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Multi-specific small-scale fisheries rely on few, locally essential, species: Evidence from a multi-area study in the Mediterranean

Antonio Calò¹ | Antonio Di Franco² |
 Federico Quattrocchi³ | Charalampos Dimitriadis⁴ |
 Patricia Ventura^{1,5} | Marco Milazzo¹ | Paolo Guidetti^{6,7,8}

¹Department of Earth and Marine Sciences (DiSTeM), University of Palermo, Palermo, Italy

²Stazione Zoologica "Anton Dohrn", Department of Integrative Marine Ecology (EMI), Sicily Marine Center, Lungomare Cristoforo Colombo, Palermo, Italy

³Institute for Marine Biological Resources and Biotechnology (IRBIM), National Research Council CNR, Mazara del Vallo (TP), Italy

⁴National Marine Park of Zakynthos, Zakynthos, Greece

⁵Thalassa—Marine Research & Environmental Awareness, Nice, France

⁶Institute for the Study of Anthropic Impact and Sustainability in the Marine Environment (CNR-IAS), National Research Council, Genoa, Italy

⁷Department of Integrative Marine Ecology (EMI), Stazione Zoologica Anton Dohrn—National Institute of Marine Biology, Ecology and Biotechnology, Genoa Marine Centre, Genoa, Italy

⁸ECOSEAS Lab. UMR 7035, Université Côte d'Azur, CNRS, Nice, France

Correspondence

Antonio Calò, Department of Earth and Marine Sciences (DiSTeM), University of Palermo, Via Archirafi 20-22, 90123 Palermo, Italy.

Email: antoniovalo.es@gmail.com

Antonio Di Franco, Stazione Zoologica "Anton Dohrn" sede interdipartimentale della Sicilia, Lungomare Cristoforo, Colombo 4521, 90149 Palermo, Italy. Email: antonio.difranco@szo.it.

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Abstract

Achieving sound management of small-scale fisheries (SSFs) is globally recognized a key priority for sustaining livelihoods, local economies, social wealth and cultural heritage in coastal areas. The paucity of information on SSFs often prevents the proper assessment of different socio-ecological aspects, potentially leading to draw inappropriate conclusions and hampering the development and adoption of effective policies to foster SSF sustainability. To respond to the growing global call to assess these fisheries, we carried out a multi-disciplinary and data-rich assessment of SSFs at 11 areas in 6 Mediterranean EU countries, combining the analysis of 1292 SSF fishing operations and 149 semi-structured surveys of fishers. Specifically, we aimed at assessing (1) landed species contribution to SSF catches and revenues and (2) the spatial variability in a set of fishery socio-ecological descriptors. Results highlighted that, in spite of a high species diversity, Mediterranean SSFs actually rely economically upon a very limited number of species with catch and revenues per unit of effort mostly determined by less than 5 species, that can guarantee high and stable catches and revenues over time. Moreover, some fishing communities were found to rely on a restricted number of gears. These evidences suggest, that some SSFs' properties often assumed, but never broadly verified, should be carefully reconsidered, especially when viewed from a broader socio-ecological perspective, as in the case of the diversified portfolio or of the polyvalence of fishing gears. Taking the local scale into proper account is

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likely to reduce the risk of implementing management strategies potentially generating socio-ecological inequalities.

KEYWORDS

CPUE, Mediterranean, RPUE, small-scale fisheries, species contribution

1 | INTRODUCTION

Achieving sound and effective management of small-scale fisheries (SSFs) is widely acknowledged as one of the major global challenges for marine scientists, practitioners and policy makers (Jentoft et al., 2017; Lindkvist et al., 2020; Pascual-Fernández et al., 2020). SSFs significantly contribute to world fisheries employing about 90% of the world's fishers while accounting for more than 25% of global catches (Chuenpagdee & Jentoft, 2016; Kittinger et al., 2013; Pauly & Zeller, 2016; Smith & Basurto, 2019; Teh et al., 2011). Over the last decade, great emphasis has been placed on the fundamental role that SSFs play in sustaining poverty alleviation, food security, social wealth and cultural heritage in coastal communities, that globally include billions of people for whom SSFs often represent the sole or primary livelihood (Pita et al., 2019; Schuhbauer & Sumaila, 2016). At the same time, SSFs are also generally acknowledged as potentially less impacting on marine ecosystems and offering more equitable economic and social benefits (e.g. higher employment) to stakeholder communities compared with other forms of fishing such as large-scale fisheries (Jacquet & Pauly, 2008). However, SSFs are increasingly suffering from space and resources competition from other sources of extractive (e.g., recreational fisheries) and non-extractive (e.g., tourism) human activities in coastal areas (Lloret et al., 2018), and the limited available data on SSFs suggest that about half of global stocks targeted by this sector are over-exploited with a negative outlook (Costello et al., 2012). Building on that, the adoption of the 'Voluntary Guidelines for Securing Sustainable Small-Scale Fisheries in the Context of Food Security and Poverty Eradication' by FAO Member Nations was the recognition of the urgent need to address SSF challenges worldwide, to overcome current issues and to foster the sustainable development of the SSF sector (Chuenpagdee et al., 2019; FAO, 2015; Jentoft et al., 2017). The Guidelines also highlight the urgent need for data on SSFs which are currently very scarce, intermittent, limited in space (small-scale if not local studies) and time (snapshots or short time-series) and remarkably difficult to collect (FAO, 2017; Pascual-Fernández et al., 2020; Pauly & Charles, 2015; Pita et al., 2019). In turn, this information is vital to enable policy- and decision-makers to set proper policies and management strategies (Chuenpagdee & Jentoft, 2016). This historical global paucity of data has been related to the intrinsic nature of SSFs, which are generally multi-specific, employ a variety of gears and techniques and encompass, over large areas, a multitude of local communities potentially heterogeneous in terms of wealth status, social organization, culture, traditions and geographical isolation (Guyader et al., 2013; Pita et al., 2019). These

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conditions are hampering data collection and the implementation or optimization of integrated SSF monitoring programs at broad spatial scales (Guyader et al., 2013; Outeiro et al., 2018; Pita et al., 2019).

