# Fishing in the time of COVID-19: Effects on fishing activities, resources, and marine ecosystems

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# Fishing in the time of COVID-19: Effects on fishing activities, resources, and marine ecosystems

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# Editorial: Fishing in the time of COVID-19: Effects on fishing activities, resources, and marine ecosystems

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COVID-19, fisheries, socio-economics, effort, fishing

Editorial on the Research Topic
Fishing in the time of COVID-19: Effects on fishing activities, resources, and marine ecosystems

The COVID-19 pandemic represented an unplanned global shock with serious impacts on the worldwide economy and human health that affected the fisheries sector with social, economic, and ecological consequences that have yet to be fully assessed. How COVID-19 impacted the activity of fishing fleets and how it reverberated on the behavior of fishers emerged as questions for fisheries and social scientists, national governments, the fisheries sector and international agencies (e.g. FAO, World Bank, etc.). The dynamics of global fisheries occurring in this exceptional situation included a series of reactions and adaptations that involved the whole sector, from fishers at sea to the whole supply chain and represent a baseline source of knowledge on fisher's behavior. The analysis of such reactions and adaptations can provide insights both for the set-up of more effective management strategies and for future social-ecological crises. The objective of this Research Topic was to collect a series of contributions documenting, analyzing, and quantifying the effects of COVID-19 on the fisheries sector. Overall, the Research Topic grouped nine original articles that provide an overview of the effects of the pandemic (and associated restrictions) worldwide.

This Research Topic includes scientific contributions which document the effects of the pandemic and associated restrictions on the activity of fleets in different areas of the world, both during the lockdown period (January-March 2020) and in the months thereafter, encompassing both small-scale and recreational fisheries. Effects were documented through the analysis of different data sources including satellite data

(VMS, AIS, SAR), landings (catch) and market data, economic indicators, questionnaires as well as state-of-the-art approach based on Synthetic-Aperture Radar (SAR) images.

With regard to small-scale/recreational fisheries, the four studies carried out in different parts of the world (Macusi et al., Pita et al., Hook et al. and Bolognini et al.) have shown a widespread and general decrease in activities, with great economic but also psychological consequences for the communities concerned. In the first contribution of the Research Topic, Macusi et al., assessed the impact of COVID-19 restrictions on the catch per unit effort (CPUE) of small-scale fishers in the Philippines. The authors found that the impacts of COVID-19 restrictions on fishers and their families were high due to the lockdown policy imposed in the fishing villages during the earlier phases of restrictions by the government. The study also evidenced a lack of mobility, food inadequacy, travel restrictions and their children's education for the fishers and their families. Pita et al. presented the result of an international research effort to understand the main impacts of the COVID-19 pandemic on marine recreational fishing, based on consultations with experts from 16 countries and documented a worldwide reduction in marine recreational fishing activity. Hook et al. documented the impacts of COVID-19 on sea anglers in the United Kingdom, reporting negative effects for marine recreational fisheries and, consequently, negative effects for participation, effort, physical activity and well-being. Bolognini et al. provided a preliminary assessment of the consistency of marine recreational fishing in a case study from the Mediterranean Sea (Italy), using the COVID-19 pandemic as one of the most unique opportunities to better understand the social phenomenon of this fishing sector and its repercussions on the environment.

With regard to the professional fisheries, the five studies included in this Research Topic have shown both a reduction in activity during the lockdown period, but also a rapid and strong recovery in the summer of 2020, with consequences for resources yet to be assessed. Russo et al. analyzed how the COVID-19 pandemic affected the fishing activities in the Northern Adriatic Sea (Central Mediterranean Sea), documenting a strong reduction in fishing effort, landings, and profits for several fleets. Declines ranged from −36% of landings for the pelagic trawling fishery, to an −85% decline in profit for the small bottom otter trawl fishery during the lockdown period. Plagányi et al. summarized the impacts of COVID-19 on a tropical lobster fishery's harvest strategy and related supply chain to inform on potential adaptation strategies. Villasante et al. developed a rapid assessment of the COVID-19 impact on the Galician (NW Spain) seafood sector, one of the most important fishing regions in the world. Their results demonstrated that the impacts were diverse. While the seafood sectors (fisheries and aquaculture) and trade were disrupted by abrupt shifts in demand, supply, and limitations on the

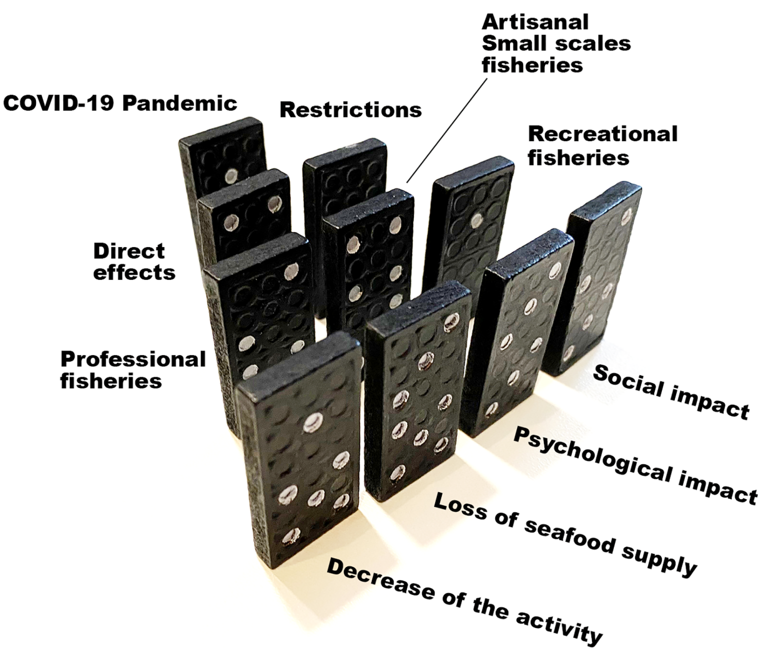


FIGURE 1
Representation of the domino effect triggered by the COVID-19 pandemic and affecting first all fisheries sectors and then, progressively, the food chain and the economic and social communities associated with fisheries.

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movement of people and goods, the canned production sector and the imports and exports of prepared and preserved seafood products followed an increasing trend during the COVID-19 pandemic. Furthermore, Russo et al. quantified the effects of the COVID-19 shock on the large fishery operated by the Italian fleet of bottom otter trawlers in the Mediterranean Sea, demonstrating that the consequences of the pandemic have been highly varied. Despite a marked overall reduction in activity in the first semester of 2020, in some cases the strategies adopted by Italian fishers and the commercial network linked to their activity have significantly reduced the impact of the pandemic emergency measures and taken back catch and effort to levels similar to those of previous years. In addition, they suggested that when fishing activities restarted the effort increased on coastal regions characterized by a greater abundance of resources and longer effective fishing times. Pita et al. used SAR images, a state-of-the-art approach, to assess human activities at sea and reveal the impact of the Covid-19 crisis on fishing activities in French Mediterranean waters. The analysis documented that ship frequentation remained at the same level during the most severe lockdown period whereas, similarly to what described by Russo et al., fishing activity increased later in the pandemic similar to the summer peak experienced in previous years. The five papers documenting the impact of the COVID -19 pandemic on commercial fisheries examined not only the direct impact on fleets, but also how that impact affected the entire supply chain. Several positive adaptive strategies emerged to deal with the Covid-19 impacts: Proximity to markets, investment in domestic or nearby supply chains and the development of new technological innovations to help avoid food shortages and mitigated the economic consequences for the sector in different areas, especially in the Mediterranean Sea (Villasante et al., Russo et al.).

In summary, the papers in this Research Topic document quite diverse impacts on the fisheries sector related to the pandemic. Most papers document that the pandemic had a massive domino effect on all categories of fishers, from amateurs to professional fishers, through its direct and indirect (restriction-related) impacts, resulting in various negative consequences in terms of psychological, social, production, and nutritional impacts (Figure 1). The negative domino effect was mitigated in very specific cases where the pandemic brought benefits. For example, the close relationship between fishers and the market chain facilitated the adaptation and adoption of local countermeasures to a generally negative situation in Italy. In addition, the negative impact of the pandemic on the production sector boosted the canned fish industry. Overall, given the complexity of the environment-fishery-market system, it is an aspect that short-term shocks such as the pandemic can lead to a general negative impact, but it does not affect all parts of the system: some well-structured parts (from production to market) can better withstand the short-term shock.

## Author contributions

All authors listed have made a substantial, direct, and intellectual contribution to the work and approved it for publication.

## Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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# Indirect Impacts of COVID-19 on a Tropical Lobster Fishery's Harvest Strategy and Supply Chain

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The Torres Strait tropical rock lobster *Panulirus ornatus* (TRL) fishery is of immense social, cultural and economic importance to the region's Indigenous fishers from both Australia and Papua New Guinea (PNG). During 2020, the COVID-19 pandemic indirectly impacted this fishery as well as a number of other fisheries reliant on international export markets. The TRL fishery is managed using an empirical (data-based) Harvest Control Rule (eHCR) to rapidly provide a recommended biological catch (RBC), based on catch, fishery-independent survey indices and catch-per-unit-effort (CPUE). Here, we summarize the impacts of COVID-19 on each of these critical data inputs and discuss whether the eHCR was considered adequately resilient to this unprecedented disruption to the system. Next, we use a quantitative supply chain index to analyze the impact of disruptions to the supply chain, and inform on potential adaptation strategies. The catch and CPUE data were impacted to varying degrees by external constraints influencing fishing effort, but the fishery-independent survey wasn't affected and hence there remains an unbroken survey time-series for the fishery extending back to 1989. The eHCR was shown to be reasonably robust because it incorporates longer-term trends over a 5-year period, and accords substantially more weighting (80%) to the fishery-independent survey rather than CPUE data which can be affected by trade and other disruptions. Despite the eHCR not having been tested for scenarios such as a global pandemic, this robustness is a positive given the types of disruptions we will likely face in future climate. The weak links identified in the supply chain were the same as those previously highlighted as sensitive to climate change disruptions. Our supply chain analysis quantifies the impact on system resilience of alternative paths connecting producers to consumers and reinforces that supply chains may be particularly vulnerable to external disruptions if they are not sufficiently diverse.

**Keywords: decision rules, fishery markets, fishery-independent survey, pandemic, MSE, fishery export**

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## INTRODUCTION

The COVID-19 pandemic (Hui et al., 2020) has indirectly led to severe economic impacts on global and Australian seafood industries (Bennett et al., 2020). This has included disruptions in shipping activity (Huveneers et al., 2021; Notteboom et al., 2021), global markets (Knight et al., 2020), food security (Steenbergen et al., 2020) and negatively impacted on commercial fisher's health and wellbeing as well as added to the challenges of protecting workers on fishing vessels (Sorensen et al., 2020). A recent review highlighted widespread heterogenous ramifications on United States fisheries (White et al., 2021). The risk of crowding and inadequate physical distancing during fishery operations has been identified as a key challenge impacting fisheries during COVID-19 (Okyere et al., 2020).

There has also been a major impact on scientific data collection in some areas of the world, such as in the United States where scientists were forced to cancel most of their major research cruises and surveys in 2020 (Link et al., 2021). Link et al. (2021) reported that the United States alone had to cancel over 50 fisheries surveys resulting in a loss of over 1,500 on-the-water days-at-sea. Although Australia was also impacted by the COVID-19 pandemic, localized outbreaks were contained relatively quickly, resulting in only a brief core "lockdown" (Huveneers et al., 2021) and hence activities such as fishing and surveys were impacted less than was the case for many other countries.

The focus of this study is the disruption caused by COVID-19 to the main export market for Australian seafood producers, and subsequent impacts on the fisheries supplying these markets. The Chinese market accounts for almost 70 per cent of Australia's $1.2 billion total seafood exports (FRDC, 2020). Three quarters of the seafood export market to China is live rock lobster, with most of the eight major lobster fisheries (**Figure 1**) reliant on exports. These exports were severely impacted during 2020, along with other high-value species including abalone, coral trout *Plectropomus* spp. and live eel (Catizone, 2020). As a result, there were short-term declines in catches around Australia of these species (Huveneers et al., 2021). Even before the World Health Organization (WHO) declared COVID-19 a world-wide public emergency, the global market for spiny lobsters, valued at United States $912 million in China alone, was halted because 90% of these high value lobsters are exported to China (Knight et al., 2020).

Primary industries such as fisheries are vulnerable not only to environmentally-induced shocks to their production phases but also to risks across the entire supply chain from supplier to consumer. This is also because in our highly globalized modern society, products such as lobsters are rarely consumed at the point where they are caught, but require being moved along progressively longer and more complex supply chains, to be consumed in distant domestic and international markets. A holistic approach to managing risk is therefore valuable as supply chain components are interrelated and mutually dependent (Lim-Camacho et al., 2015; Rosales et al., 2017; Ghadge et al., 2020; Farmery et al., 2021). An improved understanding of supply chain design on the degree of resilience or vulnerability to disruptions may shed light on improved risk management and ways to reconfigure more resilience and competitive supply chains (Lim-Camacho et al., 2017).

The science needed to support major shocks to fisheries and markets remains a challenge (FAO, 2020a,b; Link et al., 2021). In this article we use the Torres Strait tropical rock lobster *Panulirus ornatus* (TRL) fishery as a case study and summarize impacts of COVID-19 and subsequent outcomes. We also evaluate how well the harvest control rule, management system and supply chain were able to respond to the challenges that resulted due to the pandemic. To analyze the supply chain, we use a modeling approach that accounts for the relative movement of product through nodes and links in a supply chain, to theoretically identify vulnerable elements in the supply chain (Plagányi et al., 2014) and evaluate how this concurs with what actually eventuated in response to COVID-19 disruptions, as well as analyzing ways to improve the resilience of supply chains.

## The Torres Strait Tropical Rock Lobster Fishery

The TRL fishery provides an important source of income for more than 400 Torres Strait Islander license holders and many island communities, as well as supporting a non-Islander sector. Fishing in the Torres Strait is governed by the *Torres Strait Fisheries* Torres Strait Fisheries Act (1984), which protects the way of life and livelihood of traditional inhabitants.

The TRL stock is shared with adjacent fisheries in Papua New Guinea (PNG) and on the northern Queensland coast (**Figure 1**). The Australian and PNG Torres Strait catch has averaged 673 t live weight since 1989. The Australian Torres Strait catch is important economically to all sectors, and contributes to a lucrative export market for live lobsters to China (**Figure 2**).

Fishery-independent monitoring of the TRL population has been carried out annually from 1989 to 2020. These surveys provide long-term information on the relative abundance of recruiting (1+) lobsters. Prior to the introduction of mandatory logbooks in the largely non-Indigenous transferable vessel holder (TVH) sector and subsequently the docket book system in the Indigenous traditional inhabitant boat (TIB) sector in 2003, these surveys also provided the only long-term information on the relative abundance of fished (age class 2+) lobsters (Dennis et al., 2015).

The TRL fishery transitioned to an output control system on 1 December 2018, which requires the setting of a total allowable catch (TAC). The harvest strategy uses a conservative biomass target reference point that takes into account that the resource is shared and important for the traditional way of life and livelihood of traditional inhabitants and is biologically and economically acceptable. Other management measures include a ban on trawlers taking lobsters, a minimum size limit (90 mm carapace length), periodic closure of the fishery to the use of hookah (surface air supply) gear around specified new and full moon periods, prohibition of use of hookah during December to January, as well as a full closure during October to November each year.

The stock is naturally highly variable due to variability in the numbers of recruits (1+ lobsters) each year, and the fishers catch mostly a single age-class (2+) only (Plagányi et al., 2019). The unfished 2+ lobsters leave the Torres Strait at the end of August-September to breed (Skewes et al., 1994). Hence, a TAC needs to be set annually in such a way as to ensure biological and economic sustainability consistent with the principles of the Australian Commonwealth Harvest Strategy Policy

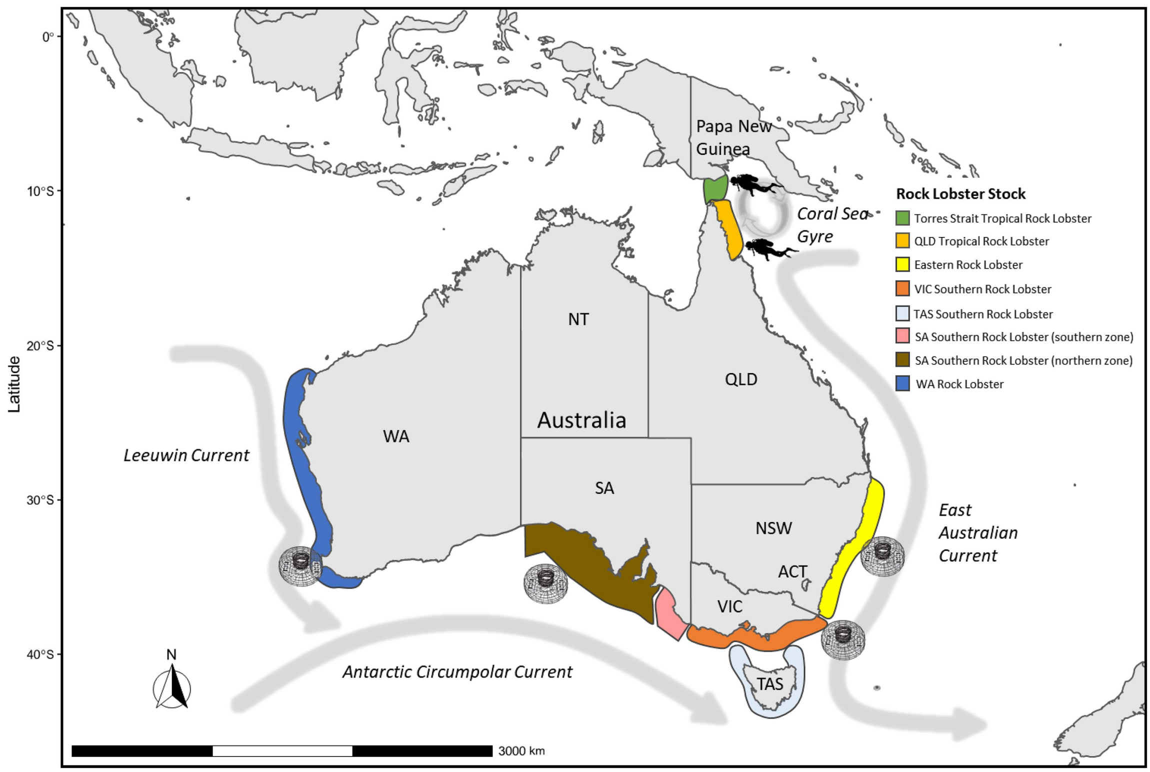


**FIGURE 1 |** Map of Australia and Papua New Guinea showing location of the Torres Strait tropical rock lobster dive fishery and linked Queensland (QLD) tropical lobster fishery as well as the six other major lobster trap-based fisheries as summarized in Plagányi et al. (2018), namely Eastern rock lobster *Sagmariasus verreauxi*, southern rock lobster *Jasus edwardsii* from Victorian (Vic), Tasmania (Tas), South Australia (SA) southern and northern zones and West Australia rock lobster *P. cygnus*.

(Australian Government Department of Agriculture and Water Resources, 2018) as well as the TRL fishery and Protected Zone Joint Authority (PZJA) objectives. For this reason, the annual fishery-independent survey of 1+ recruits is now conducted as close to the start of the fishing season as possible (during the November neap tides) to allow estimation of the likely size of the fishable stock the next year (Dennis et al., 2015). Previously, this information together with all other sources of information and data for the fishery were input to an integrated stock assessment model that was used to set the TAC (Plagányi et al., 2020b).

In December 2019, new harvest strategies were implemented for important Torres Strait fisheries including the lobster and bêche-de-mer fisheries (Plagányi et al., 2018, 2020c; PZJA, 2019). The strategies included some major changes to data collection methods and scientific assessments to ensure ongoing fishery and ecological sustainability and economic growth; important for the welfare of hundreds of fishers, regional-based processors and local and national sellers that depend on these resources.

For TRL, the harvest strategy outlines the objectives, monitoring requirements, stock assessment model, empirical (data-based) Harvest Control Rule (eHCR) and reference points (PZJA, 2019). The eHCR is used to rapidly provide a recommended biological catch (RBC) once the catch, survey indices and other data inputs (CPUE or catch-per-unit-effort) become available (Plagányi et al., 2018). The eHCR is a central component of the Harvest Strategy. It was simulation tested to be robust to a number of uncertainties and shocks, but not to the ramifications of a global pandemic.

## MATERIALS AND METHODS

### External Drivers Influencing the TRL Fishery

During the 2020 fishing season, there were a number of unprecedented external drivers that influenced fishing effort. We collated information on these through informal conversations with fishers, managers and processors. We verified information as to the impacts of changes in border regulations, charter flight availability and export demand by cross-checking with formal government announcements, such as from the Ministry of Agriculture and Rural Affairs as well as through more formal reporting of disruptions at several Tropical Rock Lobster Resource Assessment Group (TRLRAG) meetings held *via* teleconference through the year (TRLRAG, 2020). The TRLRAG forum includes Indigenous fishers and their representative bodies, non-Indigenous fisher representatives and flow-on business stakeholders, federal and state fisheries managers, and scientists. In addition to information on changes in beach prices shared by processors, we verified these decreases from

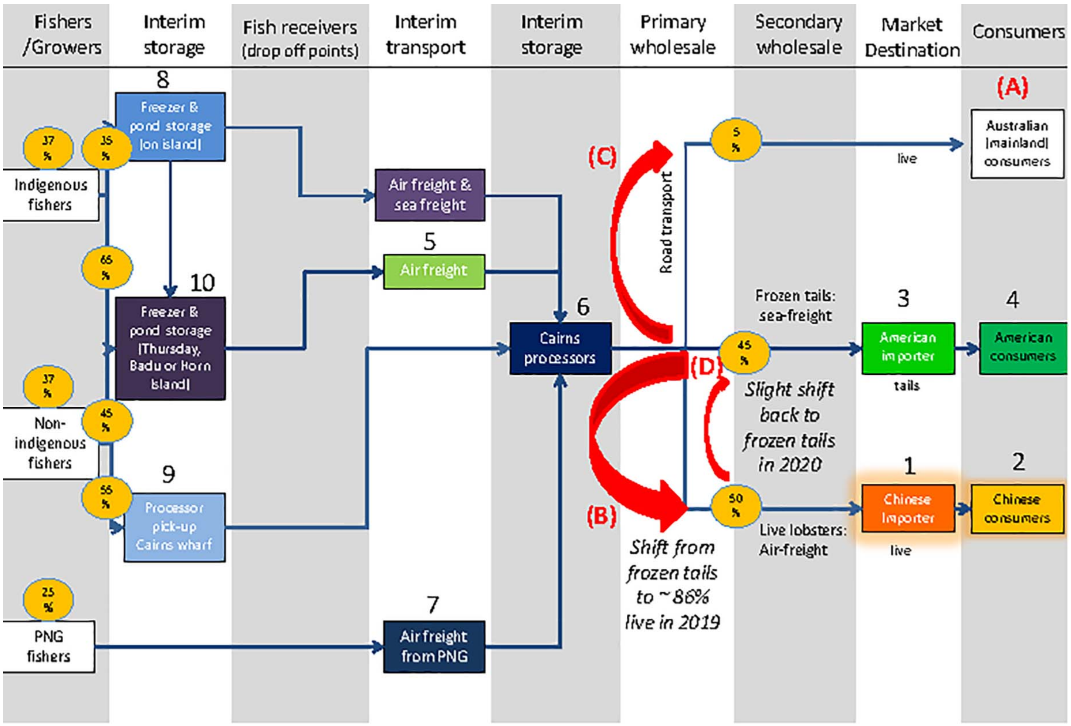


**FIGURE 2 |** Torres Strait tropical lobster 2012 supply chain schematic modified from Plagányi et al. (2014), highlighting with a red arrow the post-2012 shift to exporting almost all live lobsters, and a small reversal of that market shift during 2020. The large numbers next to nodes show the ranking of the top ten critical elements in the supply chain (orange highlights the most critical node) based on applying the Supply Chain Index method of Plagányi et al. (2014). The figure shows the 2012 base configuration **(A)** as well as variants **(B)** shift to more live; **(C)** increase domestic market and **(D)** greater domestic market and product split between live and tails, as discussed in the text.

restaurant advertisements. We extracted information on total seafood exports and value from the Australian Fisheries Research and Development Corporation (FRDC) Seafood Production and Trade Database.

