of fishing (Kelleher, 2005; Lloret et al., 2018; Tsagarakis et al., 2014), but there are evidences that SSF can contribute to the removal of vulnerable species (Di Lorenzo et al., 2022; Dimitriadis et al., 2016; Lloret et al., 2020; Voultsiadou et al., 2011). Our review has revealed that, when considering the contacts with gear as the response variable, most studies have focused only on the interaction between seafloor and traps, whereas just one article (Shester & Micheli, 2011) also included fixed gears (gill net) in its assessment. Shester and Micheli (2011) showed that, in contrast with traps that did not cause any species detachment from the seafloor, gill nets entangled and removed habitat formers (*Eisenia* kelps plants and gorgonian corals). The branched nature of the kelps and corals damaged by gill nets suggests that fixed gears could have similar impacts in other habitats with similar features. Therefore, when assessing ecological impacts of SSF gears, it is important to consider the vulnerability of habitat-forming species, as well as the nature of seafloor interactions with all the SSF gears employed.

Our field data suggest that the SSF can affect benthic habitats, despite the presence of a PPA. In particular, we estimated an annual loss of about 513 m^2 of the protected *P. oceanica* meadows driven by SSF. Rather than the loss of an entire area, the result should be interpreted as a rarefaction of shoot density. However, it is important to note that habitat fragmentation increases the meadow vulnerability, compromising the resistance of the seagrass to other impacts (Barcelona et al., 2021). Indeed, seagrass meadows tend to be exposed to several threats derived from mixed fishing activities to other multiple stressors, such as deterioration of water quality or coastal development (Herrera et al., 2022). A declining trend resulted from the comparison of the meadow extension recorded in 2003 and 2019 in a sector of our study area, with a net loss of 150,000 m^2 of *P. oceanica* habitat (https://www.seaforestlife.eu/it/).

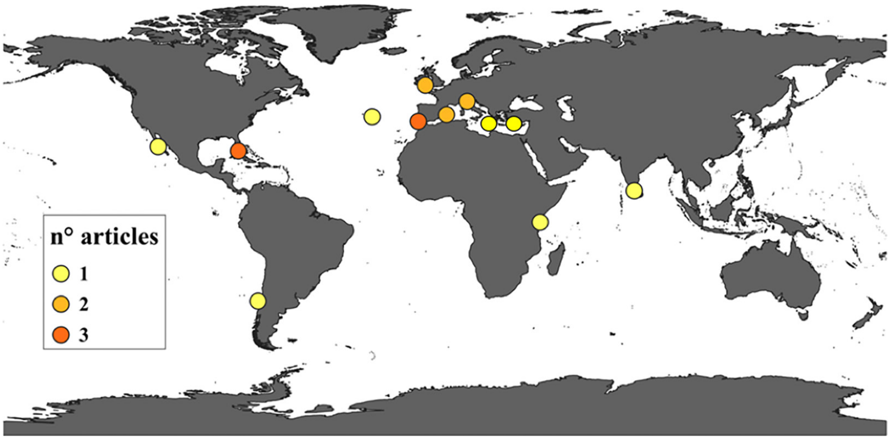

FIGURE 2 Geographical distribution of the collected studies on the assessment of the effects of SSF on marine habitats at the global scale (Print in color).