The paucity of data on SSFs often prevent the correct assessment of different socio-ecological aspects (e.g., the status of fish stocks exploited or the presence of economically pivotal species fishers rely on), potentially leading researchers and practitioners to draw partial or inappropriate conclusions about the sector (Crona et al., 2020; Pascual-Fernández et al., 2020). In this context, a common and widespread assumption is that SSFs are generally multi-gear and multi-species fisheries (Aguilera et al., 2015; Crona et al., 2020; Kittinger et al., 2013; Pita et al., 2019; Purcell et al., 2020). These attributes support SSF portfolio diversification and resilience in the face of potential socio-ecological shifts driven by local and global perturbations (e.g., climate change, market dynamics and institutional contexts) (Aguilera et al., 2015; Clarke, 1993; Gonzalez-Mon et al., 2021). Additionally, this legitimizes going beyond the application of single-stock monitoring, normally applied to large-scale fisheries, but considered insufficient for SSFs and actually thought to produce failing socio-ecological managements when applied to a limited spatial scale (Purcell et al., 2020). However, in spite of a relatively high number of species landed, their largely overlooked relative contribution to total catches and revenues could be highly

variable. In this perspective, very few evidence suggests that SSFs could markedly depend on a limited number of species (Guyader et al., 2013), but additional research is needed to investigate this issue, which may have major implications for the understanding of SSF portfolio diversification and potential socio-ecological resilience.

SSFs in the Mediterranean Sea are not an exception to the more global trend for which they have been neglected or marginalized for a long time compared with other fishery sectors (e.g., large-scale fishing, especially trawling), both by single countries and by supranational organizations (e.g., at EU level), overlooking their economic, social, historical and cultural relevance (Guyader et al., 2013; Pascual-Fernández et al., 2020; Pita et al., 2019). SSFs are, in fact, a fundamental subsector of commercial fisheries in the Mediterranean, representing more than 80% of fishing vessels, more than 50% of employment onboard vessels and almost 30% of revenues (FAO-GFCM, 2020). In the Mediterranean region, SSFs are historically part of the multiple and intensive human activities that, directly or indirectly, impact the marine resources, with important implications for the biological and cultural diversities as well as the related provision of ecosystem goods and services (Coll et al., 2012; Tsikliras et al., 2015). The crucial economic and social role of SSFs are now more and more acknowledged and so is their relevance in national and international policy agendas (Pascual-Fernández et al., 2020). However, the paucity of data on SSFs in the Mediterranean, coupled to a highly diverse socio-ecological context, makes it difficult to draw general conclusions, thus hindering sound management strategies both at local and regional scale.

Here, by combining robust and verified data on catches collected at landings with surveys administered to fishers, we gathered information on a set of socio-ecological features of SSF fleets and communities in order to identify patterns that could inform management and policy. Specifically, we aimed at (1) examining landed species contribution in determining SSF catches and revenues, (2) assessing spatial variability in a set of fishery descriptors (e.g., species diversity, catch per unit of effort, revenue per unit of effort), discussing potential implications of these features for local and regional management.

2 | MATERIALS AND METHODS

2.1 | Study area

The study was carried out between June 2017 and October 2018 (covering a period of 17 months) at 11 areas (where, in each of which, one or multiple SSF communities operate), located in 6 EU Mediterranean countries: South Corsica, Cap Roux, Côte Bleue (France), Portofino promontory, Egadi Archipelago and southern Trapani coast, northern Brindisi coast (Italy), Straits of Ibiza and Formentera, Cabo de Palos and adjacent Murcia coast (Spain), Dugi-Otok island (Croatia), Strunjan (Slovenia) and Zakynthos island (Greece) (Figure 1). All these 11 areas are in the vicinity of,

or partially include, nationally designated Marine Protected Areas (sensu Pérez-Ruzafa et al., 2017). During this study, we appointed in situ management bodies as local data collection centres, benefiting from their widespread coverage of the territory and their long-standing relationship with SSF communities.

2.2 | Fishing fleet characteristics

Here, we refer to SSFs as fishing operated by relatively small vessels, <12 m total length, ('length overall', LOA), and not using towed gear, as formally defined by the European Maritime and Fisheries Fund (EU, 2014). Typically, SSFs operate within the first three nautical miles (ca. 5.5 km) from the coast (Coppola, 2006; Guyader et al., 2013) and within a limited radius of operation from their home harbour, using low-power engines and operated by a single (usually the owner) or a few fishers (frequently family members) (Di Franco et al., 2014). The characterization of the SSF fishing fleet was carried out in 2017 and embedded in the framework of a larger collaborative project where small-scale fishers, MPA managers and researchers, agreed to work together to assess the drivers of effectiveness of SSFs management in the Mediterranean (see Di Franco et al., 2020 for further details on the collaborative project). For the purpose of this work, fishers were asked about the gears they use, distinguishing the following categories: fixed nets (i.e., trammel nets and gill nets), bottom long-lines, pelagic long-lines, multi-specific traps, traps for lobster, traps for cephalopods and 'other gears'. The total number of fishers was variable among areas (Table 1), and we interviewed, on average, about 70% of all fishers operating in the study areas (all areas pooled), with a percentage of interviewees ranging from 34% (South Corsica) to 100% (North Brindisi coast), depending on the number of fishers operating in each area. Respondents were mostly targeted through purposive, opportunistic and snow-ball sampling (Bryman, 2012). In total, 149 fishers were interviewed for characterizing the fishing fleets in each study area.

2.3 | Catch data collection

Assessment of fishing operations targeted a subsample of the fishers interviewed in each area. In order to obtain the most comprehensive dataset possible and considering that different fishers may have different fishing habits, we monitored catches from as many fishers as possible among those willing to take part in the assessment (ranging from 5 for North Brindisi coast to 12 for South Corsica). A similar sampling effort was applied in all areas in order to monitor a comparable number of SSF catches. In a few cases, the relatively small size of the SSF communities and prolonged adverse meteorological conditions, especially in the winter season, contributed to a reduced number of fishing operations assessed compared to the majority of the areas.

In order to obtain robust and verified data on SSF catches, we used a photograph-sampling technique for catches at landing. Catch