## Impacts on the Scientific Process and Survey

The indirect impacts of COVID-19 on the scientific process and data collection were also considered. A number of contingency plans were reviewed, and COVID-safe measures implemented to ensure the highest probability of the survey being conducted in a consistent and safe manner not only to the survey and boat crew but also to communities in Torres Strait.

## Fishery Data

As in previous years, the fishery catch and effort data for the Australian share of the fishery were provided by the Australian Fisheries Management Authority (AFMA), and the totals and monthly distribution compared with that of previous years. The monthly catch totals from the PNG sector for the months January to September were provided by the PNG National Fisheries Authority. As agreed previously by the TRLRAG, these values were linearly extrapolated to obtain an annual total catch for use as an input to the eHCR. The CPUE data were standardized using the same methods as applied previously (Deng et al., 2020b,c; Plagányi et al., 2020b).

## eHCR and Final Management Advice

The eHCR formula outputs a RBC in December for the following year. This calculation is the multiple of the average catch over the last 5 years and a statistic which measures the relative performance of the fishery based on the following five data inputs: (1) Fishery-independent recruiting lobster (1+) standardized relative numbers; (2) Fishery-independent recently-settled lobster (0+) standardized relative numbers; (3) standardized CPUE for TIB sector; and (4) standardized CPUE for TVH sector; and (5) total catch (TIB, TVH, and PNG) (using data available up until end of October). Different weightings are applied to the four abundance indices included in the relative performance statistic used in the eHCR, based on extensive testing to compare performance of alternative weightings and also considering the information content and reliability of each series, as well as a preference expressed by the stakeholders to use a portfolio approach in determining the RBC (Plagányi et al., 2018). The Preseason 1+ index is the primary index and is most reliable and direct in terms of indexing the biomass of lobsters that will be available to be caught in the next fishing season. Hence, this index is assigned the highest weighting of 70%. The Preseason 0+ index provides an early indication of the following year's recruitment, whereas the CPUE indices aim to index the relative abundance of the large 2+ lobsters, the survivors of which will migrate out of the Torres Strait to spawning grounds to the East. Each of these three secondary indices [Survey 0+ and CPUE (TIB and TVH)] is assigned a weighting of 10% (30% total) in the eHCR formula.

Simulation testing (Plagányi et al., 2016) showed that the best approach is to use the slope of the trends in the secondary indices over the last 5 years' data (after first taking the natural logarithm of the data) for each of the abundance indices. This allows the RBC to be based on medium term trends in abundance, rather than on just the current abundance.

Hence the HCR rule is as follows:

$$RBC_{y+1} = \left[0.7 \cdot \left(1 + s_y^{presurv,1}\right) + 0.1 \cdot \left(\left(1 + s_y^{presurv,0}\right) + \left(1 + s_y^{CPUE,TVH}\right) + \left(1 + s_y^{CPUE,TIB}\right)\right)\right] \cdot \bar{C}_{y-4,y} \quad (1)$$

where

$\bar{C}_{y-4,y}$ is the average achieved catch during the past 5 years, including the current year; i.e., from year $y$-4 to year $y$,

$s_y^{presurv,1}$ is the slope of the (logarithms of the) fishery-independent survey 1 year abundance index, based on the five most recent values;

$s_y^{presurv,0}$ is the slope of the (logarithms of the) fishery-independent survey 0 year abundance index, based on the five most recent values;

$s_y^{CPUE,TVH}$, $s_y^{CPUE,TIB}$ is the slope of the (logarithms of the) TVH and TIB CPUE abundance index, based on the five most recent values.

## Supply Chain Resilience

To inform analyses around the impacts of COVID-19 on the TRL supply chain, we used as a base example the simplified structure of Plagányi et al. (2014), which captures the key processes and activities describing the system connections from the point at which lobsters are first landed to the point at which they are consumed (**Figure 2**). The simplified representation enables structured analysis, even though we acknowledge that behind these models are complex business structures and industry relationships.

The base example from Plagányi et al. (2014) was developed for TRL using data describing fishery operations around 2012. There have since been a number of important changes to the TRL fishery, including changes in allocations per sector, management controls and market shifts. However, the focus here is on the market outlets for lobsters, and over the past decade there has been a substantial transition from frozen tail to live product: the Australian sector's overall proportion of tailed product has decreased from around 58% down to 14% (Deng et al., 2020a). This added significant value to the fishery given that the tail represents only ∼40% of the lobster by weight and live product fetches ∼30% higher $/kg at market (Hutton et al., 2016; Plagányi et al., 2017). However, when COVID-19 brought fishery exports to a standstill in February 2020, fishers (particularly the PNG and TIB sectors) were forced to again convert some lobsters to frozen tail product. There were also efforts to increase sales of lobster on the domestic market and hence we also investigate the impacts of greater diversification of the supply chain.

We also acknowledge that since 2012 there have been other positive increases in diversification of the supply chain in the form of additional processors. This increased supply chain complexity would increase the resilience score, but is beyond the scope of this paper which focuses on changes in the final market destinations.

To analyze the resilience of alternative supply chain configurations to external disruptions, we used the Supply Chain Index (SCI) from Plagányi et al. (2014) (see **Supplementary Material**).

In this study, we compare the critical elements and supply chain resilience score under the 2012 base configuration [scenario (A)] with three alternative scenarios (**Figure 2**):

(B) A pre-COVID-19 (2019) scenario with almost all live exports, few tails (14%) and small (5%) domestic market;
(C) An illustrative scenario with increased domestic market (25%) and rest mostly exported overseas as live product; and
(D) An optimized scenario (manipulated to increase the resilience score), with a large (50%) domestic share, and the rest split evenly between the international markets for frozen tails and live lobsters.

The simplified representation shown in **Figure 2** has 15 elements and 16 links which are assumed constant in the scenario analysis—here we test only the implications of altering the magnitude of flows in the network.

# RESULTS

## External Drivers Influencing the Fishery

In response to COVID-19, the last regular live tropical lobster shipment to China left on 26 January 2020, just before the ban on live markets took effect and there was a considerable pause in international exports of lobster from both Australia and PNG. This was revoked by the 6th February indirectly as live seafood was allowed into China as an exception. This period is usually a time of high demand with peak prices for lobster and other Australian seafood due to the Chinese New Year (Plagányi et al., 2017). Following the declaration by WHO of a pandemic, the Australian Government closed its international air and sea borders on 20 March, negatively impacting freight availability.

Operators around Australia were left with live catches of several species waiting for export. Average prices for exported TRL lobster reportedly dropped 75–80 per cent (Plagányi et al., 2020a). In some cases there were large backlogs of seafood in holding tanks and a switch to exporting less-valuable frozen product (Plagányi et al., 2020a). This was also the case for all other major Australian lobster fisheries, live fish exports such as coral trout and shellfish such as abalone, all of which are subject to Australia's strict export laws. In response to the inability to freight produce overseas, short-term declines in catches were observed for some fisheries (Huveneers et al., 2021).

In April 2020, the Australian Government introduced an International Freight Assistance Mechanism whereby funding was provided to recommence shipments to China and other countries in an effort to assist Australia's stalled seafood and agriculture export trade (Ogier et al., 2021). Given that many countries closed their borders to overseas visitors, these special freight flights meant that seafood shipments could recommence despite the otherwise restricted environment. Chinese demand for lobster remained low initially due to bans on large gatherings and festivals, but exports started again from Australia, while the PNG fishery remained closed.

Toward the end of the 2020 fishing season, there were few constraints affecting the export of TRL from Australia. As a result, there were reports of some diversification of the TRL supply chain, such as more frozen tails being exported. However, it was not viable to target local consumers, with the domestic market price being less than the harvest and marketing costs in the fishery. The domestic lobster price was further reduced as a result of reduced exports of lobsters from other fisheries nationally.

Following directly after the COVID-19 disruptions, in October 2020 (when the TRL fishing season had ended) there was a second major disruption to lobster exports following reports that unacceptable levels of cadmium were found in a shipment of western rock lobsters (*P. cygnus*) to Shanghai, which resulted in delays to live lobster shipments to China at the ports of entry[1]. This resulted in cessation of fishing in response to the associated uncertainty and concerns around the potential for delays in border clearance to potentially affect all seafood and several other food products exported from Australia.

## Impacts on the Scientific Process and Survey

An indirect impact of COVID-19 was that TRLRAG meetings were changed from an in-person format to teleconferences. This involved considerable preparation by the fisheries management authority given the challenges of limited suitable facilities in some of the remote island locations. However, these meetings proceeded smoothly and hence this aspect is not considered further. One ongoing aspect is that some non-critical analyses that require longer, more in-depth discussions were delayed.

There were impacts of COVID-19 on the planning and operation of the 2020 fishery-independent survey, however, this did not compromise the process of data collection once the survey commenced. Survey staff were required to liaise with government agencies, such as the State health department, and Torres Strait community stakeholders to determine requirements to enter and work within vulnerable communities. Management Plans were developed to manage the changing level of risk posed by COVID-19 for staff to travel and complete the survey. The Plans considered COVID-19 testing for survey and vessel charter operator staff, alternative travel such as chartering planes rather than commercial flights, the use of Personal Protective Equipment, Safe Operating Procedures on board the charter vessel such as daily temperature checks, strict hygiene practices, limiting contact with communities and appropriate emergency response to address possible development of COVID-19 symptoms during the survey.

Fortunately, there were no outbreaks in Queensland during the months leading up to the survey, and hence the scientific survey was successfully conducted in 2020, ensuring continuity of the 32-year data series.

## Fishery Data

The total reported catch for the Australian TRL fishery (1 December 2019 to 30 September 2020) was 361.3 tons, with 216.2 tons caught by the TIB sector and 145.1 tons caught by the TVH sector (**Table 1**). The total reported catch from PNG was 90.4 tons (January–August 2020) which was extrapolated to a full year using a pre-agreed approach, yielding 126.4 tons. The 2020 catch was 84% of the TAC with a proportion of the shortfall attributable to impacts of COVID-19 in 2020 (based on discussions in TRL RAG meeting in May 2020).

During the initial period when live lobsters could not be exported, some product was converted to tails which could be frozen and stored. It was therefore anticipated that there would be an increase in the proportion of tailed product, but this effect was barely noticeable when evaluated using the entire year's data for the Australian sector (Deng et al., 2020a).

There were clear differences in the pattern of fishing through the year by the different sectors (**Figure 3**), as well as changes in economic drivers which would have likely influenced when fishing took place as well as the product type targeted. It was noted that these factors could potentially all bias the catch and effort data in terms of their representativeness as an index of stock abundance.

A comparison of the relative proportions of the total annual catch that is taken by the TIB and TVH sectors in different months shows a particularly marked difference for the TVH sector in 2020 (**Figure 3**). There is a particularly strong signal during February, and extends slightly into March. February is usually a peak catch month but the impact on catch patterns, presumably due to the disruption to the export market, is clearly seen for the TVH sector in particular which ceased fishing entirely over this period. Both sectors then seemingly compensated for lost catches during the middle of the season with a substantial increase in catches during April. For the TVH sector, the data shows an extended increase in effort up until July, and then a drop as the TVH TAC allocation is approached (98.7% of TVH quota allocation achieved). For the TIB sector, increased effort appears to be sustained until August and drops to average levels in September leading up to the fishery closure, with the final TIB sector catch being less (75.1%) of the TAC allocation.

Both the TVH and TIB sectors recorded significant effort decreases coinciding with initial COVID-19 outbreaks in early 2020. However, catch rates for both sectors increased substantially later in the 2019–2020 fishing season, and the annual CPUE point estimates were the highest values recorded in the past five seasons.

Both the TIB and TVH standardized CPUE series showed some differences from the nominal (unstandardized) series,

[1]https://www.afr.com/politics/china-widens-trade-sanction-net-to-cover-all-fishermen-20201108-p56cig

**TABLE 1 |** Summary of recent catch (t) per Torres Strait (TS) sector shown as a percentage of the Total Allowable Catch (TAC).

| Season | TIB | TVH | AUS-TOTAL | PNG-TOTAL | TS_TOTAL | TAC | Catch/ TAC |
|---|---|---|---|---|---|---|---|
| 2013 | 142.5 | 361.7 | 504.2 | 108.3 | 612.5 | 871 | 70.3% |
| 2014 | 198.8 | 273.2 | 472.0 | 261.2 | 733.2 | 616 | 119.0% |
| 2015 | 202.6 | 152.7 | 355.3 | 235.7 | 591.0 | 769 | 76.9% |
| 2016 | 267.1 | 243.0 | 510.1 | 248.0 | 758.2 | 796 | 95.2% |
| 2017 | 111.5 | 166.3 | 277.8 | 113.0 | 390.8 | 495 | 79.0% |
| 2018 | 127.4 | 128.3 | 255.7 | 156.4 | 412.1 | 320 | 128.8% |
| 2019 | 260.6 | 155.9 | 416.5 | 167.0 | 583.5 | 641 | 95.1% |
| 2020 | 216.2 | 145.1 | 361.3 | 126.4 | 487.7 | 582 | 83.8% |

*Australian (Aus) fishery sectors are Traditional Inhabitant Boat (TIB) and Transferable Vessel Holder (TVH) sector, and third sector is Papua New Guinea (PNG).*

whereas there were minor differences only between alternative standardized series (Deng et al., 2020b,c). Two of the GLM variants that accounted for "year-by-month" effects indicated large deviations in monthly fishing patterns in the 2019–2020 fishing season, in particular for March, April, and May.

For the TIB sector, the 2020 nominal and standardized CPUE index point estimate is the highest since 2004 (Deng et al., 2020b), noting that no data were available for 2013. For the TVH sector, the 2020 CPUE index is also higher than average, although similar to the 2013 point estimate (Deng et al., 2020c). A higher than average CPUE was anticipated given the lobster stock was predicted from the survey and stock assessment to be at a high abundance level. For the TIB sector, the extremely high CPUE for the month of February and overall higher than average CPUE for all months (**Figure 4**) may be partly attributable to the change in lobster spatial distribution (more lobster along the western side) relative to the previous few years. It is also plausible that the delay in the start of intensive fishing had a positive influence on the CPUE because the lobsters had more time to grow larger (noting their rapid growth rate) during the "break" from fishing and may also have aggregated during this time. If so, there is potential for a positive bias (relative to previous years) that is not accounted for in the GLMs. It would be difficult to account for this in the GLM also because we would need an understanding of the underlying factors driving the catch rates (if not abundance).

The CPUE indices provide an index of the 2+ lobsters, which are not reliably counted during the Fishery-independent survey because most will have migrated out the survey area by this time of year. The two standardized indices can be compared to see whether they show similar trends in overall biomass, and this can also be compared with the model-estimated trend in the biomass of 2+ lobsters [in this case from 2019 stock assessment (Plagányi et al., 2020b)]. These three indices have been normalized by dividing by their mean value and the two CPUE indices show similar trends, plus are also consistent with the stock assessment model projections from the previous year (**Supplementary Figure 1**).

## eHCR and Final Management Advice

In the case of total catch, the eHCR uses the average catch over the past 5 years as a multiplier to inform the RBC. This dampens the influence of the most recent catch value, but if the recent value is negatively biased (as is a possibility in this case), then it can have a reasonably substantial effect on the calculation of the RBC. In the absence of COVID-19, it was predicted that the total catch would be close to the TAC, hence the total average catch was considered to be slightly negatively biased. On the other hand, it was acknowledged that the TIB CPUE data could be considered positively biased. All stakeholders at the TRLRAG management meeting agreed that the 2019–2020 season was an anomalous year and that COVID-19 indirectly impacted the eHCR indicators in different ways (TRLRAG, 2020). The management forum considered a range of alternative scenarios and sensitivity tests pertaining to implementation of the eHCR, before deciding whether to recommend the default implementation of the eHCR, or to undertake an *ad hoc* adjustment.

As there was insufficient information to fully quantify the impacts of COVID-19 on the fishery-dependent data, the TRLRAG felt they could not reasonably justify stepping outside the bounds of the agreed harvest strategy and hence there was agreement to accept the default application of the eHCR without any *ad hoc* adjustments. The global TAC for the Torres Strait Protected Zone (TSPZ) for the 2020–2021 season was thus of 623.5 tons, which is only slightly lower than the long-term average (**Figure 5**).

The influences of COVID-19 on the fishery-dependent data highlighted the valuable role that fishery-independent surveys play in terms of providing reliable information to ensure sustainable management. Ongoing work is focused on improving understanding of potential improvements to the standardization of CPUE data, and in particular, how to account for inter-sector interactions.

## Supply Chain Resilience

The TRL fishery is exploited by both non-Indigenous and Indigenous Islanders, for whom it has cultural significance (Plagányi et al., 2013; Van Putten et al., 2013). TRL are passed down the supply chain either as live lobsters, which are mostly exported to China or frozen tails that are exported to the United States, predominantly *via* a holding facility in Cairns (**Figure 2**). Future analyses could be extended to include more complex aspects of the associated cross-jurisdictional regulations and management with PNG, as well as the closely-related East Coast tropical lobster fishery (**Figure 1**).

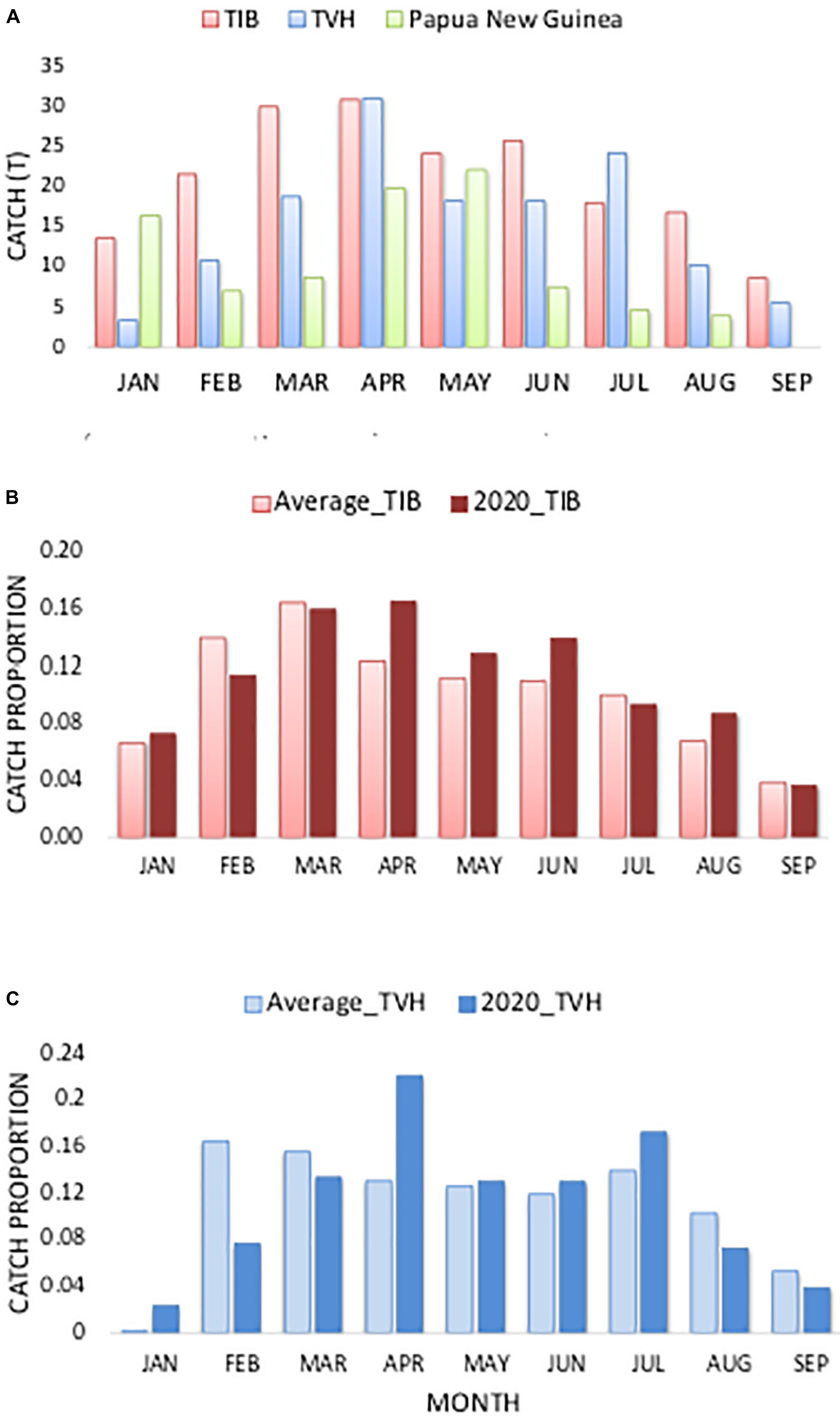


**FIGURE 3 |** Comparison of the relative proportion of fishing by **(A)** all sectors compared and **(B)** TIB sector and **(C)** TVH sector for months as indicated compared with the average pattern (average over 2004–2019). Data for Papua New Guinea (PNG) available until end of September only.

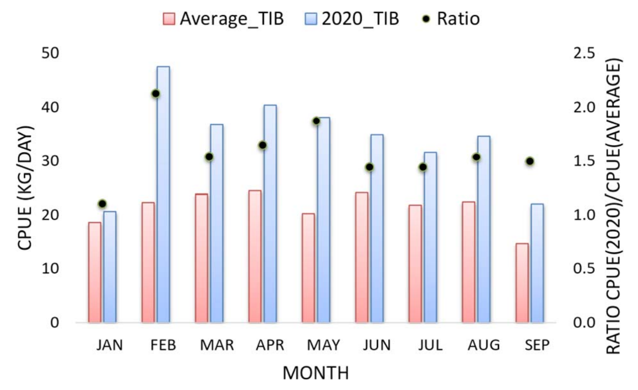


**FIGURE 4 |** Comparison of nominal 2020 monthly CPUE for the TIB sector with the average computed over the preceding period 2004–2019. The second vertical axis shows the ratio of the 2020 monthly CPUE relative to the average pattern to highlight the anomalous pattern observed at the start of 2020.

Over the past decade, live lobsters from PNG and the related East Coast tropical lobster fishery are also predominantly channeled *via* facilities in Cairns (Plagányi et al., 2017). In addition, there has been an increase in alternative TRL processors, which is not represented in **Figure 2**.