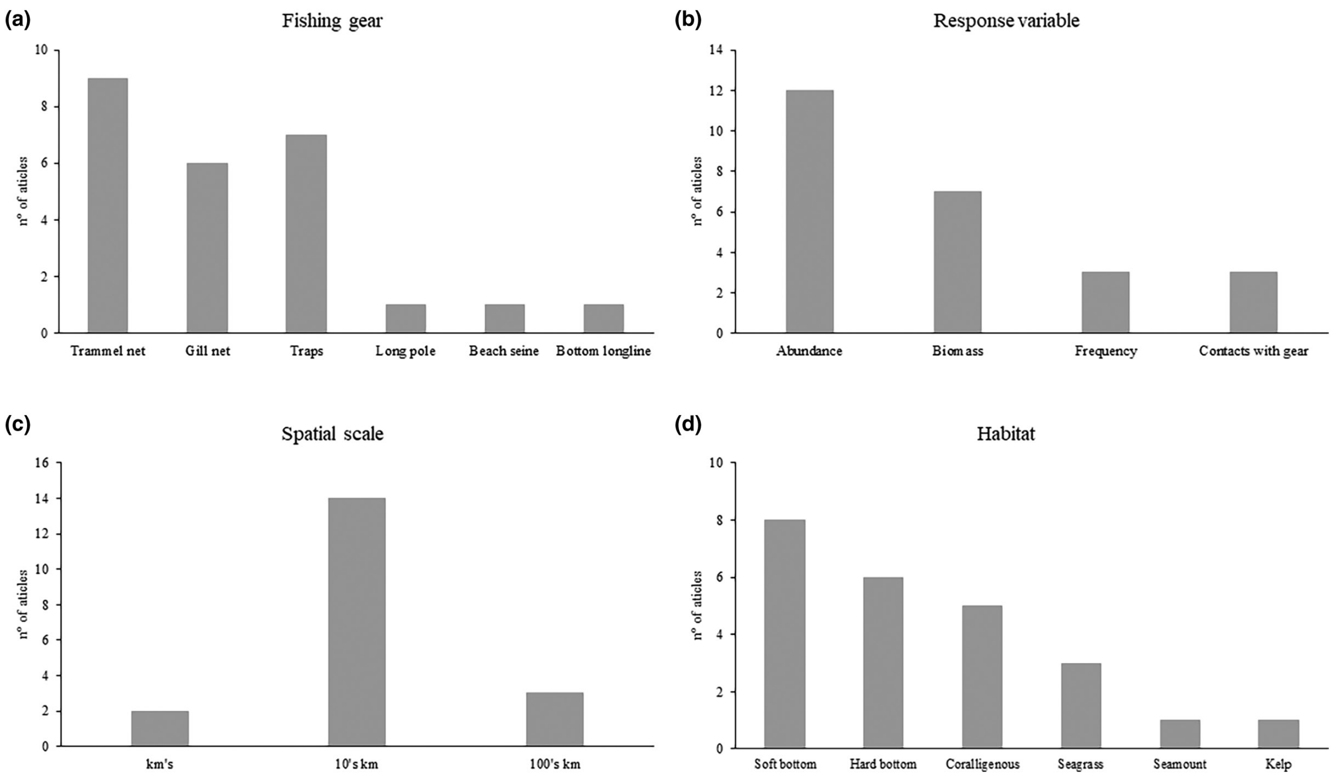

FIGURE 3 Number of articles according to (a) fishing gear employed; (b) response variable measured to assess the fishing impact; (c) spatial scale of the surveys; (d) habitat where fishing operations occurred. Note that in the case of fishing gears and response variables, the overall count of articles exceeds the number of eligible articles (19) because some studies addressed more types of gear and more than a single response variable.

According to our HL estimate, we suggest that, in the 16 years indicated (2003–2019), SSF may have contributed to the overall loss for ca 8000 m^2 (5% of the total loss). However, the lack of awareness about the role of SSF largely impairs our ability of teasing apart the effects of SSF from other sources of disturbance in order to identify and propose guidelines and best practices for protected and unprotected ecosystems.

Pivotal information for the assessment of the overall decline of the meadow could arise from the analyses of the relation between shoot recruitment and shoot mortality, as carried out by Marbà et al. (2005). This study demonstrates the importance of conducting direct censuses of seagrass shoots in permanent plots to evaluate the current status of seagrass meadows and detect possible ongoing population declines. The inclusion of direct census of seagrass meadows in monitoring programs can also help provide the early warning signals to improve management decisions in the framework of conservation and restoration actions.