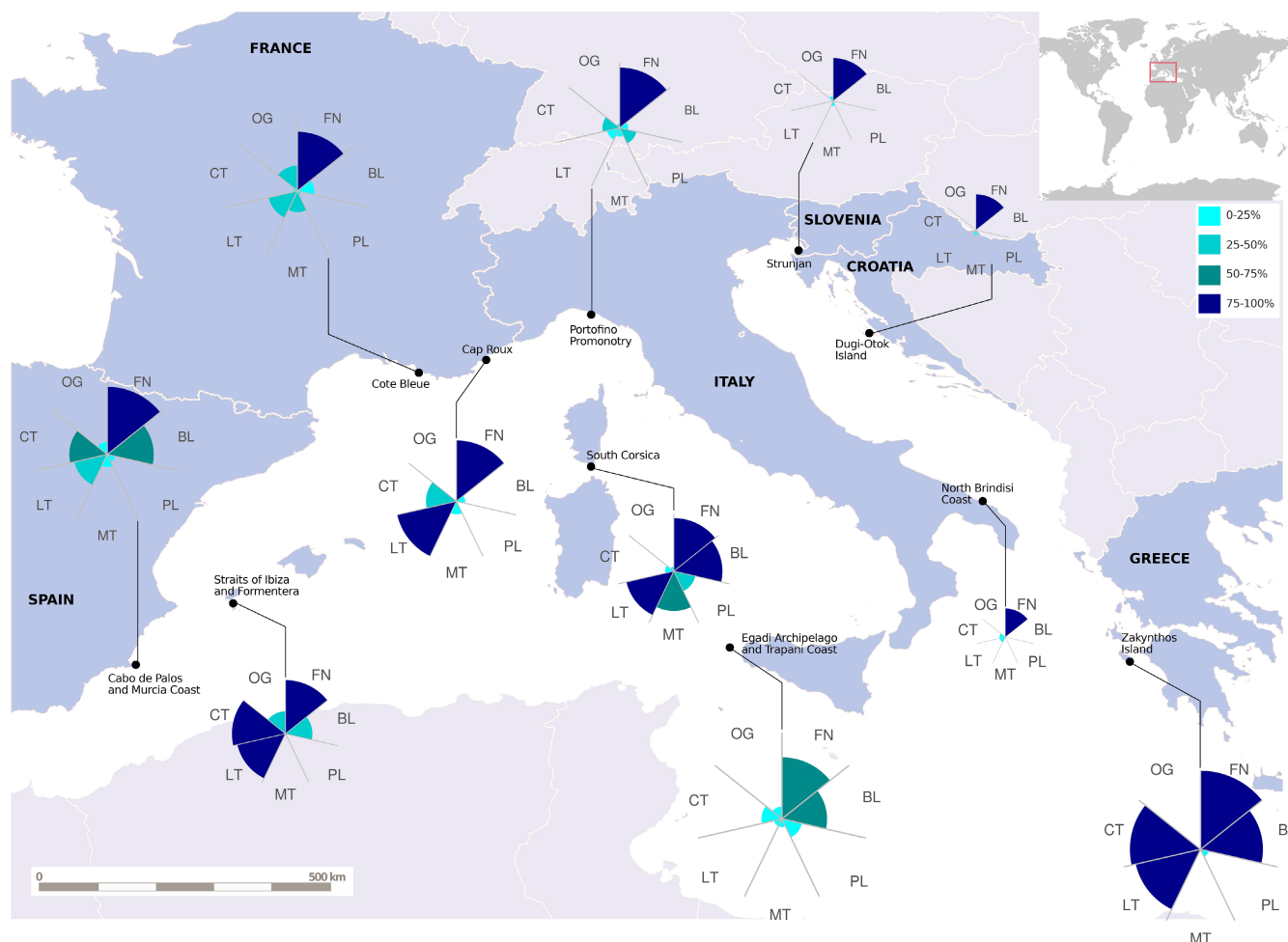


FIGURE 1 Study area. Rose charts represent, for each area, the proportion of fishers (from 0%, no slice, to 100%, full slice) using each of the seven categories of fishing gears considered (BL, bottom longlines; CT, cephalopods traps; FN, fixed nets; LT, lobster traps; MT, multispecies traps; OG, other gears; PL, pelagic longlines; see also the colour legend in the map). The overall radius of the chart is proportional to the number of fishers interviewed in each area

monitoring was restricted to fixed nets only. This choice was motivated by the fact that, although potential differences in the type of nets may exist, focusing on a single category of gears allows for a reliable comparison of fishery descriptors (e.g., catch per unit of effort, CPUE, and revenue per unit of effort, RPUE) between areas. In this sense, fixed nets were the only category of gears always present in all investigated areas and often representing the fishing gear most commonly used (see Section 3 and Figure 1, see also Grati et al., 2022).

A photograph-sampling methodology was adopted to minimize sampling time in the field and fish handling, in order to cause fishers the least disturbance possible during monitoring operations. More specifically, a scientific operator, previously trained by the project partnership, waited for the fishing vessel at landing sites, scheduling the assessment of the catch with the fisher in advance to avoid any specimens being sold before sampling. Fishers were previously instructed to land all the catch, without throwing overboard any specimen fished. The operator spread out the catch over a flat horizontal surface (e.g., a table or by directly arranging the fishes in the fish

box to minimize manipulation) and took one or more (for the largest catches) pictures to capture each entire catch, along with a ruler (as length reference) placed within the same frame (see Figure 2 for an example).

Each picture was associated with a unique identifier of the fishing operation (i.e., a small paper tag with a unique reference code) for the subsequent image analysis. Here, with the term 'operation', we indicate a single net deployed and the associated catch. For all the fishing operations monitored, a set of information was gathered immediately prior to the photograph-sampling through interviews with fishers, such as the type of fixed net used (distinguishing trammel nets, gillnets and combined trammel-gillnets), net length and mesh size, the mean depth and the duration of the fishing operation (i.e., net soak time). Fishers were also asked to indicate on a map the approximate geographic position of the catch. This information was successively used to characterize the habitat type where nets were deployed, retrieving the data from the Emodnet database and using a broad-category version of EUNIS habitat classification (i.e., distinguishing 5 broad habitat categories: sand,

TABLE 1 Small scale fishing fleet characteristics in each area

Area	Country	Number of fishers in each area	Number of fishers interviewed (% on fishers in the area)	Mean number of gear categories used	% of fishers using fixed nets	Number of fishing operations assessed
South Corsica	France	38	13 (34)	3.9	92	136
Cabo de Palos and adjacent Murcia coast	Spain	19	17 (89)	3.1	94	90
Cap Roux	France	30	14 (46)	2.8	100	82
Cote Bleue	France	27	17 (63)	2.2	82	96
Egadi archipelago and Trapani coast	Italy	40	21 (52)	2.1	71	148
Straits of Ibiza and Formentera	Spain	18	12 (66)	3.9	100	169
Portofino promontory	Italy	22	15 (68)	2	93	83
Strunjan	Slovenia	10	9 (90)	1.2	93	156
Dugi-Otok island	Croatia	15	7 (46)	1.1	93	37
North Brindisi coast	Italy	5	5 (100)	1.4	93	147
Zakynthos island	Greece	35	19 (54)	3.7	93	148



FIGURE 2 Example of a photograph-sample taken at landing that represents part of the catch of a single SSF operation. In the top-left corner, the unique ID associated with all pictures capturing the same SSF catch. The ruler at the bottom is used to calibrate the measuring tool in ImageJ

mud, mixed sediments, rock and other hard substrates, *Posidonia* meadows). Net length was successively used to calculate catch and revenue per unit of effort (CPUE and RPUE, respectively). An operator using the image-analysis free software ImageJ (Abramoff et al., 2004) then processed the images. A total of 1292 fishing operations in the 11 areas were assessed (ranging from 37 at Dugi-Otok island to 169 at Straits of Ibiza and Formentera) (Table 1). Catches were unevenly distributed among seasons, with a lower number of catches monitored in winter (9.5% of all catches), and higher and comparable numbers in the other seasons (Table S1). From each picture, we extracted information on species composition and frequency of appearance in the catches. Individual specimens were identified down to the lowest possible taxonomic level (usually species).