Under Scenario (A), the Resilience Score was 0.92 and the SCI identified the Chinese and United States markets as key elements (**Table 2**). However, under Scenario (B) which more closely reflects the pre-COVID-19 supply chain, the Resilience Score is reduced to 0.89 and the criticality of United States markets declines and is replaced by air freight being identified as a critical element. This suggests that the key mechanism for stabilizing this supply chain is to reduce uncertainty in supplying these markets. The supply chain analyses of Plagányi et al. (2014) therefore stressed that maintaining and strengthening relationships with international markets is key to underpinning the success of this supply chain. Since that time, and as illustrated by this analysis, the criticality of these elements has increased further and as they were the supply chain elements impacted by COVID-19, it is not surprising that the fishery took a huge knock.

One potential adaptation strategy that has been suggested is to increase the domestic market. Scenario (C) suggests that shifting one-quarter of product to the domestic market would increase the supply chain resilience to 0.93 (**Table 2**). The resilience of the supply chain can be strengthened further through even greater diversification of the supply chain—for example, if the domestic market absorbs half the product and the rest is split between frozen tail and live exports, then the resilience score increases to 0.94. Under optimized Scenario (D), domestic consumers are identified as the most critical node, followed by air freight handling and the Cairns processor (**Table 2**). Scenario (D) is the most diversified of the supply chain configurations analyzed and the high resilience score of 0.94 is further contrasted with an extreme streamlined scenario whereby only 5% of product is frozen and tailed, with corresponding resilience score of 0.87 (**Table 2**).

The distribution of key elements along the chain under alternative scenarios (**Figure 6**) is a useful way for highlighting the relative spread of risk across the nodes. For example, the relative distribution of SCI scores under Scenario (B) suggest a less resilient overall structure than the more evenly distributed pattern that is estimated under Scenario (D) (**Figure 6**). One important factor to consider is that the supply chain analyses have been considered as insular and independent of other changes in substitute products and products that compete on the local and international markets; and therefore future improvements in these analyses could incorporate the cross price elasticities of substitutes.

## DISCUSSION

COVID-19 exposed large differences in the resilience of different seafood systems as well as shedding light on broader inequalities across societies (Love et al., 2020). Different countries were affected by different levels and responses to COVID-19, whereas different industries fared differently depending on factors such as whether they relied on fresh or frozen produce, local or overseas export markets, as well as the diversity of networks connecting fishers to buyers and consumers. In remote fishing communities such as Torres Strait, the livelihood of many small businesses and communities depend on the TRL fishery. During the initial stages of the COVID19 pandemic, fishers were not able to work and for Indigenous Torres Strait Islanders, there were limited alternatives given their geographical setting. The effect was compounded due to their efforts over the past few years to maximize the value from their fishery by transitioning to exporting live product rather than relying on domestic markets. Torres Strait lobster fishers were not alone in absorbing the financial consequences of this risk, as much of the country's high-valued product is exported. For 2018–2019, it's estimated that lobsters, abalone, prawns and bêche-de-mer contributed nearly 60 per cent of the $2.1 billion total value of wild caught seafood.

Fortunately for TRL, the disruptions occurred for only a relatively short period early in the season and once fishing resumed, both the TIB CPUE and TVH CPUE indices suggested that fishers were able to make up some lost catches because catch rates were high. The 2020 fishery-independent survey was conducted successfully and hence the survey data were unaffected by COVID-19. The fishery-independent 1+ and 0+ survey indices that are used to inform on likely abundance in the following fishing season both exhibited positive trends. Although the 0+ index is less reliable, the positive trend provides an indication of what is to be expected in future seasons. The TRLRAG considered that the eHCR was reasonably robust to this single anomalous event. The eHCR captures longer-term trends over a 5-year period, it places substantially more weighting (80%) on the fishery-independent survey which is not affected by trade and other disruptions. Also, using a 5-year average (including average catch) helps to dampen the influence of a single anomalous year. However, using a 5-year average also means that the abnormal 2020 catch will have a dampening impact on TACs for the following years.

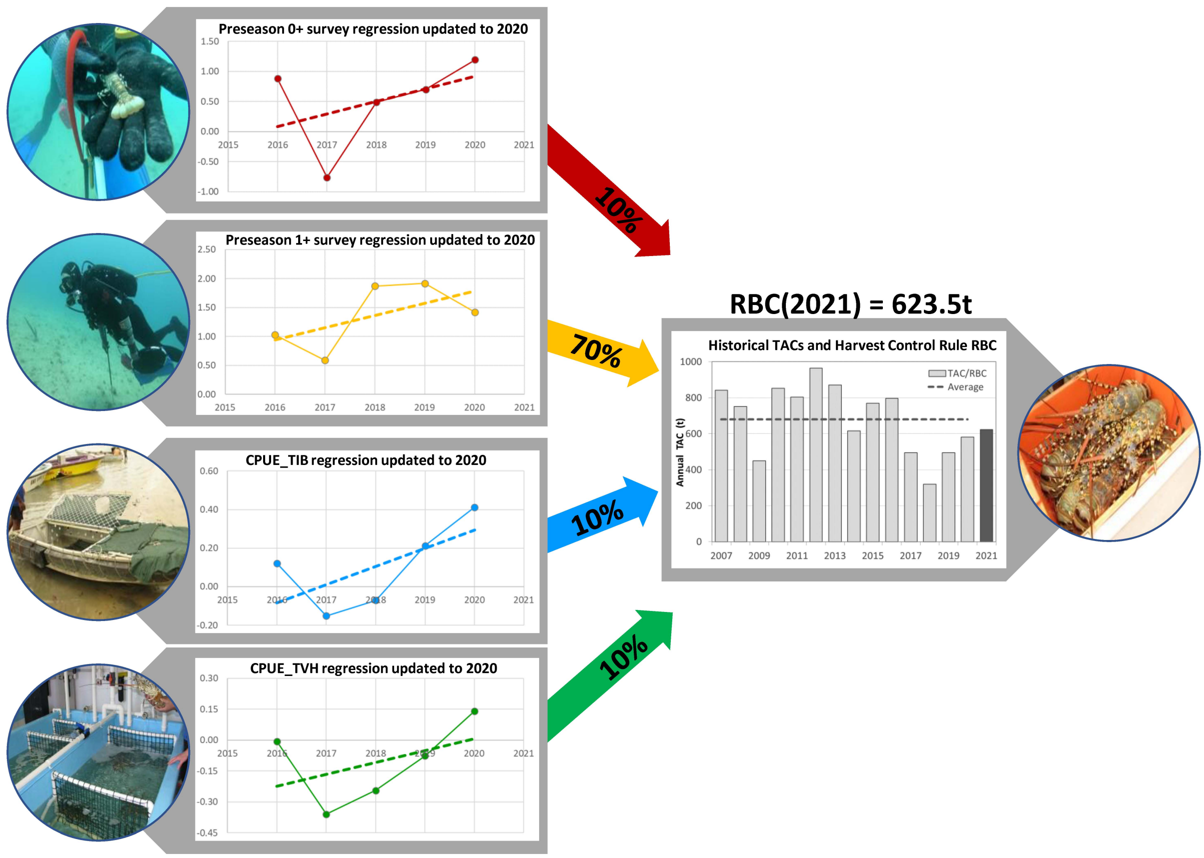


**FIGURE 5 |** Schematic summary of the empirical harvest control rule (eHCR) used to calculate the TRL (Tropical Rock Lobster) RBC (Recommended Biological Catch) based on the CPUE (Catch Per Unit Effort) data from two fishery sectors, the scientific survey indices of two age classes, and the total average catch over the past 5 years.

**TABLE 2 |** Examples of alternative supply chain scenarios showing the standardized SCI (Supply Chain Index) and Resilience Scores, together with the top three key elements identified using the method of Plagányi et al. (2014).

| Supply chain scenario | SCI (standardized) | Resilience score | Top 3 key elements | | |
|---|---|---|---|---|---|
| Base (2012) (frozen tails and live; few domestic) | 0.084 | 0.92 | Chinese importer | Chinese consumers | United States importer |
| Mostly live exports (14% tails, 5% domestic) | 0.112 | 0.89 | Chinese importer | Chinese consumers | Air freight |
| Increased domestic (25%) and similar tails and live | 0.067 | 0.93 | Air freight | Chinese importer | Chinese consumers |
| Optimized design with bigger domestic share | 0.059 | 0.94 | Australian consumers | Air freight | Cairns processor |
| Almost all live exports (5% tails, 5% domestic) | 0.129 | 0.87 | Chinese importer | Chinese consumers | Air freight |

Although there were some concerns around the representativeness of some data during 2020, the eHCR was applied without any *ad hoc* adjustments because it was designed to be robust to uncertainty and variability in inputs. However, it was also recognized that a more formal process was needed to support decision making should similar anomalous events occur in the future. It is recognized that it isn't possible to design a harvest control rule that accounts for all possible contingencies (Butterworth, 2008). This highlights the need for further development of pre-agreed "exceptional circumstances" rules to handle events that are outside the bounds considered in the testing phase, or that provide new information that underscores the need to review the original performance of the HCR (Hillary et al., 2016).

The full economic impact of the coronavirus on the Australian seafood industry will not be known for some time, as markets and exporters are attempting to adapt to the situation.

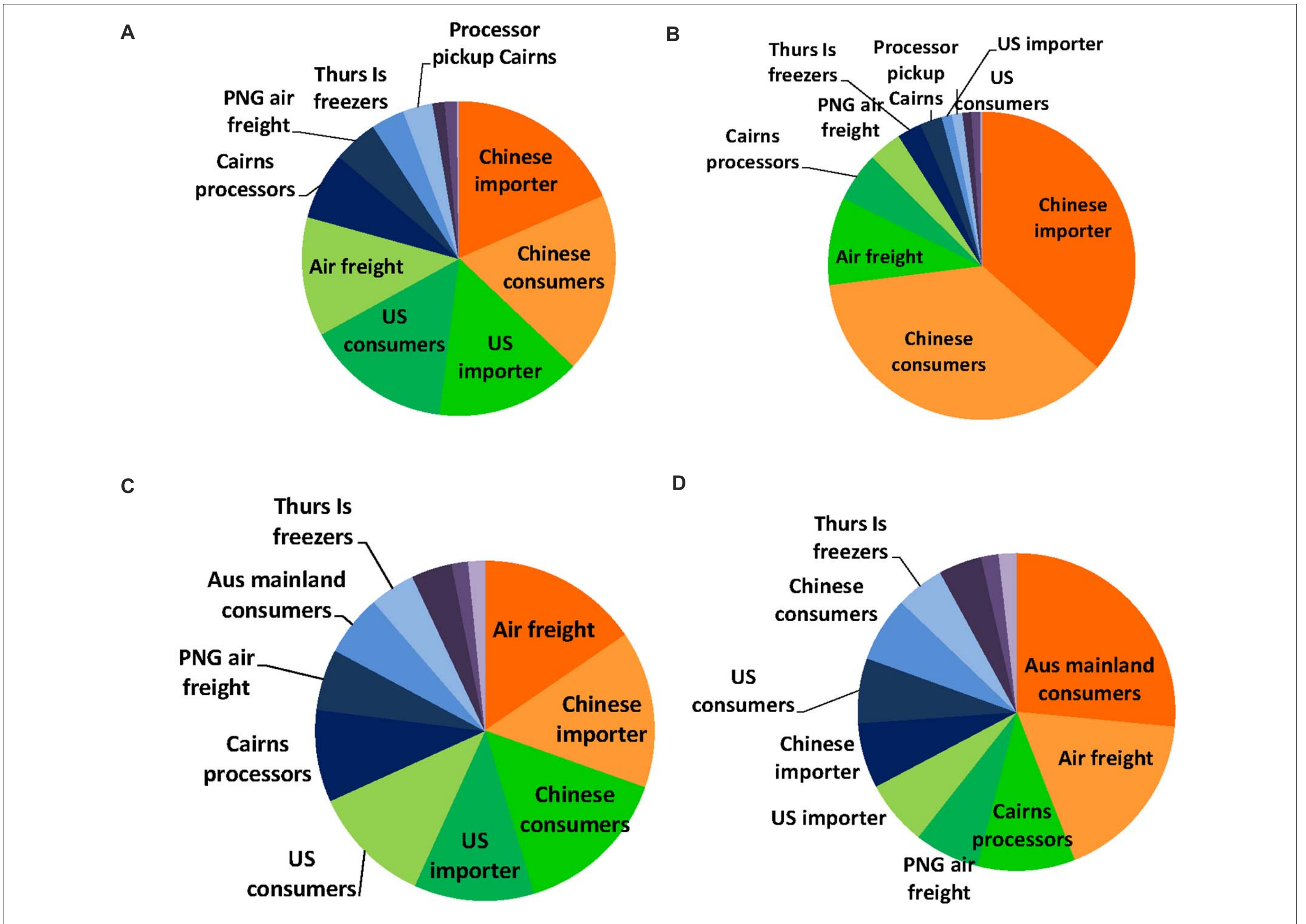


**FIGURE 6 |** Pie diagrams summarizing the criticality (based on individual Supply Chain Index score of each node) of elements in Tropical Rock Lobster supply chain scenarios: **(A)** 2012 base-scenario with substantial proportion of product sold as frozen tails, **(B)** 2019 scenario with very small proportions of tails and few domestic sales, **(C)** illustrative scenario with larger proportion of product sold on the domestic market, **(D)** optimized scenario with substantially more product going to domestic market and even split between frozen and live. The size of pie segments represents how critical a node is, and the overall distribution of segments provides an indication of the spread or evenness of the scores attached to different nodes. From highest to lowest scores, the color coding used is roughly red (>20%)-orange-green-blue-purple.

However, it is expected to be significant in terms of short-term revenue and employment.

For some fisheries that are regulated by a quota system, if they catch less this year, then it is possible they will be able to take slightly more next year without negatively affecting the resource. Depending on how management responds, they could partially (but not fully) offset economic losses longer term. This, however, will not be the case for the Torres Strait lobster fishery.

The Torres Strait lobster fishery is fairly unique in relying on short-lived, fast-growing lobster stocks, unlike many other lobster fisheries across the world which harvest the cold-water, long-lived, slower-growing species (Phillips, 2008). Catch and revenue each year depends on how many lobsters are available. This makes it different to fisheries that rely on longer-lived animals for which short-term declines in revenue and employment can be partially offset as fish not already landed may contribute to future yields once the current crisis subsides. For example, government in South Australia, Victoria and Tasmania are allowing uncaught Southern rock lobster and abalone (Victoria only) quotas in the 2019–2020 season to be rolled over to the 2020–2021 season. In Western Australia, the rock lobster fishing season was extended, and the TAC has been increased[2].

The economic market linkages and global connectedness of our trade systems may increasingly be subject to unforeseen social-ecological vulnerabilities (Adger et al., 2009) and transformative changes to develop more resilient supply chains (Lim-Camacho et al., 2017) may be needed to ensure ongoing sustainability of global production ecosystems (Nyström et al., 2019). Many small-scale fisheries lack the capacity to mitigate global market forces and more international solutions are needed, such as development of insurance opportunities by international financial institutions (Knight et al., 2020). There has been an increase in the appreciation of the need to adopt triple bottom line approaches to fisheries management (Plagányi et al., 2013;

[2]https://www.frdc.com.au/media-publications/fish/FISH-COVID19-Special-Issue-1/Management-moves-to-help-commercial-fishers

Dichmont et al., 2020) but much more work is needed to ensure that supply chains are adaptable enough to ensure that the outlets for seafood products are maintained in the future. This is vital not only for economic stability, but also the livelihood and mental health of fishers, their socio-cultural wellbeing, and food and nutrition security globally (Hicks et al., 2019).

Previous studies have identified the need to build resilience to changing climate as an increasingly important challenge to supply chains (Levermann, 2014; van Putten et al., 2016; Lim-Camacho et al., 2017). COVID-19 has confronted supply chains with similar disruptions to transport and markets as climate change is predicted to do, and hence we have applied the same method to analyze the connectivity of supply chains and to identify the key agents in these chains which may be fragile and hence in need of focused attention. Our analyses highlight the changes which can result from lessening the dependence on a single key element and strengthening or adding alternative complementary pathways and connections. We provide an example also of using the approach as a tool for supply chain design and redesign strategies. As with many other fisheries, economic rationalism has tended to favor a more streamlined, efficient and linear supply chain for lobster fisheries. Our analyses add to the growing recognition that market diversification is essential to fisheries sustainability (Plagányi et al., 2014; Lim-Camacho et al., 2017; Knight et al., 2020).

In the illustrative optimization scenario we developed (**Table 2**), we assumed that Australian mainland consumers would be able to absorb additional product (and pay a reasonable price), but in reality the resilience of any such redesigned supply chain strongly depends on the extent to which this assumption holds.

While transport costs would be significantly reduced, COVID-19 highlighted that increased supplies to the domestic market may also result in a substantial decrease in prices received. Additional contingency plans that were implemented during COVID-19 were to introduce mechanisms that helped increase efficiency in selling catches locally, International Freight Adjustment Mechanism, waiver boat license and quota fees, allow for alternative access options (i.e., permits for other fisheries) (see text footnote 2) and diversify product types that are more versatile in terms of "storability" [for example, converting fresh product to frozen tails (lobster) or canned product (abalone)], but there are significant costs to this adaptation strategy which also need to be considered. Fishery businesses should ideally pay more attention to supply chain risks and business continuity planning (Ogier et al., 2021). We recommend therefore that the SCI be used in combination with market demand (Hobday et al., 2014; Pascoe et al., 2021) and supply analysis and supplemented by qualitative assessment of each supply chain phase.

The pandemic brings to the forefront the fragility of the current economic market linkages and global connectedness of our trade systems. Some of our earlier research analyzed fishery supply chains and found that the key components of lobster supply chains that were most vulnerable to external shocks were the Chinese consumers, processors and airports (Plagányi et al., 2014). Our scientific scenarios have played out in real life and highlight the need for transformative changes to develop more resilient supply chains to ensure the ongoing sustainability and security of seafood and other natural resources production (Lim-Camacho et al., 2017).

## DATA AVAILABILITY STATEMENT

The data analyzed in this study are subject to the following licenses/restrictions: Data include details of fishing by Indigenous fishers and only available on request in an aggregated form. Requests to access these datasets should be directed to ÉP, eva.plaganyi-lloyd@csiro.au.

## AUTHOR CONTRIBUTIONS

ÉP conceived and wrote the manuscript, assisted also by SP, LB, and MT. ÉP and RD implemented the harvest strategy. ÉP did the supply chain analyses. NM, MT, SE, KS, and LD collected the field data. SP and TH collected economic information. ÉP, RD, SE, and NM analyzed the data. All authors contributed to the article and approved the submitted version.

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## SUPPLEMENTARY MATERIAL

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fmars.2021.686065/full#supplementary-material

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# Lockdown: How the COVID-19 Pandemic Affected the Fishing Activities in the Adriatic Sea (Central Mediterranean Sea)

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The coronavirus disease 2019 (COVID-19) has brought a global socio-economic crisis to almost all sectors including the fishery. To limit the infection, governments adopted several containment measures. In Italy, Croatia, and Slovenia, a lockdown period was imposed from March to May 2020, during which many activities, including restaurants had to close or limit their business. All of this caused a strong reduction in seafood requests and consequently, a decrease in fishing activities. The aim of this study is to investigate the effects of the COVID-19 in the Northern and Central Adriatic fleet, by comparing the fishing activities in three periods (before, during, and after the lockdown) of 2019 and 2020. The use of the Automatic Identification System (AIS) data allowed us to highlight the redistribution of the fishing grounds of the trawlers, mainly located near the coasts during the 2020 lockdown period, as well as a reduction of about 50% of fishing effort. This reduction resulted higher for the Chioggia trawlers (−80%) and, in terms of fishing effort decrease, the large bottom otter trawl was the fishing segment mainly affected by the COVID-19 event. Moreover, by analysing the landings of the Chioggia fleet and the Venice lagoon fleets, it was possible to point out a strong reduction both in landings and profits ranging from −30%, for the small-scale fishery operating at sea, to −85%, for the small bottom otter trawl.

**Keywords: pandemic, fishing activities, trawling, small-scale fishery, AIS data, Northern and Central Adriatic Sea, Mediterranean Sea**

## INTRODUCTION

The coronavirus disease 2019 (COVID-19) emerged in China in December 2019 (Wang et al., 2020). On January 30, 2020 the World Health Organization (WHO) declared the outbreak of COVID-19 a Public Health Emergency of International Concern (PHEIC), and on March 11, 2020 announced the global pandemic[1]. COVID-19 caused a huge number of severe infections and deaths all over the world and, up to now, it is still claiming victims. The other side of the coin was a global socio-economic crisis in almost all the sectors including fishery (Ahmad et al., 2020; Depellegrin et al., 2020; FAO, 2020; Fernandes, 2020; Laing, 2020). To limit

[1]https://www.who.int/emergencies/diseases/novel-coronavirus-2019/events-as-they-happen.

the infection, the European governments, among the first, adopted several containment measures. In Italy, a lockdown period was imposed from March 11, 2020 until May 17, 2020 (GU, 2020a,b), during which people had to stay at home, leaving the house only for necessary reasons, and many business activities, including restaurants had to close or limit their activities. In almost the same period Croatia (Jakovljević et al., 2020) and Slovenia (Dentes De Carvalho Gaspar et al., 2020) also adopted similar measures.

During the lockdown period, many people lost their jobs or were put in layoffs causing a general rethinking of food consumption, for instance with a strong reduction of the more expensive food, such as some kind of seafood (ILO, 2021). Consumers used to prefer not only cheaper products but also long-life ones (FAO, 2020). Indeed, the suggestion to limit the movement only for necessary activities as well as the fear of this not well-known and dangerous virus has made people to reduce shopping. Another issue was related to the travel ban to and from foreign countries, which caused a block of seafood exportation and total closure of the tourism sector (Dentes De Carvalho Gaspar et al., 2020). Moreover, to reduce the economic losses of the fishery sectors, the government has funded daily allowance for the fishers who did not work at all, and clearly, this opportunity made many fishers to stop their activities (Dentes De Carvalho Gaspar et al., 2020). All of this affected the fishery sector, and a strong reduction in seafood requests caused a decrease in the fishing activities and consequently also the related ones, such as fish markets and harbours. This was a worldwide situation, affecting countries, regions, and fishing segments in different ways (Dentes De Carvalho Gaspar et al., 2020; White et al., 2021).

The Northern and Central Adriatic Sea (GSA17), enclosed among Italy, Croatia, and Slovenia, is well-known to be an intensively exploited basin (Barausse et al., 2009; Pranovi et al., 2015; Fortibuoni et al., 2017; Russo et al., 2020) where a powerful fleet, composed of small-scale and industrial vessels, operates. For these reasons, this area and fleet represent an interesting case study to assess the COVID-19 effects on the fishery sector.

The importance to use vessel tracking tools, such as the Automatic Identification System (AIS), in the scientific field to monitor and assess the fishing activities, was already pointed out in previous works (e.g., Natale et al., 2015; de Souza et al., 2016; Vespe et al., 2016; Ferrà et al., 2018; Russo et al., 2020). The AIS system, introduced by the International Maritime Organisation (IMO) and designed for security purposes (e.g., navigational aid to avoid vessel collisions), provides vessel positions with high temporal frequency (from 2 seconds to few minutes) and information such as length overall (LOA), speed, and vessel name. Since the coverage of the AIS signals in the Adriatic Sea is very high (Russo et al., 2020), the use of AIS data for the assessment of the fishing activities and behaviours of fishers during this unexpected period turned out to be very useful.