Even though the data collected during the survey represent an important milestone in this framework, bycatch analysis alone cannot be considered exhaustive for a comprehensive assessment of the SSF impacts. Progress in assessing the effects of SSF on habitats can be done facing the following challenges:

1. Improve our ability to gather information about SSF fishing effort. Since tracking systems, such as Vessel Monitoring System (VMS) and the Automated Identification System (AIS), are mandatory only for vessels ≥12 and 15 m in length, respectively (EC, 2003; EU Dir 2011/15/EU), the SSF is, as a matter of fact, untracked. Limitations in tracking systems and the lack of logbooks prevent thorough assessments of the impacts of SSF. At present, fisher interviews on gear deployments are the only available source of data. Tassetti et al. (2022) recently deployed a simple and space-saving tracking equipment on board an SSF vessel and coupled this with a serverless and cost-effective architecture to collect spatial and temporal data. The use of such low-cost technologies and machine-learning automated analyses opens the potential for more integrated platforms to support the design and development of new management actions (Kroodsma et al., 2018). An improved regulation is especially urgent in MPAs where the potential effects of SSF on vulnerable habitats is largely underestimated, as shown in this study. Possibly, extensions and boundaries of the zones with different levels of protection should be revised considering the actual extension of habitats of EU importance.
2. Encourage a more consistent commitment. Despite collaborative conservation initiatives engaging small-scale fishers and researches can be effective tools to co-produce knowledge (Di Franco et al., 2020), the fisher's commitment may not have been always strong, leading to biased SSF impact estimates.
3. Perform fine-scale habitat mapping. In the investigated area, the distribution of *P. oceanica* has been mapped in 2002 (https://www.emodnet-seabedhabitats.eu/) and the only available shoot density data is at 30 m depth (Flagella, 2010). Although *P. oceanica* meadow is one of the most important habitats in the Mediterranean Sea, fine-scale data on spatial distribution and shoot densities are rarely available, making the identification of regression patterns challenging (Telesca et al., 2015). Detailed and high-resolution spatial information is a priority for implementing conservation actions and for the sustainable use of marine coastal resources.

5 | CONCLUSIONS

Although SSF represents a significant contributor in securing food and livelihoods for coastal communities (FAO, 2018), the impact of SSF on benthic habitats has received, so far, a limited attention. The results of our study suggest that SSF is a non-negligible source of impact on the *Posidonia* meadow. This habitat is important for the productivity of commercial species also due to its role as nursery. Its good health status translates into an increase in the catch revenue, benefitting the profits of the SSF sector. Our findings document that SSF affects the seafloor integrity but, at the same time, highlight the need to gather high-resolution data about habitat distribution and detailed catch and effort data of SSF. The lack of standardized methodologies and protocols to monitor the SSF effort hampers a fully quantitative understanding of the status and the impact of fixed gears on the seascape and limit the potential of concrete application of the ecosystem-based fisheries management (EBFM) approaches (Patrick & Link, 2015) required by the European Common Fishery Policy (CFP).

The achievement of the 30% target of the EU's Biodiversity Strategy will not be reached in the absence of a careful monitoring and assessment of SSF under protected and not protected conditions.

AUTHOR CONTRIBUTIONS

Silvestrini C.: Investigation, Data curation, Writing – Original draft, Writing – Review & Editing, and Visualization. Colletti A.: Investigation, Writing – Original draft, and Writing – Review & Editing. Di Franco A.: Writing – Review & Editing, Supervision, and Project administration. Colloca F.: Writing – Review & Editing, Supervision, Project administration, and Funding acquisition.Milisenda G.: Supervision and Project administration. Zampardi S.: Investigation, Data Curation, and Writing – Review & Editing. Mangano M.C.: Methodology and Writing – Review & Editing. Aglieri G.: Investigation and Supervision. Ranù M.: Investigation. Liguori G.: Investigation. Danovaro R.: Writing – Review & Editing and Supervision. Foglini F.: Resources. Grande V.: Resources. Fraschetti S.: Conceptualization, Writing – Original draft, Writing – Review & Editing, Supervision, Project administration, and Funding acquisition.

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CONFLICT OF INTEREST STATEMENT

There are no relationships/conditions/circumstances that present a potential conflict 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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