2.4 | Calculation of catch descriptors

We measured the total length of each individual fish, the length of the carapace for crustaceans and the length of the mantle for cephalopods (molluscs) to the nearest 1 mm using the ruler in the picture as a reference for calibrating the measurement tool in ImageJ. Individual biomass (i.e., wet weight in grams) of each fish specimen was estimated using specific length-weight relationships (LWR) available from www.fishbase.org (Froese & Pauly, 2019). For crustaceans and cephalopods individual biomass was estimated using LWR information available from www.sealifebase.ca (Palomares & Pauly, 2022). Whenever one or more specimens were not completely visible from pictures, the catch was not retained for further analyses (36 out of 1292 cases, i.e., 2.8% of all catches). LWR parameters can vary in space and time, this potentially influencing biomass estimation. In order to limit this potential problem, for biomass estimations, whenever possible we selected LWR parameters referred to Mediterranean samples.

The accuracy of the photograph-sampling method was tested in one of the study areas (Zakynthos island) by comparing the length of individuals measured directly at landing using a fish-measuring device with the ones assessed through ImageJ. Results showed that the deviation between individuals' length measured in the field and laboratory-estimated length from pictures was negligible ($-0.68\% \pm 0.72$, mean \pm SE) (see Supplementary Material for details). The biomass of each species and the total biomass of each fishing operation was used to estimate the catch per unit of effort (CPUE in kg/km of net), standardizing it for the length of the net.

We built an ex-vessel price (i.e., the price that fishers receive directly for their catch; Tai et al., 2017) database for all species appearing in the catches. To do so, during summer 2018, a group of fishers in each area was asked about the yearly average price per kilogram they charge to sell their fish. For each species, fishers were asked to detail, when present, size-specific prices (i.e., price changing depending on the size of individuals within each species), indicating size categories and the associated prices. These values were successively used to estimate area- and size-specific revenues per unit of effort (RPUE in €/km of net) for each fishing operation and for each species within it, by combining ex-vessel prices with the previously calculated CPUEs:

$$RPUE = \frac{\text{revenue generated}}{\text{length of the net used}}$$

where $\text{revenue generated} = \sum_{k=1}^n (\text{biomass} * \text{ex. vessel price})_k$ with n the number of species.

We therefore refer to 'revenue' as the landed value of the fishing operation (i.e., the total amount of money a fisher gains by selling the catch without considering any fixed cost or expense incurred by fishers) in accordance with Sala et al. (2018).

2.5 | Data analyses

Species diversity (measured as total number of species in the catch) and the relative frequency of occurrence (i.e., the number of catches in which a species was present at least once divided by the total number of catches monitored) were used to investigate the composition of catches.

In order to investigate species importance in generating catch descriptors, CPUEs and RPUEs were firstly inspected through accumulation curves, thus assessing the relationship between the number of species and their relative cumulative contribution to total CPUE and RPUE (i.e., over the monitoring period) in each area, and on average. To do so, species contribution to total CPUE and RPUE (i.e., pooling all catches) was sorted from the most contributing to the least contributing species for each area. For both catch descriptors, we fitted an asymptotic regression model to determine the average trend for all areas. Then, we calculated the average number of species contributing to at least 30%, 50% and 75% of both CPUE and RPUE.

Then, considering the list of species in order of contribution created above, we identified the most important species contributing to CPUEs and RPUEs for each area. We investigated species importance at the level of the single catch (i.e., fishing operation) by comparing CPUEs and RPUEs between catches containing the most important species ('ISC', important-species catches) and all other catches ('AOC'), that is, those in which the most important species had abundance equal to zero. To do so, for each area and for CPUEs and RPUEs separately, we built two catch \times species datasets: the first one containing all catches in which the most important species was present, the second one containing catches in which the most important species was not present. A meta-analytical approach was used to investigate (1) the 'dominance' between ISC and AOC in terms of CPUE and RPUE (i.e., which group of catches had higher mean values of these two descriptors), and (2) the 'stability' (i.e., inverse of the variability) of ISC compared with AOC (in terms of deviation from the relative mean). Two different meta-analyses, both on CPUE and RPUE, were done for dominance and stability (for a total of four). In details, for each area i , dominance D_i was calculated as the natural logarithm response ratio (Hedges et al., 1999; Osenberg et al., 1997) of the mean CPUE (or RPUE) of ISC and the mean CPUE (or RPUE) of AOC:

$$D_i = \ln \left(\frac{X_{ISC}}{X_{AOC}} \right),$$

where X_{ISC} is, for each area, the mean CPUE (or RPUE) of the catches containing the most important species in terms of CPUE (or RPUE) and X_{AOC} , the mean value of all other catches (i.e., those not including the most important species).

The standard error variance ($SE[D_i]$) associated to each effect size was calculated following Hedges et al. (1999) as:

$$SE[D_i] = \sqrt{\frac{(SD_{ISC})^2}{n_{ISC} * X_{ISC}^2} + \frac{(SD_{AOC})^2}{n_{AOC} * X_{AOC}^2}},$$

where SD_{ISC} and SD_{AOC} are the standard deviations of X_{ISC} and X_{AOC} , respectively. Finally, the 95% confidence intervals (CI) for D_i were calculated as $D_i \pm 1.96 * SE[D_i]$. A positive value of D_i would indicate that CPUE (or RPUE) of catches containing the most important species are, on average, larger compared with CPUE (or RPUE) of AOC, while a negative value would indicate the contrary. A significant difference is highlighted if $D_i \pm CI[D_i]$ does not include the zero.