The aim of this study was to assess the effects of the pandemic on the Adriatic fleet by comparing the fishing activities of 2019 and 2020, on a basis of different factors such as fishing effort, landings, and profits, as well as considering the before, during, and after lockdown periods. A focus on the Italian Northern Adriatic Sea was performed, and the fishing activities of the Chioggia fleet, considering both industrial and small-scale fisheries, as well as of the artisanal fleet operating in the Venice lagoon have been investigated.

# MATERIALS AND METHODS

## Study Area and Fishing Fleets

The main study area was the Northern and Central Adriatic Sea (FAO Major Fishing Area 37.2.1; FAO Geographical Sub-Area [GSA] 17), located in the Central Mediterranean Sea. Moreover, a focus on the fishing grounds of the Chioggia trawlers and the Venice lagoon was also performed (**Figure 1**).

For its high level of productivity, mainly due to the presence of river estuaries, the Northern and Central Adriatic Sea (GSA17) is recognised to be intensively exploited by multi-gear and multi-specific fisheries (Barausse et al., 2009; Pranovi et al., 2015; Fortibuoni et al., 2017; Russo et al., 2020).

The GSA17 fleet is composed of industrial and small-scale fishing segments, flying the flag of Italy, Croatia, and Slovenia. The industrial one can be classified in demersal gears, that are bottom otter trawls (OTB, classified in large [LOTB, LOA >18 m] and small [SOTB, LOA <18 m]) and *rapido* trawl (RAP), a kind of beam trawl typical of the Italian Adriatic fleet and characterised by a serrated rigid mouth used to catch mainly flatfish and pectinids (Pranovi et al., 2015), and pelagic gears, which are midwater pair trawl (PTM, typical of the Italian fleet and called also *volante*) and purse seines (PS). The Small-Scale Fishery (SSF) is characterised by fishing vessels with an LOA under 12 m and limited tonnage (Lleonart and Maynou, 2003) that use passive gears, namely as gillnets, longlines, and traps. The use of the different gears, targeting both demersal and pelagic species, is strongly dependent on the season (Lucchetti et al., 2020).

### GSA17

To assess the fishing activities in the GSA17 more than 450 trawlers (SOTB, LOTB, RAP, and PTM), composed of Italian (∼91%), Croatian (∼8%), and Slovenian (∼1%) vessels were considered.

### Chioggia

The Chioggia port is located on the Italian side of the Northern Adriatic Sea and specifically in the southern part of the Venice lagoon. Chioggia hosts one of the biggest Italian fishing fleets and one of the most important fish markets in the Adriatic Sea. The investigated fleet was composed of trawlers and SSF.

### Venice Lagoon

The Venice lagoon, a wide transitional system of about 550 km$^2$, is the largest in the Mediterranean Sea (Libralato et al., 2004; Facca et al., 2011). It hosts an artisanal fishing activity, with a long tradition, which mainly uses traps, gillnets, and fyke nets for targeting molluscs, crustaceans, and fishes, belonging to both resident and migratory species (Granzotto et al., 2001).

## Dataset

Different datasets, depending on the analysed fishing segments, were used for the analysis of the fishing activities.

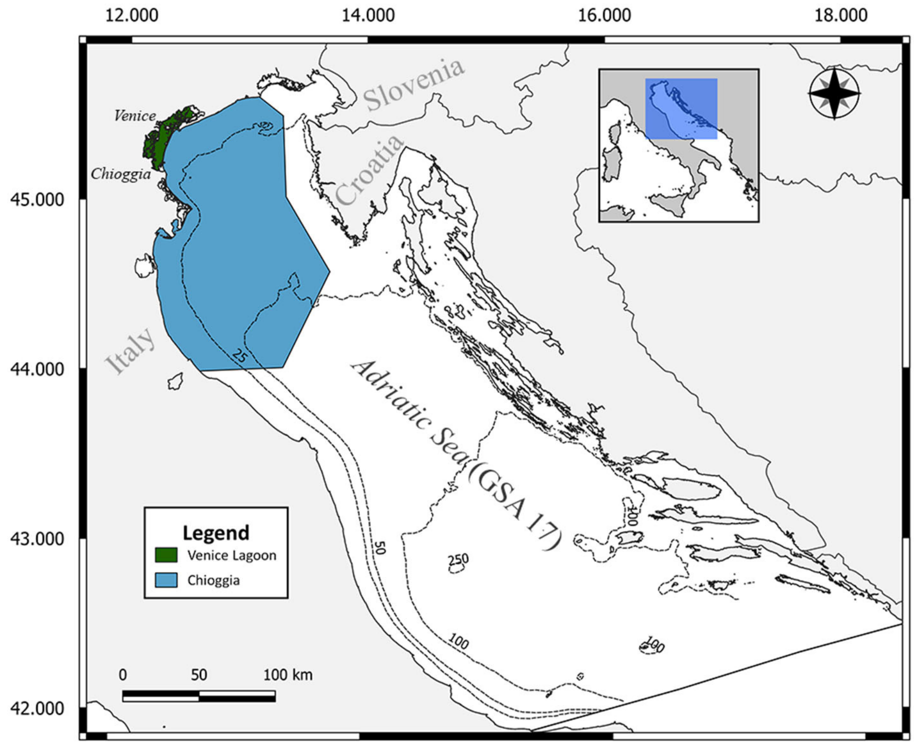


**FIGURE 1 |** Map of the investigated areas. The two-coloured polygons represent the fishing grounds of Chioggia (light blue) and Venice (green).

### Automatic Identification System Data in the GSA17

The terrestrial Automatic Information System (AIS) raw data of the first semester 2019 and 2020 were provided by the Italian Coast Guard (ITC and Traffic Monitoring Department—Rome) and consist of about 72 and 56 million positions released respectively in the first semester 2019 and 2020 by Italian, Croatian and Slovenian vessels. These data supply several information essential for the analysis and the spatialisation of the fishing activities. Dynamic information (e.g., ship positions, time, and speed) were used to discriminate the vessels activities (fishing, navigation, departure, or return in port) and reconstruct the trajectories, while static ones [i.e., Maritime Mobile Service Identity (MMSI), name of the ship and the International Radio Call Sign (IRCS)] were used for the identification of vessels. Technical information (e.g., LOA, primary gear, and secondary gear) was obtained from the European Fishing Fleet's Register[2]. Since, up today, the AIS system is mandatory for fishing vessels with a LOA over 15 m, the AIS data were used to investigate only the fishing activities of trawlers. In particular, they were used to estimate and spatialise the Fishing Effort (FE), that is a percentage of swept area (Russo et al., 2020), and extract the fishing days and the number of active vessels.

### Landings of Chioggia

Daily landings data were collected from the Chioggia Fish Market[3] and were referred to 83 target species caught by 73 trawlers and SSF. Furthermore, the monthly market price (euro/kg)[4] of each species was associated with the landing data to estimate the profit of the whole fleet of Chioggia.

### Landings of the Venice Lagoon

Monthly data reported by statistics from the main fishers' association in the Venice lagoon, namely landings, fishing days, number of vessels, and profit were used to analyze the SSF in the lagoon.

## Data Analysis

The AIS data were processed by using PostgreSQL[5], an open-source object-relational database, and its spatial extension PostGIS[6]. The analysis of the AIS data, relative to the trawling fleet of the GSA17, was performed following the procedure reported in Russo et al. (2020). Briefly, the dataset was cleaned by removing duplicate records and erroneous positions. Then, the trajectories of each fishing vessel were reconstructed by linearly interpolating the AIS data from the departure to the return port. A trajectory was therefore defined as a sequence of segments,

[2]https://webgate.ec.europa.eu/fleet-europa/index_en.

[3]www.clodia.it.

[4]http://www.sstchioggia.it/.

[5]http://www.postgresql.org.

[6]http://postgis.net.

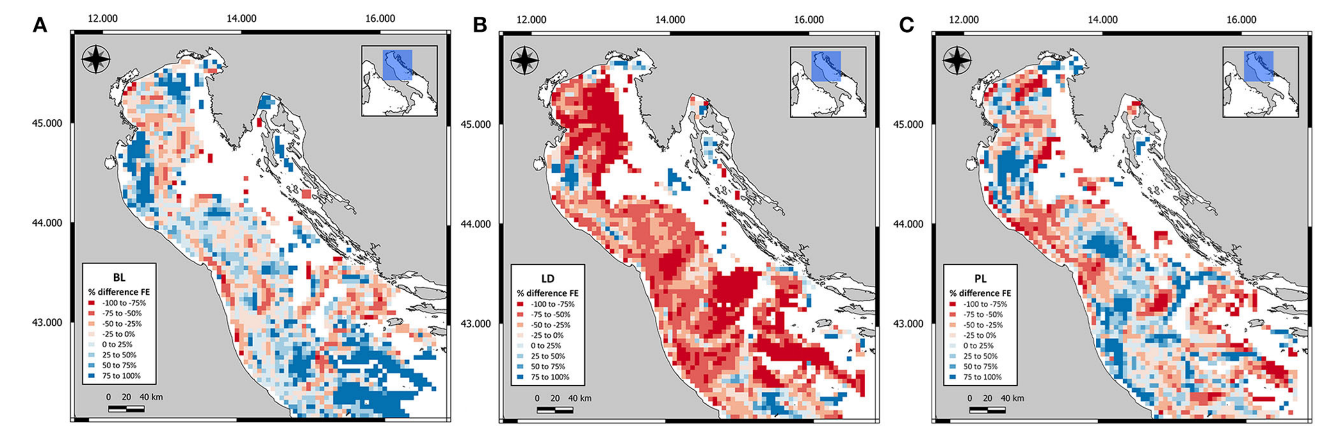


**FIGURE 2 |** Difference in terms of fishing effort distribution (%) between 2019 and 2020 for the trawling fleet of the GSA17, during the three periods [BL: before lockdown **(A)**, LD: lockdown **(B)**, and PL: post-lockdown **(C)**].

and each segment was associated with an activity performed by the vessel. We distinguished five activities: *in port*, *exiting from port*, *entering to port*, *fishing*, and *navigation*. The *in port*, *exiting from port,* and *entering to port* situations were deduced from the position of the extremes of the segment with respect to the port area. In case none of the previous situations occurred, the *fishing* or *navigation* activities were established based on the specific fishing speed range, previously defined for each fishing gear. To compute the fishing effort, the area under study was partitioned into a square grid of 1 km x 1 km cell size. The fishing effort for a cell during a fixed period of time was defined as the ratio between the area of the cell "swept" by vessels while fishing during the given time period and the total area of the cell itself. The swept area for a vessel in a cell was estimated as the product of the length of the fishing portion of the trajectory inside the cell, and the width of the net, fixed at 20 m for each gear. For computational reasons, the data for cells of 1 km × 1 km, pre-computed and stored in a data warehouse, were aggregated to 5 km × 5 km to compare the fishing effort between 2019 and 2020.

To assess the fishing activities before, during, and after the lockdown, three periods (Before Lockdown [BL]: from January 1th to March 10th; Lockdown [LD]: from March 11th to May 16th; Post-Lockdown [PL]: from May 7th to June 30th) were selected for the 2 years. The fishing effort, the number of active vessels, and the fishing days were extrapolated for each period.

The fishing segments of the trajectories of each trawler of Chioggia were annotated with the corresponding landings. Specifically, the daily landing data of the Chioggia fish market were associated with a trajectory of the vessel having the specified MMSI code. To accomplish this task, for each landing, we selected the vessel trip with the most recent arrival in the port (before 4 p.m. of the landing date). Arrivals after 4 p.m. were associated with the landing of the next day. The quantity of landings of each vessel was uniformly distributed along the corresponding fishing segments. Hence, for each trip, the quantity of landings associated with the fishing segment was proportional to the length of the segment itself (Adibi et al., 2020; Russo, 2020). As for the fishing effort, we summed up the landings according to the regular grid of 1 km × 1 km cell size. Also for the comparison of the landing, the cells of 1 km × 1 km were aggregated to 5 km × 5 km.

The spatialised fishing effort of the whole trawling fleet, and the landings of the Chioggia trawling fleet, relative to the three selected periods, were used for the comparison between 2019 and 2020. The percentage differences between the 2 years were calculated for each cell and mapped by using the open-source Geographic Information System QGIS[7]. Three maps, one for each period (BL, LD, and PL), were produced both for fishing effort (GSA17) and landings (Chioggia).

The percentage difference of the number of active vessels and the days at sea was calculated for all the fishing fleets (i.e., trawlers and SSF), while the percentage difference of the profits was calculated only for vessels from Chioggia and from the Venice lagoon, according to the following equation:

$$\% \ difference = \frac{2020 \ value - 2019 \ value}{2019 \ value} \ x \ 100$$

## Statistical Analysis

To test the significance of the obtained results, a statistical analysis was performed. First, data were tested for normality by using the Shapiro-Wilk W test. Even if the data resulted not normally distributed and considering that the robustness of a statistical test is influenced by the size of the data (Blair and Higgins, 1980; Ghasemi and Zahediasl, 2012), the two-sample Student's *t*-test was used, being the datasets formed by more than 300 values, for the landings, and more than 1,500 values for the fishing effort. The two tests were used for comparing the spatialised fishing activities, in terms of fishing effort and landings, recorded in 2019 and 2020. All analyses have been performed by using the free software R [8].

[7]https://www.qgis.org/en/site/.
[8]www.r-project.org.

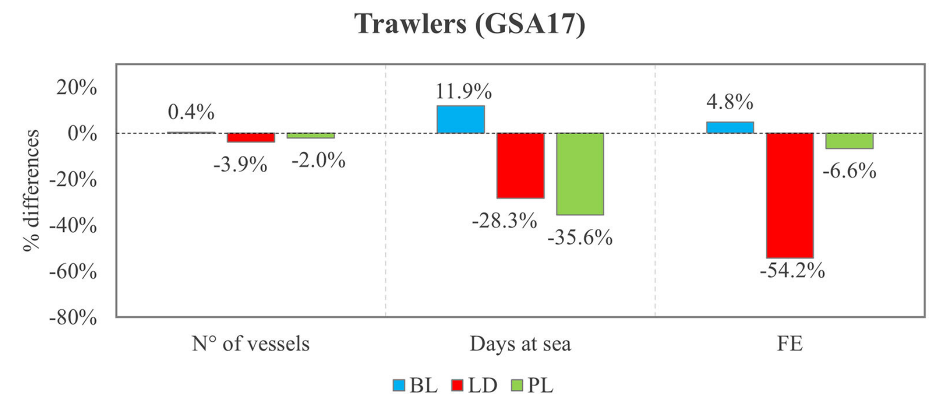


**FIGURE 3 |** Percentage differences between 2019 and 2020 during the three periods (BL: before lockdown, LD: lockdown, and PL: post-lockdown) considering the number of vessels, the days at sea and the fishing effort (FE) of the GSA17 trawling fleet.

## RESULTS

### GSA17

**Figure 2** shows the high-resolution maps (5 km × 5 km) of the Fishing Effort (FE) differences, expressed as a percentage on the annual basis, between 2019 and 2020, estimated for the periods before, during, and post lockdown (BL, LD, and PL, respectively).

In BL, the fishing activities distribution showed no significant variations, with a small increase of the FE (4.8%) in 2020, and a good overlapping of the exploited fishing grounds (**Figure 2A**). On the contrary, during the LD a reduction of more than 50% of the FE has been recorded (see also **Figure 3**), with a fishing grounds spatial distribution completely different (**Figure 2B**). Specifically, in 2020 the northernmost area, that is the fishing ground of the Chioggia fleet, as well as the central area and the Croatia fishing grounds, in the central-southeast area, resulted totally not exploited (red cells). On the contrary, small areas (blue cells), mainly located near the coasts, resulted exploited only in 2020. Finally, in PL the FE resulted quite similar in the two years (−6.6% in 2020; see also **Figure 3**) but in this case, some differences were highlighted in the fishing grounds distribution (**Figure 2C**). All this was confirmed by the statistical analysis showing no significant differences in terms of FE, between 2019 and 2020, for the BL and PL periods ($t$-test, $p$-value: BL=0.3313 and PL = 0.5249), while a statistically significant difference resulted in the comparison during the LD ($t$-test, $p$-value: LD = <2.2e − 16).

A reduction of −28% and −36% of the number of days at sea was recorded in 2020 in LD and PL, respectively, while it was positive (12%) in BL (**Figure 3**). On the contrary, no clear differences were observed in the number of active vessels.

The analysis at the fishing gear level confirmed the general pattern recorded for the whole trawling fleet, with the main reductions in terms of days at sea and fishing effort recorded in LD (**Table 1**). The *rapido* trawl (RAP) was the segment most affected in LD, with a reduction of about −10% of active vessels, −61% days at sea, and −67% of FE (**Table 1**). In PL, a recovery of the fishing activities was recorded for all the segments, and a positive trend was observed for the number of active vessels of LOTB (2%) and the days at sea of PTM (6%) (**Table 1**).

**TABLE 1 |** Percentage differences disaggregated per fishing gears (LOTB, SOTB, RAP, and PTM), between 2019 and 2020 during the three periods (BL: before lockdown, LD: lockdown, and PL: post-lockdown) considering the number of vessels, the days at sea, and the fishing effort (FE).

| N° of Vessels | BL | LD | PL |
|---|---|---|---|
| *LOTB* | 3% | -3% | 2% |
| *SOTB* | -1% | -5% | -10% |
| *RAP* | -7% | -10% | -3% |
| *PTM* | 1% | -1% | -2% |
| **Days at Sea** | **BL** | **LD** | **PL** |
| *LOTB* | 5% | -46% | 0% |
| *SOTB* | 7% | -43% | -7% |
| *RAP* | -8% | -61% | -17% |
| *PTM* | -1% | -47% | 6% |
| **Fishing Effort** | **BL** | **LD** | **PL** |
| *LOTB* | 8% | -52% | -6% |
| *SOTB* | 13% | -49% | -13% |
| *RAP* | -3% | -67% | -17% |
| *PTM* | -2% | -49% | -8% |

### Chioggia Trawling Fleet

The focus on the Chioggia trawling fleet highlighted a general negative balance for all the variables and for all the three periods (**Figure 4**). In the 2020 BL, during which there was a small reduction of the number of active trawlers (−7%), the main decrease was recorded for profits (−20%), even if in the presence of a small increase of the days at sea (4%). During the LD, the number of active vessels was reduced by −22%, and a strong decrease of all the indicators was observed (fishing effort −80%, profits −73%, and landing −48%). Then, as observed also for the whole GSA17 trawling fleet, a partial recovery of the fishing activities was observed after the lockdown (PL).

The comparison between the 2019 and 2020, in terms of the spatial distribution of landings, expressed as percentage

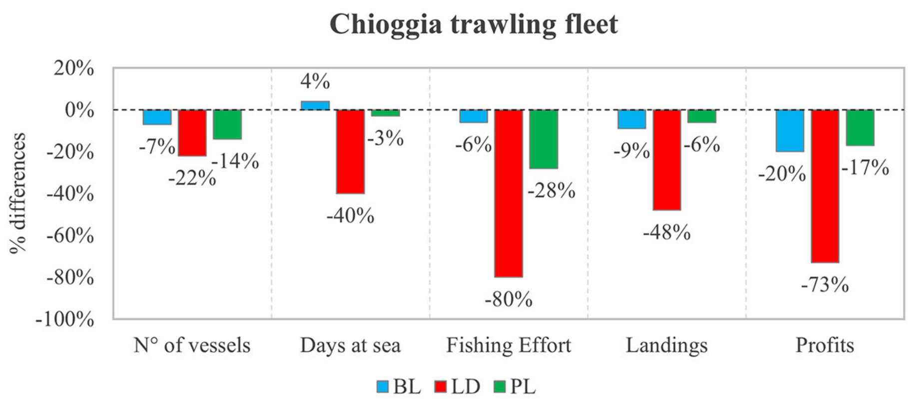


**FIGURE 4 |** Percentage differences between 2019 and 2020 during the three periods (BL: before lockdown, LD: lockdown, and PL: post-lockdown) considering the number of active vessels, the days at sea, the fishing effort (FE), landings, and profits of the Chioggia trawling fleet.

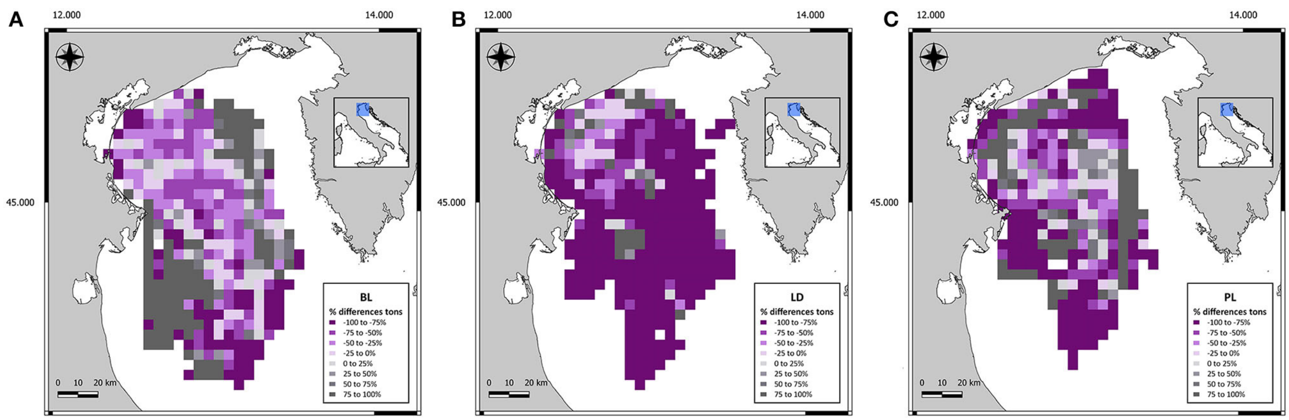


**FIGURE 5 |** Comparison of the quantity of landings recorded in 2019 and 2020 (expressed as percentage) during the three periods [BL: before lockdown **(A)**, LD: lockdown **(B)**, and PL: post-lockdown **(C)**].

difference of tonnes, showed significant differences in the LD ($p$ = <2.2e−16), with only a small portion of the area, close to the Veneto coast, where the landings distribution resulted similar in the 2 years (**Figure 5B**). On the contrary, in BL and PL, the spatial distribution of the landings resulted similar (**Figures 5A,C**), and no significant differences were observed (BL $p = 0.411$ and PL $p = 0.840$).

**Figure 6** shows FE, landings, and profits of Chioggia fleet disaggregated per fishing segments (LOTB, SOTB, RAP, and PTM). In BL, the fishing effort recorded in 2019 and 2020 was quite similar (**Figure 6A**), with the major difference recorded for SOTB (−17%). On the contrary, in LD the fishing effort recorded in 2020 was lower compared to 2019, ranging from −66% for PTM to −92% for LOTB. In PL, the fishing activities have started to recover and the reduction of fishing effort was about −30% for LOTB, SOTB, and RAP, while for PTM an increase of 1% was recorded.

Concerning the landings (**Figure 6B**), a general negative trend was observed for each fishing segment in 2020, except the PTM that showed almost no differences in the BL and PL period (5% and −2%, respectively). The major reduction, during all the periods, was observed for SOTB (−84% in LD), while the lower was observed for PTM (−36% in LD). A similar trend was observed for LOTB and RAP, recording a reduction in landings of about −20% in BL and PL and about −70% in LD.

In line with the landings pattern, profits of each fishing gear resulted always negative in 2020 compared with 2019 (**Figure 6C**), and, regardless of the period, SOTB was the segment showing the most negative balance. However, differently from the landing results, also the PTM profits showed negative values in 2020, in all the three periods. Also, in this case, LOTB and RAP showed a similar trend and a reduction in line with the one recorded for the landings.

## Small-Scale Fishery

### SSF–Chioggia

In 2020, the Small-Scale Fishery (SSF) showed an increase in the fishing activities, in terms of number of vessels (11%), days at sea (81%), landings (48%), and profits (38%), during the BL

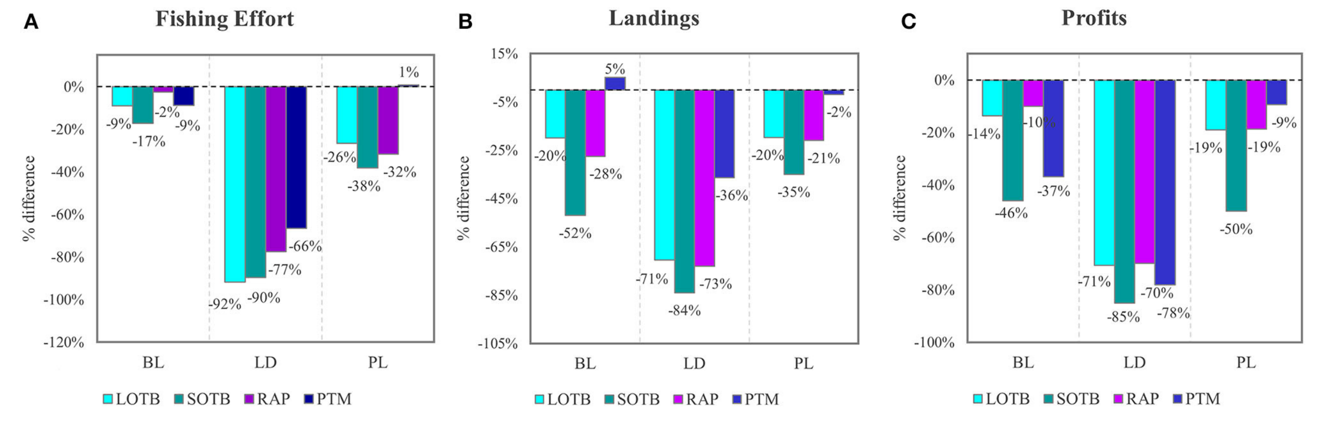


**FIGURE 6 |** Difference of fishing effort **(A)**, landings **(B)**, and profits **(C)** expressed as percentage (%), considering the three periods (BL: before lockdown, LD: lockdown, and PL: post-lockdown) and disaggregated per fishing segments (LOTB, SOTB, RAP, and PTM).

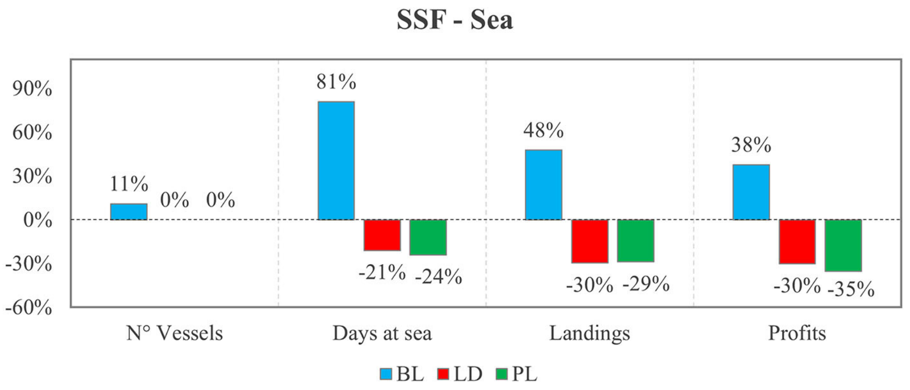


**FIGURE 7 |** Percentage differences between 2019 and 2020 during the three periods (BL: before lockdown, LD: lockdown, and PL: post-lockdown) considering the number of active vessels, the days at sea, landings, and profits of the Chioggia SSF fleet.

period. Differently, in LD and PL, a negative balance of about −20% for the number of days at sea and about −30% both for landings and profits, was recorded (**Figure 7**). However, while in LD, the same reduction was observed for landings and profits, in PL, the reduction of the latter was higher (PL: landings = −29%; profits = −35%). No difference was observed for the number of vessels.

### SSF–Venice Lagoon

The analysis performed on the SSF operating in the Venice lagoon showed a similar pattern to that operating at sea, with positive values recorded in BL and a negative trend both in LD and PL (**Figure 8**). Specifically, the number of vessels showed an increase in the BL period (21%) and a decrease in LD (−6%) and PL (−19%). The number of landings resulted stable in BL (1%) and markedly negative in LD (−59%) and PL (−76%). The same trend was observed for the profits in LD (−57%) and PL (−65%), while a considerable increase was recorded in BL (150%).

## DISCUSSIONS

The COVID-19 pandemic emergency was, and still represents, an unpredictable and never experienced condition that deeply changed all our consolidated behaviours, lifestyles, and social processes. It has caused a deep worldwide crisis, in several productive sectors, including the fishery. Even if the COVID-19 does not have direct effects on the fishery activities (FAO, 2020), since there were no restrictions for fishers, it has produced deep and long-lasting impacts on the fishery sector in many different ways. The closure of restaurants, due to the lockdown measures, on one side, and the financial and the economic crisis, combined with the preference to long-life foods by a large part of the population to reduce movements as much as possible, determined a strong decline of seafood requests. Both wholesale and retail fish markets remained unused and totally deserted for about 2 months.

In response to the demand decrease, the fishing activities strongly declined, with the reduction of the fishing effort, landings, and profits. The assessment of all these effects represents the first step for understanding a completely unknown

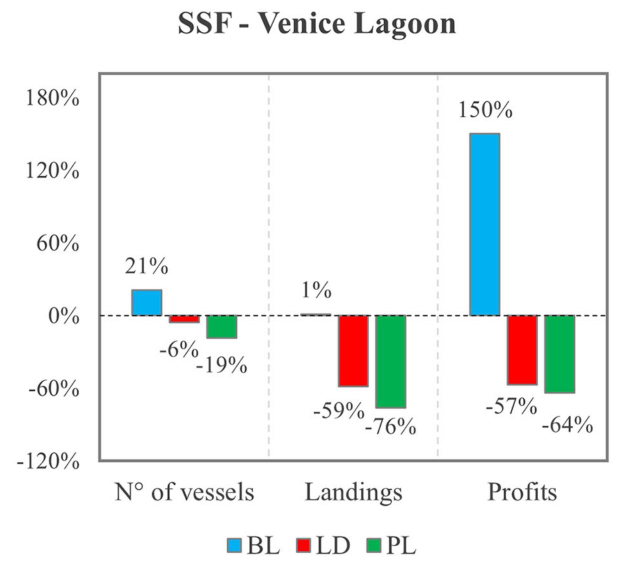


**FIGURE 8 |** Percentage differences between 2019 and 2020 during the three periods (BL: before lockdown, LD: lockdown, and PL: post-lockdown) considering the number of active vessels, landings, and profits of the Venice lagoon SSF fleet.

phenomenon, possibly identifying vulnerabilities and new strategies to cope with it.

In this study, the effects of the lockdown put in place by the national governments of the three countries overlooking the GSA17 (namely Italy, Slovenia, and Croatia) have been assessed by investigating different fishing segments, belonging to both industrial and artisanal fisheries, considering the period before, during, and post lockdown.

Generally, the before lockdown period analysis showed a slight increase of the trawling activities at the GSA17 level in 2020, reflecting in a higher number of active vessels, days at sea, and, more in general, of the fishing effort. Moreover, the high-resolution maps of the difference of the fishing effort between 2019 and 2020 highlighted a similar distribution of the fishing grounds in the period before the lockdown, confirming the already pointed out non-random behaviour of the fishers in the Northern and Central Adriatic Sea (Russo et al., 2020). Even the analysis of the data disaggregated per fishing gears highlighted the increase of the fishing activities for all the trawling segments, with the exclusion of the *rapido* trawl. On the contrary, data from the Chioggia port underlined, for all the fishing segments, a slight decrease of the fishing effort, with the SOTB showing a larger reduction (−17%). Moreover, a higher decrease, in terms of both landings and profits, has been detected, and in particular for SOTB, a reduction of about −52% of landings and −46% of profits was observed. This reduction was not totally explainable with the fishing effort reduction, suggesting the influence of other factors, such as the overexploitation of the resources, as suggested also by Russo et al. (2020), or a different spatial distribution of the target species area, may be related to environmental factors.

On the contrary, the small-scale fishery, operating both at sea, near Chioggia, and in the Venice lagoon, in the first period of 2020, showed a positive balance both in terms of landings and profits, in comparison with 2019. All of this could be related to a different spatial distribution of the target species and/or to higher prices due to the scarcity of the landings by trawling.

The situation completely changed in March, with the lockdown measures put in place by all the GSA17 countries. The fishing activities dramatically decreased (Depellegrin et al., 2020; Veneto Agricoltura, 2020), and the fishing effort of trawling vessels collapsed, on average, of about −50%, with a redistribution of the fishing grounds, being in 2020 mainly located near the coasts and in the proximity of the origin harbours. This behaviour could be due to the possibility to reduce time at sea, limiting the fuel consumption and the related costs. The reduction of the fishing activities was higher for the Chioggia trawling fleet, for which, as reported also by Depellegrin et al. (2020), a reduction of about 80% of fishing effort was recorded. The contraction of the fishing activities directly affected both landings (−48%) and profits (−73%). However, the fishing segments reacted in a different way to the lockdown, being the SOTB the most impacted in both landings and profits, whereas the PTM showed the lowest reduction, at least in terms of landings. Indeed, as reported also by STECF (2020), this fishing segment during the first period of the lockdown has suffered due to the fish market closure and the impossibility to export the product to foreign countries. But in April, the demand for small pelagic fishes, targeted by this gear, suddenly raised accompanied by a sharp decrease in the market price, producing a negative balance in profits (−78%).

Less critical was the situation of the small-scale fishery (SSF) operating at sea, recording a decrease of about 30% in landings and profits, probably because usually fishers of SSF used to sell seafood directly to consumers or local fish markets (STECF, 2020). For the SSF operating in the Venice lagoon, the reduction in landings reached 60%, which may be related to the fact that those fishers used to sell in the wholesale market (the same issue of the trawlers) and to the restaurants deeply affected by the crushing of tourism-related activities in Venice. Possible ecological effects of this could be assessed on a wider temporal scale. A good portion of the species targeted by SSF in the lagoon belongs to the marine migrant functional group, exploiting nursery habitats as juveniles, for trophic purposes, or during migrations between marine and freshwater habitats (Franzoi et al., 2010; Scapin et al., 2019), and so possible positive effects could be visible in the following seasons outside the lagoon environment itself.

The analysis of the fishery activities during the period immediately after the lockdown, from May 17th to June 30th offers the opportunity to analyse the recovery capability of each fishing segment, since in this period fish markets and restaurants gradually resumed their business.

The trawl fishery operating in the GSA17 showed a quick upturn, at least in terms of fishing effort, reflecting in a partial recovery of both landings and profits, even if the 2020/2019 comparison remained negative, for the Chioggia fleets. The small-scale fishery was revealed to be less resilient, and for this more vulnerable, with no recovery at all in the case of the lagoon activities, mostly related to the fact that the tourism in Venice showed no recovery in that period.

It is worth noting that even if the main differences highlighted in this study were related to the lockdown measures, however, other factors, both environmental and managerial, could also have contributed to this situation. Indeed, as highlighted for Chioggia, a reduction in fishing activities was also observed during the period before the lockdown, and therefore not related to the pandemic.

From an environmental perspective, the positive side of the lockdown was the reduction of the fishing pressure to the marine ecosystem, as 45% of the Northern and Central Adriatic Sea was intensively exploited (Russo et al., 2020). For instance, in the JRC report (Dentes De Carvalho Gaspar et al., 2020), it was highlighted how the Slovenia fishery has benefited from the reduction of the Italian and Croatian fishing activities. Indeed, an increase in the quantity of Slovenian landings in the period March–May 2020 was observed, as well as a rise in the seafood price, due to the possibility to sell seafood directly to customers. However, even if the near-term effects of the lockdown on the marine environment could be positive, there is an uncertainty of the long-term ones (Coll, 2020).

Further analyses would be required, monitoring both the stocks and the landings, for highlighting possible positive effects, for instance in terms of enhanced recruitment, due to increased reproductive outputs.

## CONCLUSIONS

In conclusion, this study analysed how an external factor, that is the COVID-19 pandemic, affected fishery in the Adriatic Sea, a very important sector that is at the base of several socio-economic businesses, and therefore needs to be well-managed to guarantee an effective support for fishers and also to protect the marine ecosystem. In this study, SSF was detected as the most vulnerable fishing sector, in relation to the short-term socio-economic effects induced by the lockdown. For instance, a modification of the fishing behaviour during the lockdown was detected, providing valuable evidence about the social aspects of this sector. Moreover, the possibility to use AIS data, coupled with landing data, provided essential information about the effects on the species caught and the relative revenues. However, future studies should also consider the long-term effects of the pandemic situation, which is still ongoing, both in terms of fish stock recovery and fishing sector decline.

The pandemic effects on the fishery have underlined the importance of the fish market and of the preferences of customers to determine the exploitation choices. Of course, this highlighted the need to act in different directions and levels to implement new fishing management strategies to reach a more sustainable fishery.

## DATA AVAILABILITY STATEMENT

The datasets presented in this article are not available because the raw AIS data are protected by confidentiality.

## AUTHOR CONTRIBUTIONS

FP and ER have developed the initial idea. ER and GT collected the data. ER and CS performed the analyses. ER, FP, and MAM interpreted the results. ER, FP, and AR wrote the first draft of the manuscript. All the authors have contributed to the manuscript revision and have read and approved the submitted version.

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# Rapid Assessment of the COVID-19 Impacts on the Galician (NW Spain) Seafood Sector

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This paper aims to develop a rapid assessment of the COVID-19 impact on the Galician (NW Spain) seafood sector, one of the most important maritime regions in the world. Here, we focus not only on the immediate COVID-19 impacts on the extractive fisheries sector, but also on the capacity of the aquaculture and the canned industries to supply seafood markets before and during the pandemic. We synthesize multiple data sources from across the seafood supply chain to show the relative initial responses and variables of recovery during a pre-COVID-19 period (2015–2019) and during the pandemic (2020). Our study shows that seafood sectors and trade were disrupted by abrupt shifts in demand, supply and limitations on the movement of people and goods, with a wide range of impacts and consequences for the seafood sectors. We find that domestic landings, Galician aquaculture production and imports and exports of seafood products (fresh, live and frozen) in 2020 showed an important decrease. In contrast, the canned production and the imports and exports of prepared and preserved seafood products followed an increasing trend during the COVID-19 pandemic. We record a change in the consumption behavior of the Galician population, which significantly increased expenditure in fresh and canned seafood products during the first confinement. Overall, the Galician seafood sectors were able to ensure the supply of seafood products to the population during the period of confinement decreed as a result of the COVID-19 crisis. Proximity to markets, investment in domestic or nearby supply chains and the development of new technological innovations helped to avoid food shortages and loss of livelihoods in Galicia. Fishers and fishing enterprises have also acted collectively to reassert their rights to provide essential and high quality seafood products to the Galician population, their livelihoods and safe working conditions, and have leveraged relationships and collaborations with their government counterparts to continue fishing.

**Keywords: Galicia (NW Spain), extractive fisheries, canning, aquaculture, crisis, confinement, pandemic**

# INTRODUCTION

The COVID-19 pandemic and resulting economic and financial crisis represent a global-scale disturbance that has impacted all economic sectors (Food and Agriculture Organization of the United Nations [FAO], 2020). Economic impacts may also differ across countries and industries due to previous capacities in terms of efficiency and resilience (Bennett et al., 2020; Love et al., 2021; White et al., 2021). Particularly, in the seafood industry, key activities such as the extractive fisheries, aquaculture and canned sectors have been disrupted or stopped by COVID-19 impacts. Seafood is among the most traded food commodities in the world (Food and Agriculture Organization of the United Nations [FAO], 2020), and the growth of seafood trade has resulted in a wide range of socioeconomic benefits, including employment opportunities and food security for coastal communities (Stoll et al., 2020). However, this growth also makes the seafood system highly vulnerable to social-ecological shocks that disrupt the flow of products and the livelihoods that depend on it (Cottrell et al., 2019; Stoll et al., 2020). Seafood trade has also been affected by the COVID-19 pandemic due to impacts on the supply or demand side, depending on the capacity of a territory to satisfy the domestic seafood consumption and, alternatively, to provide seafood products to foreign countries (Scientific, Technical and Economic Committee for Fisheries [STECF], 2020, 2021).

Recent studies dealing with the impacts of COVID-19 on fisheries have focused on several areas, including: the immediate effects on the fisheries and aquaculture sectors (Food and Agriculture Organization of the United Nations [FAO], 2021); effects on coastal communities (Bennett et al., 2020) and across tropical small-scale fishing (SSF) communities in Indonesia (Campbell et al., 2021); vulnerability of SSF markets (Knight et al., 2020); impacts on the US seafood sector (White et al., 2021); responses and lessons for building resilience in the seafood system (Love et al., 2021); impacts on commercial fisheries workers (Sorensen et al., 2020); the adaptive capacity of commercial fishers in the Northeast of the US (Smith et al., 2020) and the adaptation of Newfoundland and Labrador fisheries in Canada (Asante et al., 2021); the impacts on small-scale fishers in Bangladesh (Sunny et al., 2021); and the physical distance and risks of small-scale fishers in Ghana (Okyere et al., 2020). In the European Union (EU), research efforts have focused on marine fisheries in the Mediterranean Sea (Coll et al., 2021); UK fisheries (Kemp et al., 2020); and the economic effects on the fisheries (Scientific, Technical and Economic Committee for Fisheries [STECF], 2020) and aquaculture sectors (Scientific, Technical and Economic Committee for Fisheries [STECF], 2021).

Although these studies are necessary and important, none have focused entirely on the impacts of COVID-19 on the seafood supplier sectors. Therefore, this paper aims to develop a rapid assessment of the COVID-19 impact -namely on volume and value production, prices and seafood trade-, on the Galician seafood sector, one of the most important maritime regions in the world (including small-scale and industrial marine fisheries, shellfisheries, the aquaculture industry and the canned seafood industry). Here, we focus not only on the immediate impacts of COVID-19 on the extractive fisheries sector but also on the capacity of the aquaculture and canned industries to supply Galician and global seafood markets before and during the pandemic.

# STUDY AREA

The Galician coast (NW Spain) extends for approximately 1,295 km and has a highly varied morphology, with rías and inlets, cliff areas with beaches or marshes, and areas (Penas, 1986). From a biological point of view, the Galician rías are ecosystems with high primary production. The richness of Galician rías, which consist of old tectonic valleys occupied by the sea as a result of the high sea level during the last glaciations, is due to upwelling phenomena (Fraga and Margalef, 1979).

Galicia is such an important area for fishing because, for example, primary production can reach 250 g C/m$^2$/year in the Ría de Arousa, the most extensive estuary of the Rías Baixas (Varela et al., 1984), which is far higher than the average primary production observed in the Atlantic Ocean (100 g C/m$^2$/year) and is close to the estimated average for land ecosystems (Fraga and Margalef, 1979). The fisheries sector is a major contributor to the regional gross domestic product (GDP) (Galician Institute of Statistics [IGE], 2020; Pascual-Fernández et al., 2020). Galicia is also the main fishing region in Spain (Freire and García-Allut, 2000), and one of the most fishing dependent areas in the EU (Villasante et al., 2016). Galicia accounts for around 40% of Spain's fleet, approximately 60% of total Spanish employment in fishery-related sectors and 50% of catches reported by Spanish fishing vessels in EU waters (Scientific, Technical and Economic Committee for Fisheries [STECF], 2020; Xunta de Galicia, 2021).

# MATERIALS AND METHODS

## Media Reporting on COVID-19 and Galician Seafood

The impacts of COVID-19 on the Galician fisheries sector were studied by analyzing the frequency of the use of words in press articles about this topic. Thereby, the texts of all articles that included the keywords "covid," "fishing," "shellfishing," and "Galicia," from March 2020 to February 2021, were collected by using the open search engine *Google News*. Additionally, the same search was carried out without the keyword "covid" in order to compare the results. The text of the articles was pooled in a single file and the relative frequency of the words used in the articles was obtained by using the *termdocumentmatrix* tool included in the *tm* package (Feinerer and Hornik, 2014) of the R statistical software version 4.0.4 (R Development Core Team, 2020).

The frequencies of the most recurrent words (frequencies > 0.09% of the total) were plotted, after translation into English, using the *wordcloud* tool of the *wordcloud* package (Fellows, 2013) of the R statistical software R. Common stop words were before removed using the *stopwords* and *removeWords* tools of the *tm* package. While this information is not intended to represent a complete accounting of all press coverage in Galicia on the impacts of COVID-19 on the fisheries sector, it does represent a sample of the early impacts on the supply chain of fishery products (wild catch and aquaculture) from small-scale fisheries and industrial production.

## Official Seafood Production Statistics

In Galicia, the only official statistical data regarding fishery product landings in all fish markets are available at the Fishing Technological Platform *PescadeGalicia*,[1] which is developed by the Galician Regional Government. *PescadeGalicia* collects daily information about transactions for 294 commercial species traded in the 64 fish markets governed by the Galician Administration. This information is extracted from sales receipts issued by species and auction markets that are provided to the Platform by the owners of fresh fish and shellfish-selling markets. For each 6-year period available, landing data can be retrieved based on fish markets or traded species for the desired periodicity (weekly, monthly, or even daily).

Galician fish markets receive landings from both local fishing areas and those far away from the local coast. Although the Galician Autonomous Government has invested significant effort to improve the reliability of its fishery statistics in the last decade, the database does not provide complete information about the origin of landings (Rocha et al., 2004; Otero et al., 2005; Villasante et al., 2015) therefore we do not include this data in our analysis. Furthermore, data on discards and Illegal, Unreported and Unregulated (IUU) data are unavailable and not included.

For the canned industry, Anfaco-Cecopesca[2] provided data for Galician production by type of seafood products (fish and bivalves), while the Galician Regulatory Mussel Council[3] provided information on mussel production. In every case, we used data for all commercial landings from the previous 5-year period (2015–2019) to the year when COVID-19 restrictions began in Spain (2020).

## Official Seafood Trade

Seafood products (fresh and frozen landings, canned and aquaculture species) constitute an important market product in Galicia, where they are considered a top seafood attraction in first-class restaurants. To analyze the seafood supply, we used the Galician monthly seafood trade data (in volume and value) which come from the DataComex Database.[4] The dataset includes information about imports and exports (in volume and value) of fresh, frozen and canned fish, crustaceans and mollusk products by origin and destination (e.g., countries) from the previous 5-year period (2015–2019) to the year when COVID-19 restrictions began in Spain (2020).

## Household Expenditure on Seafood

We study seafood demand by analyzing official household food consumption data downloaded from the Spanish Ministry of Agriculture, Food and Environment's Food Consumption Panel[5] for the period 2015–2020. This panel provides data about household demand on food (including seafood) from the Spanish population. Monthly expenditure (in euros per inhabitant) on fresh, frozen and canned products (fish, mollusks and crustaceans) in Galicia was collected from this panel. Logarithmic transformation was performed to evaluate the monthly evolution and trend of expenditure (€ per capita) and price (€/kg) on fresh, canned and frozen products (including fish, mollusks and crustaceans).