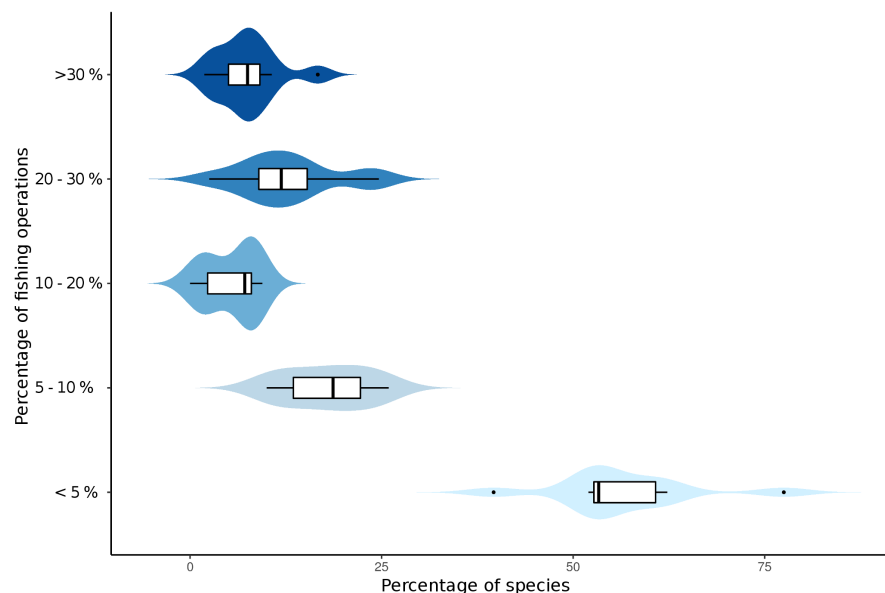
The same approach was used, for each area, to calculate the effect size for the stability of the catches and relative variance.

$$S_i = \ln \left(\frac{1}{\frac{Y_{ISC}}{Y_{AOC}}} \right),$$

where $Y_{ISC} = \frac{\sum \frac{\text{abs}(x_{ISC} - X_{ISC})}{X_{ISC}}}{n_{ISC}}$ and $Y_{AOC} = \frac{\sum \frac{\text{abs}(x_{AOC} - X_{AOC})}{X_{AOC}}}{n_{AOC}}$ with n_{ISC} and n_{AOC} ,

the number of catches containing and not containing, respectively, the

FIGURE 3 Violin plots showing the relationship between the percentage of unique species and the percentage of fishing operations in which they occurred. Plot values are relative to the 11 areas



most important species. Confidence intervals for S_i were calculated as above. A positive value of S_i would indicate that CPUE (or RPUE) of ISC are, on average, more stable (less variable) compared with AOC, while a negative value would indicate the contrary. Note that, ISC for CPUEs are not necessarily the same as for RPUEs, as the most important species for CPUEs and RPUEs could differ within each area. The overall effect size (considering all areas) for CPUE and RPUE was calculated both for dominance and stability using the 'metafor' package in R (Viechtbauer, 2010).

Finally, in order to obtain a genuine assessment of spatial variation in SSF features among the considered areas, we regressed species diversity, CPUE and RPUE, on a set of potential predictors of catch variability by using three linear mixed models (lmm), implementing the 'lme4' package in R (Bates et al., 2015). In the case of species diversity, the analysis was performed on the Shannon diversity index (computed from a matrix of CPUE with catches as rows and species as columns) in order to take into account both species occurrence and their proportion within the catches. For each of the three response variables, the full lmm used was the same: 'area' was treated as a random factor with 11 levels; 'habitat' (5 levels) and 'net type' (3 levels) were treated as random and nested in 'area'; a factor 'season' (random, 4 levels) was also included to account for temporal variability in catch descriptors; 'depth', 'fishing operation duration' and 'mesh size' were included as continuous covariates. In the case of the RPUEs, in order to enhance comparability among different areas, RPUEs values were standardized by a factor proportional to the per capita Gross Domestic Product (GDP) relative to each sampling area (source: <https://ec.europa.eu/eurostat>). For each lmm, model validation was visually performed by inspecting the residuals vs fitted plot (for homogeneity assumption) and the histograms of residuals (for normality distribution assumption), detecting no assumptions violation (see Supplementary). A measure of model goodness of fit (R^2) was calculated implementing the package MuMIn (Bartoń, 2019), distinguishing the variance explained by the full model (R_c) and the variance explained by the fixed components of the model (R_m). Prior

to these analyses, we checked sample size adequacy (in our case the minimum number of fishing operations to be monitored) for properly discriminating sampling areas by implementing the pseudo multivariate dissimilarity-based standard error (MultSE), developed for multivariate datasets but applicable to univariate cases (Anderson & Santana-Garcon, 2015). MultSE showed that between 20 and 25 catches were sufficient to detect differences between sampling areas (Figure S1), a number far lower than the minimum sample size per area considered in this study (37 catches). All statistical analyses were performed using R 3.4.3 (R Core Team, 2020).

3 | RESULTS

3.1 | Fishing fleet characteristics

Overall, fishers used from one to all seven different categories of gears (including the category 'other gears') (Figure 1), but some areas were associated to only 1–2 categories, normally with a high contribution from a single gear (Figure 1 and Figure S2). Fixed nets were the only category of gears always present in all areas and the far most used gear by small scale fishers (Figure 1), with almost 95% of the fishers interviewed using these nets (Figure S3). They were also always the widely most used gear in the case of fishers using multiple gear categories (Table 1). Among fixed nets, trammel net was the most used type (93%), followed by gillnet (6%) and combined trammel-gillnet (1%).

3.2 | Catch composition

Overall, we identified 33,439 individuals in the catches (including fishes, crustaceans and molluscs). The total number of taxa caught was 142, encompassing 106 taxa of bony fishes (specifically, 105 identified at the level of species plus the family of Mugilidae), 24

species of cartilaginous fishes, 8 species of crustaceans and 4 species of molluscs (Table S2). Note that, from now on, in order to avoid confusion, we use the term 'species' also when referring to a group of species including the family Mugilidae. The total number of species caught per area ranged between 40 and 85 (Figure S4), with an average of 65.2 ± 4.3 species per area (mean \pm SE). A total of 66 species (representing 46% of all the identified species) were recorded in less than 1% of all the catches. On average among all areas, 56.3% of species appeared in less than 5% of catches (Figure 3).

3.3 | Species contribution to catches and revenues

Mean value of CPUE was 13.05 ± 0.55 kg per 1000m of net. Concerning CPUEs, in all areas, few species were found to determine a high proportion of total CPUE (Figure 4). Specifically, averaging all areas, at least 30% of CPUE was determined by 1.81 ± 0.18 species (mean \pm SE), at least 50% of CPUE was determined by 3.81 ± 0.48

species and at least 75% of CPUE was determined by 10.18 ± 1.20 species (Figure 4).

Overall, mean RPUE was 220 ± 11 €/1000m of net (mean \pm SE). As for CPUE, a very low number of species was found to generate a high proportion of RPUEs in all areas (Figure 4). In every area, a single species was always responsible for at least 18% of the total RPUE. In detail, at least 30% of RPUE was determined by 1.54 ± 0.16 species, at least 50% of RPUE was determined by 2.73 ± 0.43 species and at least 75% of revenues was determined by 7.18 ± 1.00 species (Figure 4).