# RESULTS

## Media Reporting on COVID-19 and Galician Seafood

In total, 214 press articles (109 with the keyword "covid" and 105 without) in 36 different media (print and digital newspapers) were collected from March 1, 2020 to February 15, 2021 (**Figure 1**). During the first 2 months (March to April 2020) 88.1 ± 8.81% of the press articles published on the Galician fishing sector were related to COVID-19. During the following 4 months (May to September 2020) this percentage decreased to an average of 55.6 ± 10.8%, and by October 2020 to February 2021, these press articles represented only 16.8 ± 9.8%. The number of covid-related press articles decreased progressively from March 2020 to February 2021, unrelated to the COVID-19 waves.

A notable proportion (2.8%) of the words used in Galician press articles about the fisheries sector and COVID-19 pandemic (109 articles) related to the impact of the pandemic on the markets and to economic grants for the sector (**Figure 2A**).

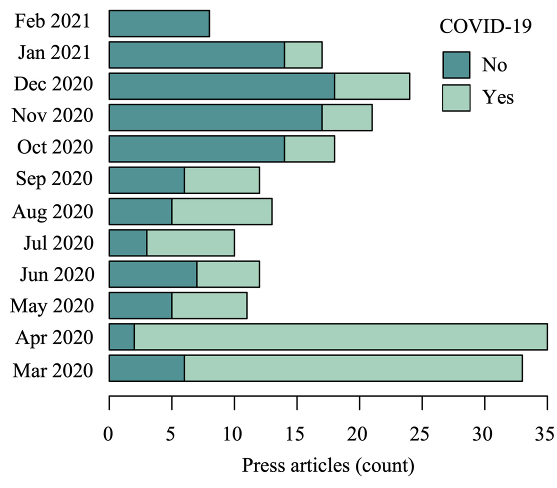


**FIGURE 1 |** Press news (count) about the Galician fisheries sector published with the keyword *covid* (light green) and without it (dark green) from March 1, 2020 to February 15, 2021.

[1] http://www.pescadegalicia.gal/
[2] http://www.anfaco.es/es/
[3] https://www.mexillondegalicia.org/?page_id=27
[4] https://comercio.serviciosmin.gob.es/Datacomex/
[5] https://www.mapa.gob.es/es/alimentacion/temas/consumo-tendencias/panel-de-consumo-alimentario/series-anuales/

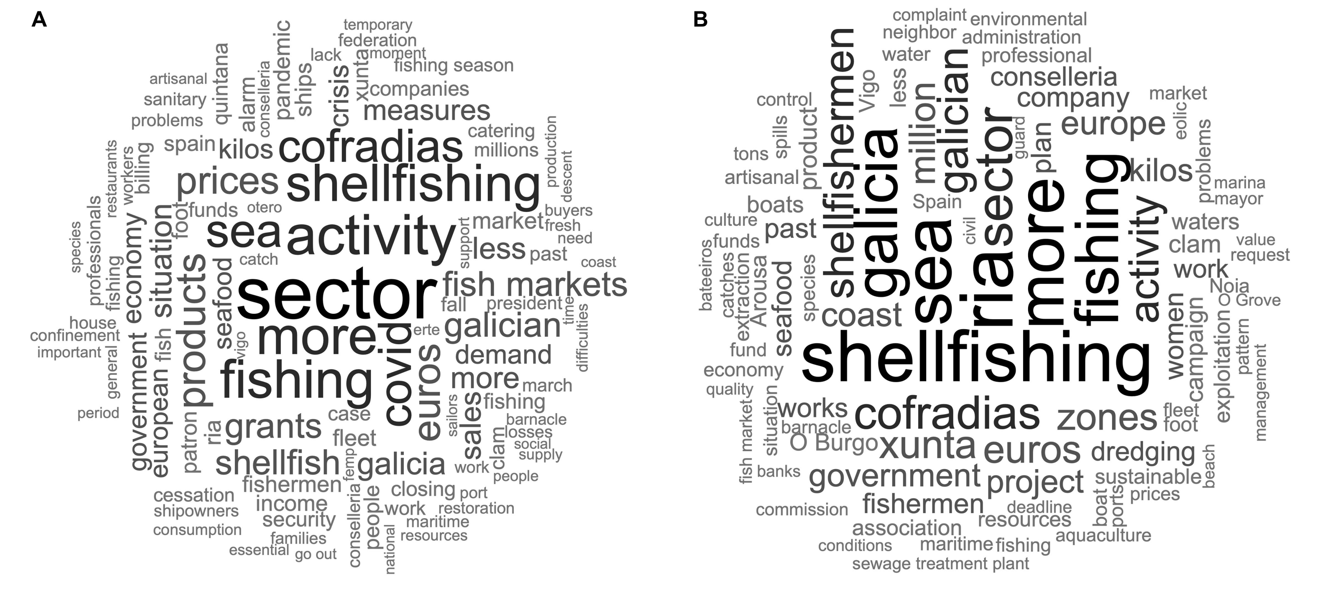


**FIGURE 2 |** Relative frequency of use of the words included in Galician press news about the fisheries sector, with the keyword *covid* **(A)** and without it **(B)**. Letter size refers to frequency; only the most frequent words (>0.09% of the total) were plotted.

Words in press articles, like "products," "euros," "prices," "grants" or "fish markets" (frequency > 0.5%), were all related to this. In contrast, articles (105) that did not mention COVID-19 mostly related to the dredging of shellfish beds, shellfishing management and European fisheries funds (**Figure 2B**). Words like "cofradías," "activity," "xunta," "euros," "zones," "million," "Europe," "government," "A Coruña," "plan," "dredging" or "consellería" (frequency > 0.2%), were all related to these topics.

## Domestic Landings

In 2020 more than 150,000 tons of seafood were sold in the Galician first sale markets, with an overall value of € 413 million (**Table 1**). Finfish were the group of species that in 2020 showed higher landings (138,006 t) and economic value (€ 303 M), followed by bivalves (6,481 t, € 67 M), cephalopods (3,185 t, € 18 M), crustaceans (1,210 t, € 19 M), echinoderms (723 t, € 6 M), seaweeds (432 t, € 0.3 M), and miscellanea (213 t, € 0.7 M), while sea worms sold as angling bait (4 t, € 0.2 M), and gastropods (2 t, € 0.02 M) were less important for the fisheries sector (**Table 1**).

Compared with the average of the previous 5 years (2015–2019), total landings in 2020 showed a relevant reduction, both in terms of volume (18%; **Figure 3A**), and economic value (14%; **Figure 3B**). Although gastropods showed the sharpest reduction in landings (62%) and commercial value (31%) their relatively low importance with respect to the total species traded in Galician first sale markets only implied a minor economic impact for the sector, of about € 8,000. On the contrary, despite the reduction in finfish sales being moderate (17 and 14% in volume and value, respectively), the economic impact exceeded € 50 million. The strong reductions in the sales of bivalves and cephalopods also caused important economic impacts, representing losses of € 12 million, and € 8 million, respectively.

The landings of seaweeds did not contract in 2020, and even experienced a moderate increase in economic value (15%). Notably, echinoderms also showed a steep increase in the value obtained from sales (27%), despite a reduction in their landings (8%). These increases in value contrasted sharply with landings of crustaceans where, despite a slight increase in landings (5%), fishers obtained lower economic benefits than in previous years (2%). The strong reduction in sales of sea worms is notable insofar as it reflects the significant reduction seen in the demand for fishing goods for recreational activities.

## Domestic Supply and Seafood Trade

Most of the research studies about COVID-19 impacts on fisheries mainly focused on specific variables such as catches, landings or revenues (Scientific, Technical and Economic Committee for Fisheries [STECF], 2020; Asante et al., 2021; Campbell et al., 2021; Coll et al., 2021). While these studies are important, it is also critical to consider early impacts and responses on the fisheries sector by analyzing the landings trends which are part of the local production. This is because a social-ecological crisis could also affect the capacity of the seafood sectors (fisheries, aquaculture and the canning industry) to cover seafood demand by imports and/or exports (White et al., 2021).

Regarding local production, our results show that Galician landings suffered a 17 and 14% reduction in volume and value, respectively. Overall, the impact of COVID-19 on shellfishers on foot caused low economic loss. This is because in general the regional government financially compensated this sector with public aid, which helped to maintain a similar level of income according to previous years. However, the shellfishers on boat suffered a complete economic loss in the following months after the first confinement. In some Galician rías, with the restart of the activity in May and June in 2020 the losses cannot be calibrated by

**TABLE 1 |** Annual landings in **(A)** volume (t), **(B)** sale value (M€), and **(C)** prices (€/kg) by main biological groups between 2015 and 2020 in Galicia.

| **A. Volume (t)** | | | | | | |
|---|---|---|---|---|---|---|
| **Taxa** | **2015** | **2016** | **2017** | **2018** | **2019** | **2020** |
| Bivalves | 7776.6 | 8054.1 | 9735.1 | 9522.1 | 9828.9 | 6481.3 |
| Cephalopods | 5067.4 | 7054.9 | 4539.0 | 4391.1 | 4175.8 | 3185.3 |
| Crustaceans | 980.4 | 1062.3 | 1237.5 | 1283.0 | 1203.8 | 1210.0 |
| Echinoderms | 640.6 | 742.6 | 910.5 | 790.7 | 831.7 | 722.8 |
| Fishes | 165148.7 | 170904.6 | 195611.8 | 157590.4 | 141419.8 | 138006.0 |
| Gastropods | 2.7 | 6.2 | 8.1 | 3.9 | 2.8 | 1.8 |
| Polychaetes | 4.6 | 4.8 | 4.6 | 5.0 | 5.5 | 3.6 |
| Seaweeds | 450.2 | 420.0 | 363.7 | 421.6 | 404.6 | 432.2 |
| Other | 392.7 | 353.9 | 374.2 | 290.5 | 294.4 | 213.2 |
| **Total** | **180463.9** | **188603.4** | **212784.5** | **174298.2** | **158167.3** | **150256.1** |
| **B. Value (M€)** | | | | | | |
| **Taxa** | **2015** | **2016** | **2017** | **2018** | **2019** | **2020** |
| Bivalves | 64.1 | 70.3 | 81.7 | 86.2 | 88.1 | 66.5 |
| Cephalopods | 19.0 | 29.7 | 24.6 | 28.8 | 25.9 | 17.6 |
| Crustaceans | 16.4 | 19.7 | 20.8 | 20.6 | 21.1 | 19.3 |
| Echinoderms | 2.5 | 3.7 | 4.8 | 4.7 | 6.0 | 5.5 |
| Fishes | 354.8 | 366.8 | 375.3 | 349.1 | 322.2 | 302.7 |
| Gastropods | 0.01 | 0.02 | 0.05 | 0.03 | 0.03 | 0.02 |
| Polychaetes | 0.3 | 0.3 | 0.3 | 0.3 | 0.3 | 0.2 |
| Seaweeds | 0.3 | 0.2 | 0.2 | 0.3 | 0.3 | 0.3 |
| Other | 0.9 | 0.9 | 1.0 | 1.0 | 0.9 | 0.7 |
| **Total** | **458.2** | **491.7** | **508.7** | **491.0** | **464.9** | **413.0** |
| **C. Prices (€/kg)** | | | | | | |
| **Taxa** | **2015** | **2016** | **2017** | **2018** | **2019** | **2020** |
| Bivalves | 7.6 | 8.3 | 8.4 | 8.0 | 8.1 | 8.9 |
| Cephalopods | 4.1 | 4.4 | 5.7 | 6.0 | 7.2 | 6.5 |
| Crustaceans | 17.1 | 15.6 | 17.4 | 15.1 | 16.8 | 15.4 |
| Echinoderms | 3.2 | 3.1 | 3.2 | 3.5 | 4.1 | 4.0 |
| Fishes | 3.9 | 4.1 | 4.5 | 4.4 | 4.4 | 4.0 |
| Gastropods | 6.6 | 6.0 | 5.7 | 5.5 | 5.7 | 6.8 |
| Polychaetes | 36.5 | 38.5 | 42.2 | 40.8 | 46.1 | 45.9 |
| Seaweeds | 0.7 | 0.6 | 0.7 | 0.9 | 0.9 | 0.7 |
| Other | 2.8 | 3.3 | 3.9 | 4.7 | 4.5 | 4.4 |
| **Average** | **9.2** | **9.3** | **10.2** | **9.9** | **10.8** | **10.7** |

the presence of toxin, which prevented shellfishing for many days. The SSF sector (namely harvesting hake, horse mackerel, octopus, sardine) also suffered a reduction in landings due to a drop in prices, being unable to sell their products at auction markets, loss of traditional clients (schools, hospitals, HORECA), and a lack of demand from tourists and international clients.

The health of fishers was also affected after the first lockdown (March 2020) because they were scared about the virus, not only due to the lack of space on board to respect social distancing between crew members and the scarcity of sanitary material for fishers, but also because of the need to protect family members. This ultimately made it difficult to find crew for fishing vessels. One of the most important and valuable SSF in the EU, the Galician common octopus fishery, was synergistically affected by changing environmental conditions, overfishing and the COVID-19 pandemic. This combination of perturbations led to a reduction of 52% in landings (from 2,100 t in 2019 to 1,000 t in 2020) and 51% in value (from 16.1 million euros to 7.8 million euros in the same period) (Xunta de Galicia, 2021). Such drastic changes in landings can lead to disruptions of local and international seafood dynamics and coastal communities that, combined with abrupt shocks such as from COVID-19, can seriously impact SSF viability because of the effects of a decrease in productivity on enterprises' revenues and the rapid growth in uncertainty.

Our results also indicate that other seafood sectors apart from fisheries (e.g., the aquaculture and canning industries) have also been affected by COVID-19. Indeed, Galician aquaculture production decreased by 10.6 and 12.4% in volume and value, respectively, in comparison with the average production during the previous 5-year period (2015–2019) (**Figure 4**).

The aquaculture sector in Galicia is dominated by mussel production, which accounted for 95% of the total aquaculture in volume (255,513 t) and 53% in value (€ 111.8 million) in 2019 (Xunta de Galicia, 2021). Regarding mussel production, official data indicate a reduction of 8.9 and 9.7% in volume and value in the periods before (2015–2019) and during COVID-19 (2020) (Xunta de Galicia, 2021). The most direct effects for aquaculture companies have been the reduction in incomes due to the decrease in sales and prices, and the increase in operating costs, mainly feed. In the medium term, producers are also concerned about a potential drop in prices once the markets open and all producers market the accumulated stocks [Spanish Aquaculture Business Association [APROMAR], 2020].

Although the mussel sector made huge efforts to continue extracting mussels from rafts and developing the activity during the COVID-19 pandemic, it appears to be difficult to recover the level of production before the pandemic. Demand for fresh mussels certified by the Galician Protected Designation of Origin (PDO) has reduced due to lower demand from European markets (namely France and Italy) and the closure of traditional HORECA channels (restaurants and hotels). However, consumer demand for transformed and canned mussels continued to be stable after the first lockdown.

The COVID-19 pandemic was not the only factor which negatively affected mussel production in Galicia. The sector suffered, again, the occurrence of red tides in the Ría de Pontevedra, and partially in other rías (e.g., Ares-Betanzos, Muros-Noia), as a result of which the extraction of mussels was prohibited from April to June of 2020. The sector also suffered considerable delays in collecting sales payments, attributed to organizational difficulties that arose due to the state of alarm in the country (Galician Mussel Regulatory Council, 2021). Another factor which influenced the development of the Galician mussel market is that imports of mussels from Italy seem to have increased during the lockdown (Galician Mussel Regulatory Council, 2021).

Our results also show that the canned sector (mainly the large companies) has been able to positively adapt to the COVID-19 pandemic. Indeed, canned production increased 2.2% in volume

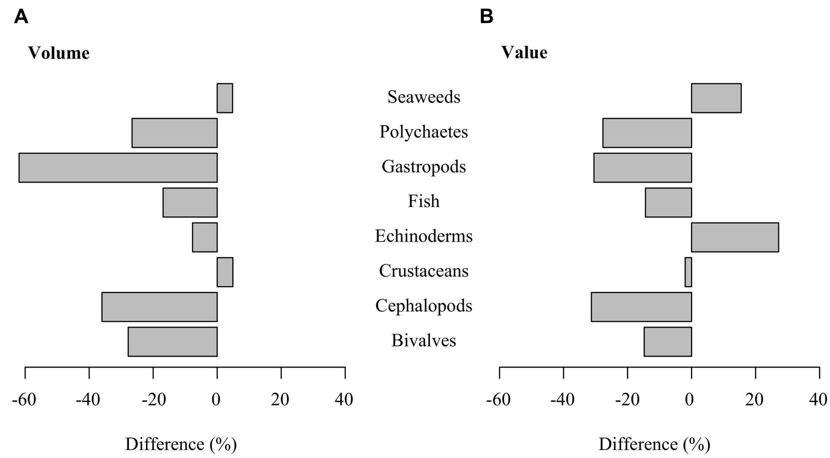


**FIGURE 3 |** Difference (%) in annual landings in **(A)** volume and **(B)** sales value by main biological groups between 2015 and 2019 vs. 2020 in Galicia.

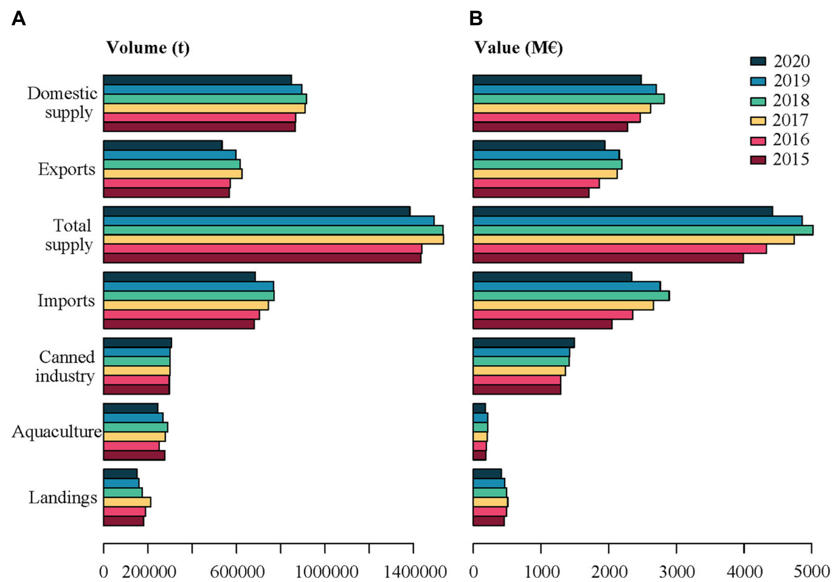


**FIGURE 4 |** Impacts of COVID-19 on the Galician seafood sector in **(A)** volume (t) and **(B)** value (M€).

and 9.8% in value in 2020 compared to the previous 5-year period due to the response of the Galician population to obtain a regular, safe and high quality of seafood (**Figure 4**). The characteristics of these products in terms of durability, ease of storage and versatility have favored their immediate collection at Galician households, which will imply a decrease in demand due to the accumulation of stocks in the near future. However, not all canned enterprises have positively adapted; small and medium enterprises suffered most, namely due to the drastic decrease of revenues because of their high exposure to HORECA channels.

Finally, imports of seafood have also decreased by 6.6% (volume) and 8.1% (value) during 2020 compared to pre-COVID-19 period, and exports suffered a 10.3% reduction (volume) and 3.4% (value), namely due to the initial shock of the lockdown in other traditional international seafood markets such as France, Italy or Portugal (**Figure 5**). However, these impacts have been mainly focused on fresh, live and frozen seafood trade flows, which show a reduction of imports (10% in volume and 11% in value) and exports (19% in volume and 16% in value). On the contrary, both prepared and preserved seafood follow a growing trend during the COVID-19 period, imports (9.7 and 6%) and exports (17 and 25.7%) have been significantly increased.

The evolution of the seafood trade flows before and during the COVID-19 pandemic also affected the Galician trade balance. During the 2015–2019, the Galician seafood trade deficit was growing progressively until the pandemic emerged. However, the COVID-19 caused positive impacts on the trade balance by reducing the deficit by 11.6% in volume and 34.4% in value, respectively (**Figure 5**). As a result of the aforementioned results,

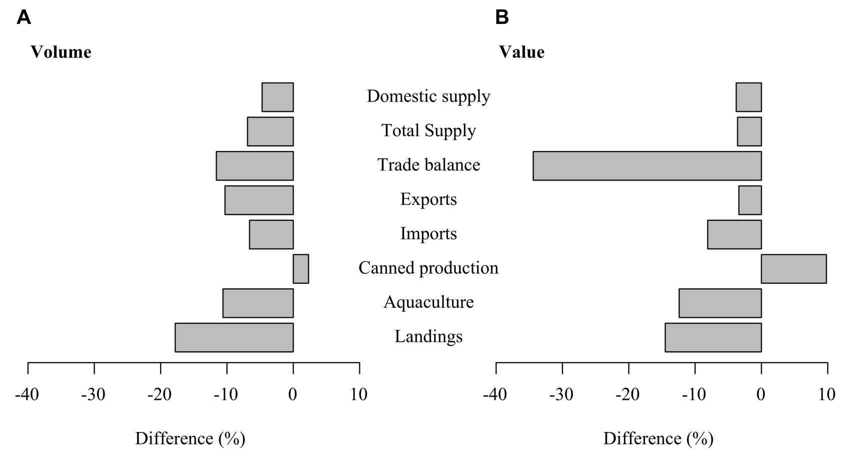


**FIGURE 5 |** Impact of COVID-19 on the Galician seafood sector in **(A)** volume and **(B)** value, the difference (in %) between 2015 and 2019 vs. 2020 is shown.

the domestic supply of seafood products in Galicia was not seriously impacted by the COVID-19 pandemic: 4.7% in volume and 3.8% in value.

## Households' Expenditure on Seafood

Interannual variation rate in March 2020 over the previous March months (2015–2019) showed steep negative anomalies of up to –25% in expenditure on frozen products and –24% in fresh seafood, evidencing the early impact of confinement (starting on March 15th) on the consumption of seafood in Galician households. In fact, spending on fresh and frozen seafood in March 2020 was on average 15 and 9% lower (respectively) than during the same month of the previous 4 years. However, canned products increased up to 47% in the same period (41% on average), being clearly the preferred means of preservation of food for situations of high uncertainty for the population (**Figure 6**).


**FIGURE 6 |** Expenditure (€ per capita in log) on **(A)** fresh, **(B)** canned, and **(C)** frozen products (includes fish, mollusks and crustaceans) in Galicia. Monthly evolution of expenditure (green) and trend (orange) were plotted.

Our results also indicate that expenditure on fresh and frozen products in Galician households experienced a notable increase immediately after the first weeks of the lockdown. Thus, in April 2020 the highest interannual increases of the analyzed period (4 years) were observed for frozen (increased by 80%) and fresh products (27%). Over the following months the expenditure of both frozen and fresh seafood tended to stabilize, and showed the traditional growth during Christmas (**Figure 6**).

Looking at evolution of prices (**Figure 7**), we found that prices of fresh seafood products suffered an anticipated reduction as it was already observed during the previous years before the COVID-19, mostly due to the closure of the HORECA channels. Prices of frozen seafood continued increasing during the whole year 2020, except in the first 2 months after the first confinement. In fact, the interannual variation rate of prices of frozen seafood in March 2020 over the previous 2 years was negative (up to –8%). Meanwhile, prices of canned seafood food did not experience significant changes over the whole of 2020 in relation to the previous years, except that prices did not grow during Christmas times as in previous years.