Concerning the contribution to the most important species for CPUEs and RPUEs, on average the dominance was found to be positive and statistically different from zero for both CPUE and RPUE (Figure 5), that is, both descriptors were found to be statistically higher for ISC (containing the most important species) compared with AOC, although some variability was detected among areas (Figures S5 and S7). Moreover, catch stability, both in terms of CPUE and RPUE, was found to be significantly higher for ISC compared with AOC (Figure 5), i.e., both CPUEs and RPUEs

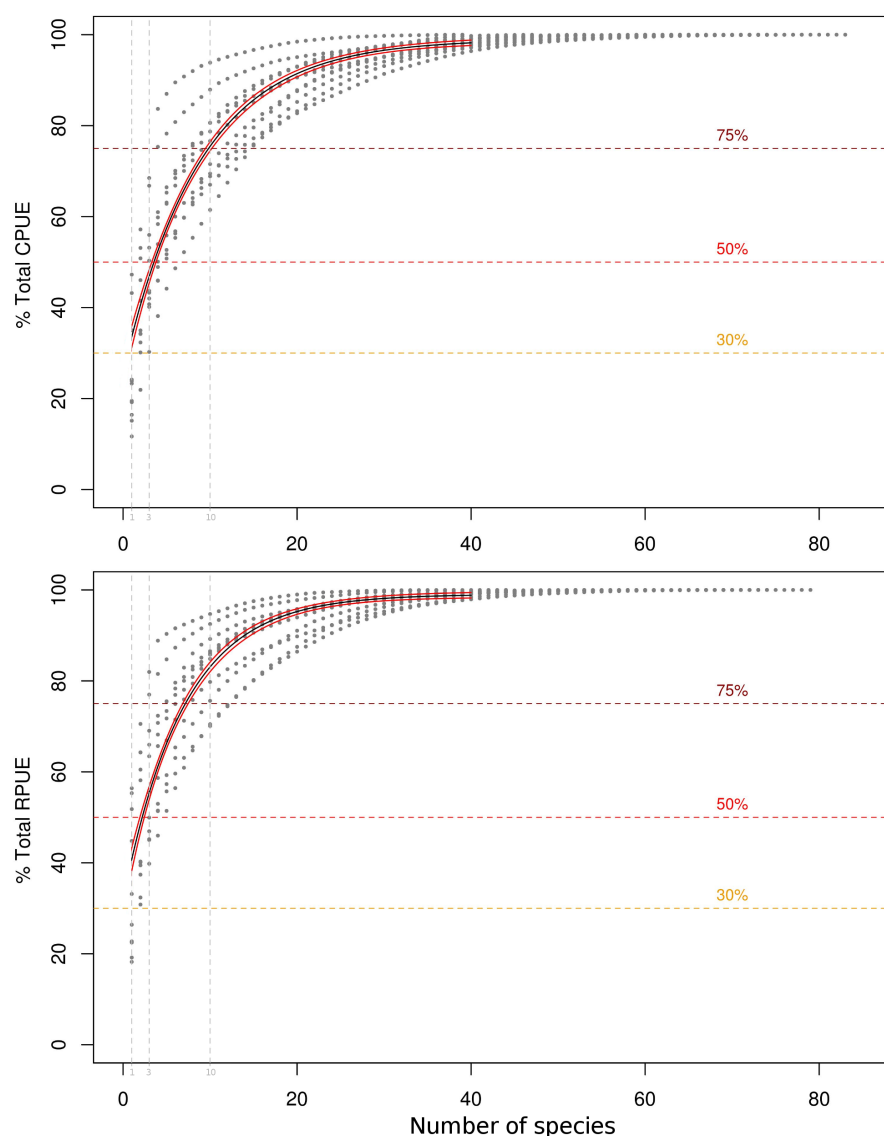
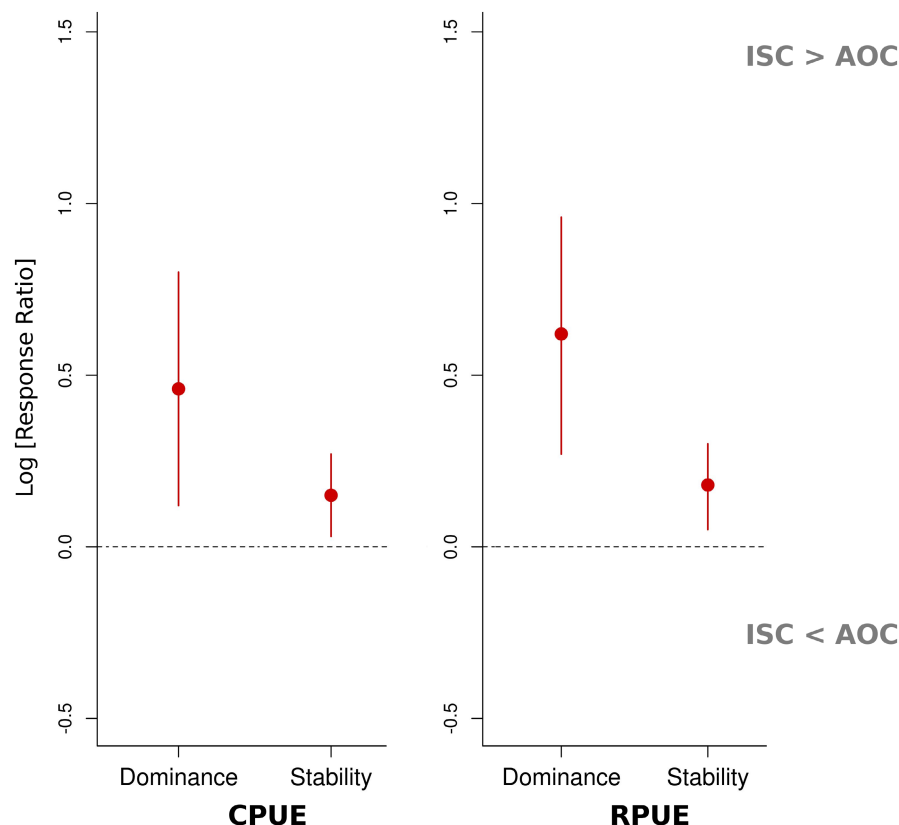


FIGURE 4 Accumulation curves showing cumulative relative contribution to CPUE (top panel) and RPUE (bottom panel) with increasing number of species. In each panel, the black line, and associated red lines, are model fit and 95% confidence intervals, respectively. Points indicate the value for each area. Fitted lines are shown only for the first 40 species (minimum number of species for all areas)

FIGURE 5 Dominance and stability of ISC (i.e., catches containing the most important species for CPUE and RPUE) vs. AOC (i.e., catches without the most important species). Dots represent the log-transformed ratio of mean and stability (i.e. inverse of variability) for CPUE and RPUE between ISC and AOC. The average effect size for all areas is reported $\pm 95\%$ CI



were significantly less variable when containing the most important species in each area. Moreover, for stability, some variability was detected among areas (Figures S6 and S8). The relative contribution of the most important species in ISCs varied considerably among areas, ranging from less than 1% of the RPUE of a single catch to 100% (Figure S9). In some cases (e.g., South Corsica or Cap Roux), the RPUE of ISCs was predominantly generated (70%–80%) by the most important species; in other areas the relative contribution of the most important species greatly vary among ISCs with median contribution around 30% (e.g., in North Brindisi coast) (Figure S9).

3.4 | Spatial variability of fishing operations

Shannon diversity index was significantly and negatively related with mesh size ($\text{Chisq} = 38.256, p < .001$) and depth ($\text{Chisq} = 7.351, p < .05$) of fishing operation. A significant variability was detected among areas and among seasons within each area (Table S3), with these two factors explaining most of the variability in the dependent variable.

Values of CPUE were significantly and positively correlated to the net mesh size ($\text{Chisq} = 16.927, p < 0.001$) and were found to vary significantly among areas and among seasons and habitats within each area (Table S3), these factors explaining the most of the variability in the dependent variable (Table S3).

RPUEs significantly increased with increasing mesh size ($\text{chisq} = 30.427, p < 0.001$) and duration of the fishing operation

($\text{chisq} = 6.342, p < 0.05$). RPUEs also differed significantly among areas and among seasons and habitats within each area, these factors explaining the most of the variability in the dependent variable (Table S3).

4 | DISCUSSION

Our data-rich and multi-area study revealed that despite being highly multi-specific, Mediterranean SSFs actually depend on a fairly limited number of species, largely contributing to both catches and revenues. This is particularly evident for RPUEs and at the local level. Out of the total number of species landed (66 on average, considering all areas), fishers' revenues are in fact substantially generated by very few species, with more than half of RPUEs within each area produced on average by less than 3 species and with multiple areas where this proportion of RPUEs is determined by a single species. This strong dependency is also highlighted considering species contribution to CPUEs, with about 50% of catches generated by less than 4 species (on average). This pattern is in agreement with the few available studies that tried to understand the contribution of different species to SSF catches and revenues (Guyader et al., 2013; Tzanatos et al., 2005). We highlight here that the assessment of catches conducted in this study refers to SSFs employing set nets only. From this perspective, catch descriptors assessed should not be considered as representative of the entire SSF sector of the Mediterranean. In fact, although fixed nets are the most frequently used gears and the only ones always present in the

SSF communities investigated, as also pointed out in other studies (Battaglia et al., 2010; Grati et al., 2022), other gears (e.g., longlines and traps) can represent a relevant portion of SSF activity in multiple areas of the Mediterranean.

Our results suggest that features normally associated with SSFs are actually less common than expected in the geographical domain considered. The assumptions of balanced exploitation and the local diversification of fishery resources (i.e., the ability to switch the species caught without changing fishing locality, *sensu* Gonzalez-Mon et al. (2021)) that have traditionally been associated to SSFs (Lloret et al., 2018), and are often considered socio-ecological *pros* of SSFs compared to large-scale fisheries, do not seem in line with what showed in this study. On the contrary, the high dependence on few, locally essential, species poses important socio-ecological issues for the sector considered. The predominant contribution of few species to catches and revenues is likely the manifestation of a concentrated fishing effort on these resources that could eventually lead to their over-exploitation, with important negative effects on their stock dynamics (Lloret et al., 2018). Moreover, the removal of key species, or specific size classes, by selective fishing strategies could also affect broader ecosystem dynamics in coastal environments, finally worsening the functioning of the ecosystem and the services we receive from it (Sbragaglia et al., 2021).

The ecological pauperization might inevitably generate social issues. The local stock depletion of one or two fundamental species fishers rely on could determine a major economic loss that could further exacerbate the crisis the sector is already facing. The reliance on a reduced number of species can, in fact, critically affect the resilience of SSFs against abrupt socio-ecological shifts (Cline et al., 2017). Coastal marine environments are notoriously highly unpredictable systems where abrupt shifts can occur as a consequence of multiple drivers (e.g., rapid market or environmental changes) (Steele, 1998). In this sense, the absence of a diversified fishery portfolio could hamper fishers' capacity to face changes. This condition is further worsened by the reduced spatial diversification that characterize SSFs (i.e., reduced mobility of fishers, Gonzalez-Mon et al., 2021), making them extremely dependent on local ecosystem resources (Guyader et al., 2013) as well as exposing them to the consequences of both global and regional stressors (e.g., climate change, market fluctuations and overfishing). All this could be further exacerbated by global environmental changes, such as the one we are experiencing, that could worsen the results of the extremely selective fishing strategies.

Our results seem to be in contrast with the evidence coming from other geographical contexts. The presence of local diversification was pointed out in other regions of the world where abrupt environmental changes (e.g., those due to 'El Niño') are more common and local communities could have co-evolved strategies to face potential consequences of these phenomena (Gonzalez-Mon et al., 2021). On the contrary, the relatively stable conditions of the Mediterranean Sea could have made the SSFs of this region unprepared against the possible occurrence of unexpected and/or rapid changes.

The absence of a diversified and balanced portfolio observed in our study does not seem to be a consequence of a limited number of resources. Catch composition diversity was, in fact, overall high, in line with evidence from other assessments conducted in the Mediterranean Sea. The total number of species observed (i.e., 142) is actually, to the best of our knowledge, the highest ever recorded in the Mediterranean Sea for SSFs (see Battaglia et al., 2010; Falautano et al., 2018; Forcada et al., 2010). Also at the local scale, the total number of species landed was high, with several tens of species recorded over the study period in each area. This is likely a reason why SSFs are often indicated as multi-specific, but the predominant importance of a restricted set of species suggests that this multi-specificity is rather an ecological property, and it should be cautioned when SSF are viewed from a broader socio-ecological perspective. Most species are in fact sporadic or very rare with about 80% of species appearing in less than 5% of all catches. The occurrence of a large number of less profitable species in the catches could be the consequence of the subsistent roots of SSFs. Small-scale fishers have historically learnt to take advantage of non-target species, either by selling or using them for household consumption, unlike what happens in the case of large-scale fishing where most of non-target species are discarded (Jacquet & Pauly, 2008). However, although fishers can find a way to sell every species landed, the majority of the species are practically economically irrelevant.