# DISCUSSION

The COVID-19 pandemic has highlighted the long-standing decouplings in the fisheries and seafood data availability and the need to have integrated diagnostics for rapid and effective policy (re)actions to deal with social-ecological crises (White et al., 2021). In this paper we analyzed the immediate impacts of the COVID-19 lockdown on seafood sectors in Galicia (including the fisheries, aquaculture and the canned seafood industries) with the aim of providing key insights that will be useful for policy makers when managing future social-ecological shocks or crises.

In Galicia there is a deep-rooted culture around the sea, with a profound integration of the fishing sector into Galician social norms and traditions, including the configuration of art, culture, gastronomy and language (Villasante et al., 2005). For this reason, news items about the Galician seafood sector are

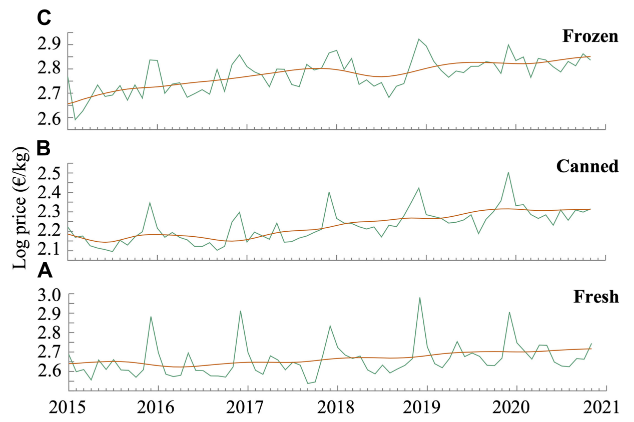


**FIGURE 7 |** Price (€/kg in log) on **(A)** fresh, **(B)** canned, and **(C)** frozen products (includes fish, mollusks and crustaceans) in Galicia. Monthly evolution of price (green) and trend (orange) were plotted.

relatively frequent in the Galician press. The notable proportion of press releases during the beginning of the pandemic related to the impact of the pandemic on markets and economic subsidies to the sector is a reflection of the concern about the consequences of COVID-19 on the sector. Our rapid assessment based on open-access media reports and datasets shows heterogeneous impacts of COVID-19 across the seafood sectors. Regarding production, overall landings and aquaculture in 2020 showed a 14 and 12% reduction of the economic value, respectively, compared with average production in the 5-year period (2015–2019) previous to the COVID-19 restrictions due to the closure of the HORECA channels. The volume of seafood imports and exports also suffered a 6 and 10% reduction (8 and 3% reduction in value) during this period. The decrease is comparable to the global financial crisis of 2007–2008, which resulted in an estimated 7% decline in seafood exports worldwide (Food and Agriculture Organization of the United Nations [FAO], 2010). On the contrary, the canning industry production increased by 10% probably due to the response of the Galician population to obtain a regular, safe and high quality of seafood during the pandemic.

The decline of tourism in the 2020 summer season did not help recovering seafood sectors, affecting them in different ways. For example, the small-scale fisheries sector (including shellfisheries) has been seriously affected due to the closure of the traditional HORECA channels and abrupt reduction of fresh supply of these actors. These results for the fisheries sector are also consistent with the findings of the COVID-19 impacts on the EU fisheries sector (Scientific, Technical and Economic Committee for Fisheries [STECF], 2020).

The small-scale fisheries sector rapidly adapted to the abrupt shock by selling their products to other intermediaries and clients (namely the canning industry) and also by requesting financial support from the administration to support the decrease of revenues after the first lockdown. The regional administration also adopted several logistical and organizational measures to contain and mitigate the COVID-19 impacts on the fisheries sector. For example, by regulating the mandatory use of masks, use of personal protective equipment, indicate signs in the selling points of seafood products at auction markets to avoid group meetings, and avoiding sharing work equipment and physical contact between the crew with less than 1.5 m on board in vessels or in the auction markets (Xunta de Galicia, 2020a,b).

Both in the fish markets, as in the supermarkets and the fishmongers, telephone and online sales have been progressively imposed, triggering home delivery, while direct sales have also been recovering over time. The retail commerce sector has made a great effort to promote online sales and home delivery to facilitate the consumption of fresh fish products. Regarding the industrial fisheries sector which mainly operates in EU waters, around 95% of the Spanish fishing fleet (mainly based in Galician ports) continued to fish, selling their products to Spanish markets, while the majority of the freezer fleets fishing outside EU waters continued to fish too (National Federation of Provincial Associations of Fish and Frozen Products Retail Businesses [FEDEPESCA], 2020). Regarding the Galician freezing fleet, one of the key problems was the replacement of the crews due to the difficulties and restrictions of air communications, which led the shipowners to request the extension of fishing trips for a few more weeks. Another drawback was the renewal of fishing licenses due to the lack of inspectors and administrative staff in third countries as a result of the restrictions imposed on them (Spanish Fishing Confederation [CEPESCA], 2020). The high innovation of the Galician fisheries sector contributed to ensure the seafood supply during the whole course of the year, extending its adaptive capacity to commercialize seafood through new online channels, both from the auction markets to the retail distribution.

On the other hand, several mussel farms could not manage to sell all their stocks, which impacted in the form of increased operating costs. Aquaculture farms and shellfish industries selling to processors and retailers managed to maintain their levels of activity, despite the decrease in prices. The mussel aquaculture industry in Galicia suffered the initial shock due to the lockdown. However, this situation has improved after the lockdown, namely because of the high demand for mussels from the canning industry (Scientific, Technical and Economic Committee for Fisheries [STECF], 2020). In general, the operation of fishers, shellfishers, fish markets and markets, wholesalers, transporters and retailers confirmed that there were no problems in the supply of seafood. In other words, the Galician seafood sectors were able to ensure the supply of fishery products to the population during the period of confinement decreed as a result of the COVID-19 crisis.

Our results are in line with recent studies which highlight that seafood sectors and trade were disrupted by abrupt shifts in demand, supply and limitations on the movement of people and goods (Love et al., 2021). Locally caught fresh fish decreased due to the lockdown of the fleets, but household consumption of frozen and canned fish continued to remain stable or increased (Love et al., 2021). Seafood companies trading with frozen and preserved products and with consolidated trade connections with retailers are better positioned to avoid contractions in production (Love et al., 2021). However, small and medium size enterprises may have to decrease their activity due to financial risks in a scenario of increasing costs.

Financial markets have also been severely shocked as a result of the effects of the reduction in productivity on companies' revenues and the increasing uncertainty. In a scenario of limited investments and credit (Nicola et al., 2020), solvency and liquidity appear as key factors for preventing further contractions in seafood supply causing continued losses for the companies and consumers over a more prolonged period. On March 13th, the European Commission approved the € 37 billion euro Coronavirus Response Investment Initiative (CRII) to provide small businesses and the health care sector with liquidity. On April 2nd, 2020 the European Commission launched the SURE initiative (European Commission [EC], 2020b), with a budget of €100 billion euro in the form of loans at favorable terms to support national public expenditure in developing schemes implemented for maintaining employment and workers' incomes. In particular, the initiative supports the fisheries and aquaculture sectors to overcome the financial challenges caused by the temporary cessation of fishing activities and suspension or reduction of post-harvest production activities (European Commission [EC], 2020a; Food and Agriculture Organization of the United Nations [FAO], 2020).

Knock-on economic effects from market disruptions have mostly impacted the ability of small-scale fishers and enterprises to pursue their livelihoods through reduced demand reduction and drop in prices. As already put in place in other European countries, more or less severe lockdowns and other mobility and social distance limiting measures have been adopted in Galicia in order to prevent virus transmission and ultimately contain the growth of the death toll. Such measures have been found to be highly effective in containing the COVID-19 pandemic, but at the cost of disruption to supply chains and temporary closure of businesses and industries, with a wide range of impacts and consequences for the seafood sectors (Nicola et al., 2020; Love et al., 2021).

However, there were also positive insights that are worth highlighting to learn from the COVID-19 pandemic. Where there was a high uncertainty regarding the ability to commercialize seafood products and difficulties in logistical transportation due to the measures to contain the spread of the virus, proximity to markets and investment in domestic or nearby supply chains (including markets and processing) helped to prevent food shortages and loss of livelihoods in Galicia. High collective action within and across seafood sectors and fishing communities has also manifested in several ways. New technological innovations such as the online commercialization of seafood have also been developed to ensure seafood supply through online systems in auction markets. Fishers and fishing enterprises have acted collectively to reassert their rights to provide essential and high quality seafood products to the Galician population, as well as their livelihoods and safe working conditions, and have leveraged relationships and collaborations with their government counterparts to continue fishing.

## DATA AVAILABILITY STATEMENT

Publicly available datasets were analyzed in this study. This data can be found here: https://www.mapa.gob.es/es/alimentacion/temas/consumo-tendencias/panel-de-consumo-alimentario/series-anuales/; www.pescadegalicia.gal; and https://comercio.serviciosmin.gob.es/Datacomex/.

## AUTHOR CONTRIBUTIONS

SV conceived the idea. All authors analyzed the data, wrote equally contributed to the article, and approved the submitted version.

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# First Assessment of the Impacts of the COVID-19 Pandemic on Global Marine Recreational Fisheries

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This work is the result of an international research effort to determine the main impacts of the COVID-19 pandemic on marine recreational fishing. Changes were assessed on (1) access to fishing, derived from lockdowns and other mobility restrictions; (2) ecosystems, because of alterations in fishing intensity and human presence; (3) the blue economy, derived from alterations in the investments and expenses of the fishers; and (4) society, in relation to variations in fishers' health and well-being. For this, a consultation with experts from 16 countries was carried out, as well as an international online survey aimed at recreational fishers, that included specific questions designed to capture fishers' heterogeneity in relation to behavior, skills and know-how, and vital involvement. Fishers' participation in the online survey (5,998 recreational fishers in 15 countries) was promoted through a marketing campaign. The sensitivity of the fishers' clustering procedure, based on the captured heterogeneity, was evaluated by SIMPER analysis and by generalized linear models. Results from the expert consultation highlighted a worldwide reduction in marine recreational fishing activity. Lower human-driven pressures are expected to generate some benefits for marine ecosystems. However, experts also identified high negative impacts on the blue economy, as well as on fisher health and well-being because of the loss of recreational fishing opportunities. Most (98%) of the fishers who participated in the online survey were identified as *advanced*, showing a much higher degree of commitment to recreational fishing than *basic* fishers (2%). *Advanced* fishers were, in general, more pessimistic about the impacts of COVID-19, reporting higher reductions in physical activity and fish consumption, as well as poorer quality of night rest, foul mood, and raised more concerns about their health status. Controlled and safe access to marine recreational fisheries during pandemics would provide benefits to the health and well-being of people and reduce negative socioeconomic impacts, especially for vulnerable social groups.

**Keywords: fishers' profiles, leisure activities, expert knowledge, fishery surveys, virus outbreak**

## INTRODUCTION

In late 2019, an outbreak caused by a novel coronavirus started in China (Graham and Baric, 2020; Hu et al., 2020; Maxmen, 2021). A global pandemic was declared in March 2020, as COVID-19, the disease caused by the coronavirus (World Health Organization, 2020b), escalated outside China (World Health Organization, 2020a). In mid-2021, when vaccination campaigns began to show positive effects on the control of the disease in several countries (Kaur and Gupta, 2020), the COVID-19 pandemic caused millions of deaths and hundreds of millions of infections (Dong et al., 2020).

To fight the pandemic, governments reacted with measures designed to contain the spread of the virus, especially through measures aimed to reduce social interactions, including lockdowns (Wilder-Smith and Freedman, 2020), travel restrictions (Chinazzi et al., 2020), and limiting people's access to non-essential activities (Storr et al., 2021). Humanity suffered a notable impact as a result of the pandemic, including losses of jobs and an abrupt disruption in global demand of goods and services (Barua, 2020; McKibbin and Fernando, 2020; Nicola et al., 2020). The pandemic further degraded the quality of life of the most vulnerable people, particularly those with mental health problems (Brooks et al., 2020), victims of domestic violence (Usher et al., 2020), children (Singh et al., 2020), or indigenous populations (Lane, 2020). As a result, an increase in economic inequality and worldwide poverty is expected, especially in developing countries (World Bank, 2020), and a peak in the suicide rate (Kawohl and Nordt, 2020).

On the other hand, global reduction of human activities has had some positive effects on the global environment, especially for air and water quality (Rutz et al., 2020), and noise reduction (Zambrano-Monserrate et al., 2020). Marine ecosystems for example experienced less impacts derived from commercial fishing due to disruptions in large markets such as the United States (White et al., 2021a) or the European Union (Prellezo and Carvahlo, 2020; Coll et al., 2021). In developing countries with large informal sectors, the lockdown and social distancing measures have especially impacted small-scale fishers and communities (FAO, 2020). Therefore, marine ecosystems are showing positive effects derived from the reduction of human impacts, e.g., in the occurrences of flora and fauna in coastal areas (Soto et al., 2021), or in reef fish abundances (Edward et al., 2021).

Increasing human pressure on global ecosystems is likely to lead to outbreaks of viruses that remained hidden until now, leading to new pandemics in the future (Wilkinson et al., 2018; Schmeller et al., 2020; Platto et al., 2021). It is therefore urgent to know the effects of the current COVID-19 pandemic on the different socio-ecological systems, and especially on those human activities that positively affect the health and well-being of people. The lessons derived from these studies will help policy makers to develop contingency plans and adaptive strategies to deal with similar crises in the future.

In this sense, the COVID-19 pandemic has also had significant effects on people's recreation, with undesired consequences. For instance, access restrictions to outdoor activities practiced in blue areas due to lockdowns in Europe (Belgium, France, Germany, Ireland, Italy, Portugal, Spain, and United Kingdom) and other regions (Australia, New Zealand, and United States) limited protection against the negative effects of the pandemic on people's health and well-being (Astell-Burt and Feng, 2021; Guzman et al., 2021; Pouso et al., 2021). Recreational fishing is one of the most common human activities in the world's blue areas (Cisneros-Montemayor and Sumaila, 2010; Arlinghaus et al., 2014; Hyder et al., 2018), and its practice is beneficial to fishers' health and well-being (Snyder, 2007; Griffiths et al., 2016; Young et al., 2016). Considering that the recreational sector has suffered major socioeconomic impacts during the COVID-19 pandemic (Roy et al., 2021), an assessment of the impacts of the pandemic on marine recreational fisheries was needed.

In this manuscript we assessed the overall impacts of the COVID-19 pandemic on marine recreational fisheries by a consultation with experts involved in marine recreational fisheries in different countries (mainly scientists, managers, and representatives of recreational fishers' organizations). In addition, we developed an international online survey of recreational fishers, with a focus on the perceived intensity of the impacts depending on different groups of fishers. Our hypothesis is that the greater the fishers' involvement in the fishery, the greater the negative perception of the socio-ecological impacts of the COVID-19 pandemic on marine recreational fisheries.

## MATERIALS AND METHODS

### Study Design

An expert consultation about impacts of COVID-19 on marine recreational fisheries was performed from May 2020 to March 2021. A semi-structured questionnaire was distributed between international experts in marine recreational fisheries (mostly scientists, marine resource and spatial managers, and representatives of recreational fishers' associations) integrated in the Spanish Working Group on Marine Recreational Fisheries (GT PMR), composed by approximately 60 members, and the International Council for the Exploration of the Sea (ICES) Working Group on Recreational Fisheries Surveys (WGRFS), composed by approximately 50 members from Australia, Europe, New Zealand, and North and South America. Semi-structured questionnaires ensure that experts provide information on key topics, and allow them to expand on items that are more relevant to them (Bryman, 2016).

Experts were asked to identify their country of residence and institutional affiliation, and to: (1) report changes in access to marine recreational fishing during the COVID-19 crisis, e.g., because of mandatory or voluntary lockdowns, and to explain any COVID-19-related restriction in place, their duration, and the areas and activities affected; (2) provide their perception on expected changes in marine ecosystems due to the COVID-19 crisis, e.g., resulting from changes in fishing activities or in other human impacts; (3) provide their perception on expected impacts on the economy, e.g., derived from the reduction in expenses and investments of recreational fishers, if any (including tourism); and (4) provide their perception on the expected impacts of lockdowns or new habits due to social distancing on the social life, well-being and public health. Experts were asked to score how certain they were about their perceptions on ecological, economic, and social changes, on a scale from "1," which meant very low confidence, to "5," which meant very high confidence.

In addition, an online survey was conducted between April 2020 and January 2021 to collect perceptions of fishers on the different impacts of COVID-19 on marine recreational fisheries. A self-administrated, structured questionnaire was made available online in seven different languages, i.e., Dutch, English, French, Greek, Italian, Portuguese, and Spanish (English version is available in the **Supplementary Information, Annex I**). The language and layout of the questionnaire and quantitative economic questions were adapted to different socio-cultural contexts and ongoing surveys already in place. Thus, there were different versions for Portugal and Brazil, and for Spain and Spanish-speaking countries of South America. The links to the different questionnaires were disseminated through social media and the web portals of the scientific institutions of coauthors involved in this study following a snowball-style sampling approach (Goodman, 1961), starting with a core group of initial collaborators involved in the GT PMR and the WGRFS, and expanding through their contacts and social networks. A 3-month marketing campaign in Google Ads was also put into force to increase the scope of the survey. A small team of collaborators of the GT PMR and the WGRFS was responsible for the design of the questionnaire, the verification of the consistency of the translation, the collection and storage of the information, and the dissemination of the links among the fishers in each country/region. All questionnaires used in the study were anonymous and no personal information was collected.

Information on the different socio-ecological impacts of the COVID-19 pandemic affecting marine recreational fishing was gathered in section "Introduction" of the questionnaire. To prevent temporal trends in the responses, recall periods were less than 3 months (Pollock et al., 1994). Thus, fishers' perceptions of ecological changes on marine ecosystems derived from variations in recreational and commercial fishing efforts on fish stocks because of the COVID-19 crisis were obtained first (question 1, **Supplementary Annex I**). Thereafter, social impacts derived from the COVID-19 crisis were assessed by analyzing the perceived degree of satisfaction of night sleep (Bobes et al., 2000) (question 2) and negative affect (question 3), which accounts for the affective state characterized by aversive emotional states driven by stress (Bolger et al., 1989). Also, we obtained information on consumption habits of fish (question 4), fresh fruits, and vegetables (question 5) to assess potential variations in nutritional value of fishers' diets (Öhrvik et al., 2012). Information of changes in employment (question 6), health (question 7), physical activity (question 8), and of expected changes in recreational fishing activity after the pandemic was also obtained (question 9). Finally, we assessed the overall economic impact derived from the loss of running costs during the lockdowns, excluding long-term investments such as annual insurance and licenses costs, or expenditures on boat maintenance and anchoring. We estimated this economic impact as the difference between the regular expenses incurred during the COVID-19 crisis (question 11), and the sum of the average monthly regular expenses incurred before the crisis (question 10), with investments not made because of the pandemic, e.g., during holidays (question 12).

Research on recreational fisheries must pay careful attention to human dimension aspects because recreational fishers exhibit an extraordinary diversity of behaviors and attitudes, which plays a fundamental role in understanding key socio-ecological dynamics, such as fishers' motivations for access (Fedler and Ditton, 1994), or the distribution of effort intensity and catches (Arlinghaus, 2006). Various approaches have been used to measure the heterogeneity of recreational fishers, and how different profiles of fishers show differences regarding preferences for, e.g., site (Salz and Loomis, 2005) or catch (Beardmore et al., 2011). Newcomers and infrequent recreational fishers tend to focus more on catches, while the more committed fishers value the fishing activity as a whole, tend to exhibit conservationist attitudes toward fish stocks, use increasingly sophisticated equipment and techniques, and show a growing dedication to the activity (Scott and Shafer, 2001).

In this study, we identified different profiles of recreational fishers through an assessment of their heterogeneity. Following Scott and Shafer (2001) we focused on three dimensions: (1) behavior, in particular orientation toward catches; (2) skills, i.e., fishing technique and fishers' ecological knowledge (Beaudreau and Levin, 2014); and (3) involvement, in the sense of how central recreational fishing is to their lifestyle in comparison with other activities (Kyle et al., 2007).

Fishers' behavior was assessed in the section "Materials and Methods" of the online questionnaire by asking about selectivity preferences toward target species (questions 2 and 3, **Supplementary Annex I**), the practice of catch and release (C&R) of live fish (question 4), preferences regarding fish and catch size (question 5), and frequency of consumption of the catches (question 6). Self-perceived involvement in the fishery was put into context in relation to the importance of fishing compared to other social activities and work (question 7). We also asked how often the respondents participate in fishing competitions (question 9) because it requires a certain degree of personal commitment. Finally, self-reported skills and fishers' know-how was obtained in question 8. In the analysis we considered anthropometric and socioeconomic variables included in the questionnaire as potential modifiers (section "Results" and **Supplementary Annex I**).

## Data Processing and Statistical Analyses

### Expert Consultation

Responses of the different consulted experts about changes in fishing access, marine ecosystems, economy, social life, well-being, and health were summarized for each country. Country summaries were updated and reviewed by the same group of experts and discrepancies were discussed until consensus was reached. Thereafter, to obtain overall estimations of impacts on access, ecosystems, economy, and societies, each of the experts' responses was categorized on the same scale (i.e., between "-1," meaning lower, or poorer, and "1," meaning more, or higher, while "0" meant no changes, or opposing trends). Subsequently, the mode of the different values available for countries with more than one expert was used to obtain a single set of observations for each country. Finally, responses were weighted proportionally to respondents' degree of certainty, i.e., the observations with a certainty score of "2" were doubled, the observations scored with "3" were tripled, and so on until the observations scored with "5" were quintupled.

### Online Survey to Fishers

Hierarchical cluster analysis was done on the dissimilarity matrix of the fishers' responses to the seven questions designed to capture fishers' heterogeneity by using the *hclust* function of the software R version 4.0.2 (R Core Team, 2019). The Hopkins' statistic (H) was obtained first to assess the clustering tendency of the responses by testing the spatial randomness of the data (Lawson and Jurs, 1990). Silhouette width measure (S) was used to assess the degree of confidence of up to 20 different clustering assignments to select the optimal number of clusters. Finally, we selected "average" as the best linkage method (compared to "complete" and "Ward") by evaluating the different correlation coefficients between the cophenetic distances of the different dendrograms (height of the nodes) and the original distance matrix (Sneath and Sokal, 1973). The rescaled matrix of fishers' responses (with mean 0 and standard deviation 1) was used instead of raw data because it obtained better fits in the above-described metrics.

As a sensitivity analysis for the clustering procedure we assessed the single contribution of the seven questions designed to capture fishers' heterogeneity by a SIMPER procedure (Clarke, 1993), included in the *vegan* library of R (Oksanen et al., 2019), performing pairwise comparisons to estimate the average contributions of each question to the average overall Bray-Curtis dissimilarity. Furthermore, we assessed the contribution of each of the questions to support the identified clusters by generalized linear models (GLMs) in R. Fits of each of the seven questions as predictors of the clusters were obtained from unadjusted models, whereas a backward stepwise selection procedure was followed to fit adjusted models (i.e., from unadjusted to saturated models).

Unadjusted and adjusted GLMs were also used to assess the differences between identified clusters of fishers in relation to different perceived COVID-19 impacts, i.e., changes in fish abundances because of expected variations in recreational and commercial fishing effort; experienced health concerns; reported negative affect; perceived sleep quality; fish consumption habits; healthy food consumption habits (fruits and vegetables); developed physical activity; expected fishing activity after the crisis; economic perception (qualitative); and economic impact (quantitative).