The limited portfolio could be rather a consequence of fish market dynamics in the region and local consumers' preferences. Historically, the Mediterranean Sea has been characterized by market demands for locally appreciated species, reflecting consumers' (either in restaurants or households) demand for high-quality seafood products (Lloret et al., 2018; Penca et al., 2021). Some of these gastronomically important species (e.g., scorpionfishes, lobsters and sea breams) can be supplied mainly by SSFs, that take advantage of the low fluctuation in the prices of these resources and use their traditional knowledge to harvest sufficient quantities, in order to guarantee stable and acceptable revenues throughout the year (Penca et al., 2021). Stability is an important feature for fishers. Strong fluctuations in revenues, because of either volatile product prices or unpredictable catches, in fact, can induce fishers to look for ways to prevent poor catches, generally increasing fishing effort, thus potentially generating negative loops in the long term (Penca et al., 2021). In this sense, the comparison of catches with the important species (ISC) and those without it (AOC) within each area further underlines the paramount importance that a single species can assume in (1) determining higher CPUEs and RPUEs and (2) positively stabilizing fishers' catches and revenues over time. It is worth noting that we cannot know a priori if ISC were associated with fishing operations specifically targeting the relatively important species of each area, as we did not gather information about which species were deliberately targeted by fishers during each fishing operation. However, for some areas, the predominant contribution of the important species to the RPUEs of the catches containing it, may suggest a specific fishing choice toward that species. Conversely, in other areas, the identified important species variably contributed to the RPUEs of

ISC, suggesting that this species could represent either the fishing target or an accessory capture. Especially in this latter case, higher RPUE values or stability of ISC compared with AOC would indicate a buffering effect of the important species, able to improve and stabilize catches even when it does not represent the target of a fishing operation.

The uneven contribution of a few species that emerges from our results also reflects the use of a selected set of fishing gears in the areas investigated. In fact, although the use of multiple fishing gears is a prevalent characteristic of SSFs, generally considered a multi-gear sector compared to large-scale fishing (Guyader et al., 2013; Kittinger et al., 2013; Pascual-Fernández et al., 2020), polyvalence is not necessarily a rule (Guyader et al., 2013). There are cases in which most of the investigated fishing communities use only one category of fishing gears. This is a relevant aspect when specific fishing gears are subject to changes in regulations at local or regional level, as in some cases, these changes can considerably affect an entire fishing community that is strictly dependent on that gear.

The results of our models highlighted a significant variability in catch descriptors among areas. Concerning species diversity, all areas differed widely in terms of Shannon's Index. Spatial differences could reflect large-scale regional differences in the structure of the fish assemblages exploited by SSF, provided that the CPUE is proportional to the biomass of the resource [i.e., no occurrence of hyperdepletion—CPUE declining faster than biomass—or hyperstability—CPUE being insensitive to declines in biomass (Hilborn & Walters, 1992)], so that it can be used as a proxy for fish species abundance (but see Harley et al., 2001). Spatial variability can also respond to local environmental features, probably shaping the overall fish assemblages linked for instance to habitat and substrate geomorphological characteristics (García-Charton et al., 2004), seasonal variation or area-specific fishing behaviours. From this perspective, we sought to both control potential effects of fishing tactics (i.e., including gear type, characteristics and depth in the models) and to account for habitat, area and seasonal variation, thus estimating a genuine spatial and temporal variability of catch diversity.

A wide variability between areas was also recorded for the other fishery descriptors considered. Differences in RPUE reflect the variability in CPUE between areas, as higher catches produce, theoretically, higher revenues. However, RPUE is also driven by catch composition, as certain species are more valuable than others are (Sumaila et al., 2007; Swartz et al., 2013). We highlight here that observed differences in RPUEs among areas likely describe real differences for fishers as their revenues were weighted by area-specific per capita GDP. However, we also point out that the relative differences in RPUE between areas may not necessarily mirror differences in fishers' net incomes and overall well-being, that are also related to the expenses fishers incur. In that perspective, a finer investigation of fishers' revenues should be also taken into account, for example, market dynamics capturing the variation in ex-vessel price due to the total amount of fish caught in a day (the price of a species generally decreases with increasing amounts caught) (Sumaila et al., 2007).

5 | CONCLUSIONS

The collection of accurate data in multiple areas allowed us to shed a light on different features of Mediterranean SSFs. Focusing on the most widespread and frequently employed category of SSF gears (i.e., fixed nets, that however do not necessarily represent the entire spectrum of SSFs), we highlight that some properties often assumed for SSFs should be probably reconsidered, especially when viewed from a broader socio-ecological perspective. This would reduce the risk of implementing management strategies potentially generating socio-ecological inequalities. Firstly, we suggest caution when SSFs are claimed as multi-specific, especially when this diversified portfolio paradigm is used as an argument to sustain the potential resilience of SSF in the face of abrupt socio-ecological changes (Aguilera et al., 2015; Gonzalez-Mon et al., 2021). In fact, although fishers can potentially shift the composition of resources they harvest, this does not necessarily imply that the loss or abrupt reduction of a locally valuable species can be easily compensated by targeting or increasing the fishing effort on others. This information is of crucial importance when particular species are targeted by ad hoc management and conservation actions at regional or local level, as catch-regulation measures can differentially affect fishers from different areas.

In the last 20 years fishery assessment and management have been oriented toward holistic ecosystem approaches. Stock assessment has been rarely, if ever, applied in the context of SSFs (Outeiro et al., 2018) and SSFs are even considered sectors for which the implementation of single-species approaches could generate deleterious managements. However, in the light of the results of our study, we suggest that while shifting towards a holistic ecosystem-based approach for coastal resources (García & Cochrane, 2005), researchers, managers and policy makers should not disregard the possibility to apply single-species (or paucispecific) approaches, aiming at maximizing and sustainably managing the restricted set of species on which SSFs are highly dependent. This will allow to provide solutions for mitigating the impact of approaching socio-ecological shifts. In this sense, we suggest that few locally essential, and area-specific, species need to be assessed through accurate species-specific approaches that would allow the identification of optimal management strategies for their stocks.

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DATA AVAILABILITY STATEMENT

All the data that support the findings are available upon reasonable request to Dr. Antonio Calò (antoniovalo.es@gmail.com) or Dr. Antonio Di Franco (antonio.difranco@szn.it).

ORCID

Antonio Calò  <https://orcid.org/0000-0001-6703-6751>

Antonio Di Franco  <https://orcid.org/0000-0003-3411-7015>

Federico Quattrocchi  <https://orcid.org/0000-0002-2030-5640>

Charalampos Dimitriadis  <https://orcid.org/0000-0002-8381-4362>

Patricia Ventura  <https://orcid.org/0000-0001-9351-3670>

Marco Milazzo  <https://orcid.org/0000-0002-2202-0542>

Paolo Guidetti  <https://orcid.org/0000-0002-7983-8775>

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