The country of residence of the fishers, along with their anthropometric (age and Body Mass Index, BMI) and socioeconomic variables (gender, marital status, and academic and income levels[1]), were included in the models as potential predictors. Furthermore, the effect of social support was also included (people sharing the household), because it is considered a basic resource for coping with stress, modulating the response to stressors (Sarason et al., 1987).

The fit of different error structures and link functions was assessed in the different model selection procedures. The best models were selected based on the Akaike's information criterion (Akaike, 1973), goodness of fit ($R^2$), and appropriate residual structure. Models with highly dispersed and anomalous distributions of residuals were discarded.

## RESULTS

### Global Results of the Expert Consultation

We obtained 48 answers to the semi-structured questionnaires from different experts on marine recreational fisheries distributed in 16 countries of America and Europe (**Figure 1**). Most of the consulted experts were scientists (75% of total), followed by resource and spatial managers (13%), and by representatives of recreational fishers' associations (10%).

The different experts' responses about changes in recreational fishing access, expected ecological status of marine ecosystems, projected economic scenarios, and perceived people's health and well-being are summarized in the following sections ("Argentina" to "Uruguay"). In general, experts acknowledged a decrease in fishers' access to marine recreational fishing during roughly the first year of the COVID-19 pandemic, since the mean score was -0.63 ± 0.72 (SD) (in a scale between "-1," meaning lower, or poorer, and "1," meaning more, or higher, while "0" meant no changes, or opposing trends, see section "Expert Consultation"). Marine ecosystems are expected to experience limited benefits derived from some reductions of human impacts during the first year of the pandemic, as the mean experts' score was 0.32 ± 0.47. On the contrary, the economic scenario anticipated by the experts is very poor, with a mean score of -0.66 ± 0.48. Finally, experts also anticipated relevant impacts on social life, especially on fishers' health and well-being, with a mean score of -0.70 ± 0.48 (**Figure 2**).

[1]Four levels of monthly net household income were used, the lowest being less than € 1000 for developed countries, and less than € 600 for developing countries, while the highest was more than € 4000, and more than € 2000, respectively.

### Country-Specific Results of the Expert Consultation

#### Argentina

Argentina decreed a strict and mandatory lockdown between late March 2020 (shortly after the first 100 cases of COVID-19 and the first deaths from this disease were verified in the country) and late April 2020. During that period, essential activities continued almost normally, while others, including tourism, recreation, and cultural services, faced an indefinite lockdown (Niembro and Calá, 2020). Thereafter, territorial less-severe measures (i.e., social distancing) were implemented, depending on the local epidemiological development. Some activities, including marine recreational fishing, began to be gradually allowed from mid to late May only for residents of some coastal cities, as mobility continued to be strongly restricted. In the absence of official statistics, consulted experts considered that compliance with social restrictions was high during the lockdowns, while in the following months marine recreational fishing was highly demanded in coastal cities (Aire Libre, 2020; Albanese, 2020).

The consulted expert did not expect relevant changes in marine ecosystems due to the reduction of the recreational fishing effort on the coast of Argentina after the lockdowns mainly because the effective prohibition extended only for a couple of months in most places (late March to late May 2020), and because it did not affect the austral summer season,[2] between January and February, when most tourists travel to coastal cities and practice recreational fishing. It is difficult to anticipate ecological effects derived from the summer season of 2021. In some cases, it seems reasonable to expect some ecological benefits at local level, compared to an average year before COVID-19. For example, the *Fiesta Nacional del Salmón de Mar*, an important annual fishing competition of Chubut (South of Argentina) was canceled due to the pandemic in 2020 and 2021. During this fishing competition, up to 900 individuals of reef fish are caught every year, mainly Argentinian sandperch *Pseudopercis semifasciata*, Patagonian grouper *Acanthistius patachonicus*, and Patagonian redfish *Sebastes oculatus*. Moreover, the overall operational level for commercial fishing and fishing-related activities in Argentina was estimated at approximately 70% of its normal capacity between April and September 2020 (Niembro and Calá, 2020).

In the absence of information on the economic importance of marine recreational fisheries in Argentina it is difficult to assess the economic impacts of the COVID-19 pandemic on this sector. However, suspension of important annual fishing competitions in the Buenos Aires province, with more than 13,000 participants (Dellacasa and Braccini, 2016), or the *Fiesta Nacional del Salmón de Mar*, whose attendees double the local population during the event, are economically relevant. The impact of the poor tourist season of the summer of 2021 on businesses related to recreational fishing could also be important.

Although some studies on the effects of the COVID-19 pandemic into mental health of different sectors have been already carried out in Argentina (e.g., Alomo et al., 2020; Johnson et al., 2020; Rogers et al., 2021), none of those studies

[2]Unless we indicate otherwise, we will refer in a generic sense to the seasons of the boreal hemisphere in the text.

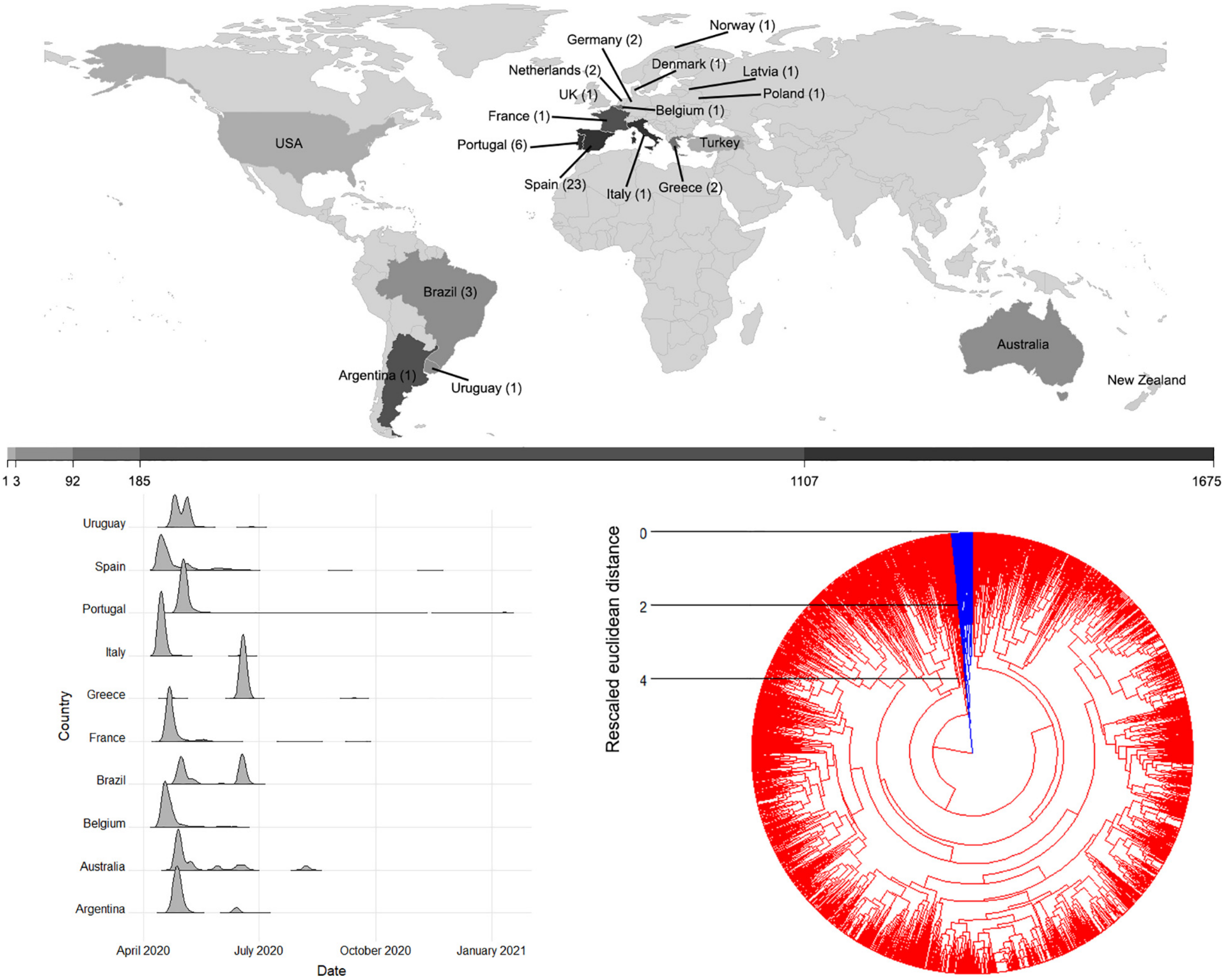


**FIGURE 1 |** Map showing the number of respondents by country, (although some responses were obtained from recreational fishers living in outermost regions, they are not included in the map. For example, the French Martinique, Guadeloupe, Guyane, and La Réunion, the Portuguese archipelagos of Madeira and Azores, or the Spanish Balearic and Canary Islands) both in the online survey of recreational fishers (the color refers to the number of responses) and in the expert consultation (in brackets the number of responses). Below in the *left* is the kernel density estimation of the temporal distribution of the responses to the online survey (we show countries with more than one answer). In the *bottom right* of the panel are the groupings of recreational fishers after a hierarchical clustering procedure on the Euclidean distance of the rescaled matrix of scores obtained in seven questions of the online survey designed to capture fishers' heterogeneity (see text in section "Study Design" and **Supplementary Appendix A** for details of the questions). In red Group 1, in blue Group 2.

dealt with the effects on recreational fishers. In part, this reflects the poor attention that in general has been given to this activity by the national and provincial fisheries agencies (Venerus and Cedrola, 2017).

## Belgium

Fishers' compliance with a strict lockdown between March and May 2020 was high in Belgium. Thereafter, recreational fishing was gradually allowed, although limited in practice due to different partial restriction measures, including maximum number of people onboard recreational fishing boats, and temporal and spatial restrictions to people's movements. In Belgium, fishers do not need a license to practice marine recreational fishing, but they do need one to fish in freshwater. The number of freshwater licenses increased by 30% in 2020 compared to 2019. It is expected, therefore, some increase in fishing activity at sea after the strict lockdown period.

Some local effects derived from the reduction of recreational fishing effort cannot be ruled out due to the coastal nature of Belgian marine recreational fishing. The experts expect that the reduction in catches was probably around 40 tons between March and May 2020, affecting especially Atlantic cod *Gadus morhua*, whiting *Merlangius merlangus* and common dab *Limanda limanda*. However, the effects of the recreational fishing ban is likely to become concealed by reductions of up to 30% in commercial fishing activity in the Belgian part of the North Sea during the lockdown (Verleye et al., 2020a,b).

The direct economic loss during the first complete lockdown in Belgium (between March and May 2020), mostly related to an

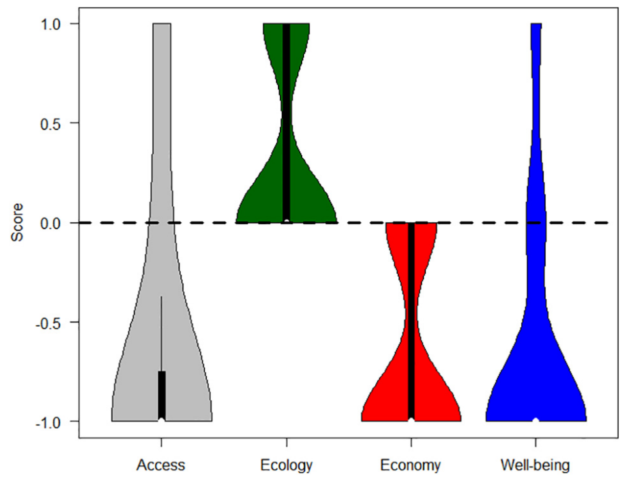


**FIGURE 2 |** Results of an expert consultation about changes due to COVID-19 in marine recreational fishing access, expected ecological status of marine ecosystems, projected economic scenarios, and perceived people's health and well-being. Mean values of the experts' coded answers scores are shown, which ranked between "–1," meaning lower, or poorer, and "1," meaning more, or higher, while "0" meant no changes, or opposing trends (identified with a dashed line). The top and bottom of the thick black lines correspond to the first and third quartiles of the data, the thin black lines extend to 1.5 times the interquartile range, and the median is indicated with a white dot. A two-side rotated kernel density estimation of each distribution is also shown.

average reduction of 84% in fishers' running costs, was estimated at a minimum of 0.6 million euros (Verleye et al., 2020b). Moreover, due to the gradual lift of social restrictions affecting recreational fishing and some expected reluctance to go back fishing by some people, total economic impact is likely to grow until the COVID-19 crisis ends.

In Belgium most recreational fishers regard that their hobby is of great importance to their lifestyle. Therefore, restrictions to fishing, and economic and social crisis derived from the pandemic (unemployment increased among recreational fishers by more than 25% during the first months of the pandemic) are probably behind the recent reduction of perceived well-being shown by Belgium recreational fishers (Verleye et al., 2020b).

## Brazil

During the start of the COVID-19 crisis (March and April 2020), there were no mandatory restrictions regarding recreational fishing at the country level. However, while in some states such as São Paulo in the southeast, non-essential activities were not allowed and access to beaches, marinas and natural areas was denied, in other states only voluntary restrictions on social activities were in place, with uneven follow-up throughout the country. In the state of Espírito Santo, at the central coast, recreational fishers seemed to access the fishery almost normally, as reported in the expert consultation. However, in Bahia, a state in the northeast of Brazil with the longest coastline (about 1,000 km), consulted experts observed an 80% reduction in the access of recreational boats, while the average number of fishers onboard was reduced from six to two. In addition, experts acknowledge relevant decreases in numbers of shore anglers, especially at urban beaches of Bahia, but also at rocky shores and in mangroves. Normal activity has not yet reached there 1 year after the start of the pandemic.

In the absence of an official fisheries monitoring in Brazil (Reis-Filho et al., 2019, 2021), consulted experts collected perceptions of some fishers in the Bahia state (NE Brazil) who consistently reported that the decrease in human presence and derived pollution, including noise, following voluntary lockdowns favored closer proximity to the shore of different species, especially of the families Serranidae, Lutjanidae, and Scombridae. Some boat owners indicated that they were benefited by less port and marine traffic, and more fishing opportunities in traditional fishing spots, with up to 20% increases in fishery yields compared to pre-pandemic scenarios. On the other hand, experts noticed that in the last months of 2020, and because of lower levels of enforcement and control, instead practicing C&R, a growing number of fishers were retaining endangered species, like Atlantic goliath grouper (*Epinephelus itajara*) and billfishes (genus *Makaira, Kajikia*, and *Istiophorus*).

Tourism is very important for many Brazilian coastal communities and catches from different fisheries are sold to local restaurants to be consumed by tourists (Lopes et al., 2017). In some places where recreational fishers sell their catch to restaurants their revenue must have been reduced considerably. Furthermore, in places with serious social mobility restrictions, as in São Paulo, service providers who depend on recreational fishing as a source of income (e.g., charter boat owners and fishing guides) have been especially impacted. For this reason, the impact of the pandemic on reductions of national, and especially international tourism had an important effect on the recreational fisheries, and in local economies.

Interviews conducted by consulted experts with recreational fishers in Bahia, revealed that shortage of fishing gear, cancellation of fishing competitions, and closure of some charter fishing boats resulted in some disappointment among recreational fishers.

## Denmark

During spring 2020 Denmark was locked down due to the COVID-19 outbreak. Non-essential activities were severely restricted, and the borders were also closed. Other less-severe lockdowns followed the gradual reopening after successive waves of the pandemic. Recreational fishing was allowed during the lockdowns and was even encouraged by the Danish Government (Miljøministeriet, 2021), with high media coverage about increased angling activity. Sales of mandatory licenses for recreational fishing increased by 24% compared with previous years, beginning to grow in April 2020, shortly after the first lockdown, and remaining higher than in previous years during the following months (Ministeriet for Fødevarer Landbrug og Fiskeri, 2021a). It is likely that younger, more urban, and less devoted fishers have accessed the fishery for the first time during the COVID-19 pandemic in Denmark (Gundelund and Skov, 2021).

Based on citizen science data, the only data available about angling activities during the lockdown, the increase in access to the recreational fishery that was observed during spring 2020 did not result in more angling trips compared to previous years, but in more effort during labor days and evenings, instead of weekends and early in the day (Gundelund and Skov, 2021). For sea trout *Salmo trutta*, the most popular target species among Danish marine anglers, lower catch rates were observed, especially among the less experienced participants that entered the fishery during the spring lockdown in 2020. This may result in a lower biological impact on the species. On the other hand, the citizen science data also suggested that the anglers during the 2020 spring lock down tended to retain more fish than in previous years, which increase fish mortality in a way that may have counterbalanced the concurrent lower catch rates (Gundelund and Skov, 2021).

The lack of international fishing tourists during the border closures, resulted in some negative impacts on local economies, especially in the areas of Denmark where tourism is an important industry (Tress, 2002; Andersen et al., 2018). For example, this resulted in less rentals of summerhouses, lower activity in restaurants, or lower sales of fishing tackle. The charter boat industry was negatively affected during the lockdowns and periods with social distance restrictions. The sales of 1-week licenses, mainly purchased by foreign visitors, dropped by 40% in 2020 compared with previous years (Ministeriet for Fødevarer Landbrug og Fiskeri, 2021b). When the country borders reopened during the summer of 2020, international visitors purchased more licenses than during the same months in previous years. On the other hand, the increase in the sales of annual fishing licenses in 2020 with respect to previous years suggests the recruitment of new recreational fishers in Denmark. Newcomers must have needed to purchase their fishing equipment, with direct positive economic impact. It is unclear, however, if newcomers will remain in the fishery, or if they will abandon it after the international health crisis ends.

Social isolation can have dramatic effects, both on physical and mental health, especially in vulnerable groups of people. In this sense, there was an increase in the number of women seeking help because of sexist violence and abuse (Danner, 2021). Several demonstrations have been in place in Denmark against the governmental decision on the different lockdown (Euronews, 2021). However, it remains unclear if the reported increase in recreational fishing activities in Denmark influenced the collective well-being.

## France

A strict and mandatory lockdown was implemented in mainland France from March to May 2020. Mobility of the population was restricted to essential activities. All sea-related leisure activities, including access to the beaches, sailing, or swimming, were forbidden by law at the national level. Therefore, recreational fishing was completely stopped during the first months of the pandemic. Fishers' compliance during this first lockdown was high, as well as in other recreational and cultural activities. The second lockdown took place from October to December 2020, including another ban for recreational fishing. Recreational fishing was resumed in 2021 in all France. The context was somewhat different in French overseas territories (with differences in dates and conditions of the lockdowns), however, access to recreational areas and activities was highly reduced in general.

The consulted expert collected perceptions of different fishers and the general perception is that local shellfish stocks (i.e., size and biomass of clams and cockles) benefited from the reduction of recreational fishing effort during the pandemic. This is relevant information considering that recreational shellfish gathering in mainland France is very popular (Herfaut et al., 2013). The first lockdown in 2020 did not affect the high season, during summer, but shellfish gathering is already relevant during spring. Therefore, it seems reasonable to expect some ecological benefits at the local level, compared to previous years. The effects of the recreational fishing ban are also difficult to predict but should be limited because of the short duration of the lockdowns, and because commercial fishing activities did not stop.

It is difficult to assess the economic impacts of the COVID-19 pandemic on the marine recreational fishing sector due to the current lack of data. However, the two lockdowns took place when the weather was not the most appropriate for recreational outdoor activities in mainland France. Weather and fishing practices are very different in outermost regions, where impacts could be even higher. French national economy has been negatively impacted during the pandemic, and negative consequences for the recreational fishing sector are also expected, even if those effects could have been limited with the reopening of the recreational fishing activities after the lockdowns.

In France, to date there was no specific survey to assess the effects of the COVID-19 pandemic on mental health and well-being for recreational fishers. After a strong initial coalition of social groups with very different political agendas stopped supporting government measures to contain the pandemic, social protests have been organized, illustrating the bad effects of social isolation for people during the lockdowns (Jørgensen et al., 2020). The recreational fishing ban could have increased the erosion of well-being in the French population because this activity is a source of relaxation and socialization. Sometimes, especially for people with low incomes, it could also be a relevant source of food or money. These social impacts could have been more important in French overseas territories, where subsistence fishing is more frequent (Failler et al., 2015, 2020).

## Germany

Most (65%) of marine recreational fishers in Germany are domestic tourists (Strehlow et al., 2012). Following first severe COVID-19 restrictions to non-essential activities in March 2020, access of marine recreational fishers to the coast was highly reduced. Consequently, the restrictions due to COVID-19 had a strong impact on marine recreational fisheries. In general, compliance with these regulations was high among the German population and this was also the case for the recreational fishing community. The specific regulations were under the jurisdiction of the different federal states, leading to a variety of local and regional restrictions. During the first lockdown, between March and May 2020, coastal states imposed a travel ban for domestic tourists (residents were allowed to travel in their home state) restricting access to the Baltic and North Sea coastal states. In addition, accommodation opportunities and marinas, as well as charter boat businesses and tackle shops were closed. Some municipalities even stopped selling daily fishing licenses (mainly sold to anglers targeting spring-spawning Atlantic herring *Clupea harengus* in the Baltic Sea). After June 2020, restrictions on marinas, charter boats, and domestic tourists were lifted. During subsequent lockdowns between November 2020 and May 2021, restrictions on tourism access to coastal areas were resumed, affecting fishers' access to the coast. Even though the consulted experts noted some increase in angling activities by residents (e.g., due to short-time work and more free time), it is unlikely that this compensated for the decrease in fishing effort by domestic tourists due to the travel restrictions. In this sense, available license data for one federal state on the Baltic Sea revealed a drop in the sales of sea angling licenses of up to 14% in 2020 compared to 2019. Moreover, trolling fishing effort in the 2020 Atlantic salmon *Salmo salar* season in the Baltic dropped by 50% compared to 2019, as stated in a recent survey developed by the consulted experts (MSW and HVS, unpublished data). On the other hand, the situation in freshwater recreational fisheries, that remained mostly unrestricted, was very different, with strong regional increases in fishing effort. It is expected that some marine recreational fishers (non-residents) have shifted from marine to freshwater fisheries.

Marine recreational fishing effort has been severely reduced in Germany in the spring and winter of 2020 and 2021, with less disturbances due to recreational boat traffic, beach walking and potentially lower recreational fishing mortality. However, the effect on marine ecosystems through reduced fishing mortality is limited because the strict lockdowns were relatively short. Nevertheless, lower fishing effort due to the travel restrictions in combination with lower catches per unit of effort resulted in an 80% reduction of fishing mortality in the 2020 Atlantic salmon trolling fishery in the Baltic Sea compared to 2019 (MSW and HVS, unpublished data). On the other hand, human disturbances caused by visitors and hikers may have increased during the lockdown, as people spent more time outdoors.

In general, the German economy has been impacted negatively due to the pandemic, affecting employment and household income, with potential negative consequences for the recreational fishing sector. Since domestic angling tourism makes up two thirds of the total marine recreational fishing effort in Germany, the COVID-19-related restrictions are expected to have a strong negative impact on fishers' expenditures in tackle shops, guided fishing tours, and boat rental and charter businesses, especially in coastal communities. On the other hand, some of these economic losses may be partially compensated, e.g., due to increased sales of tackle shops after the lockdowns, while others will not, e.g., canceled fishing trips, or guided and charter boat tours. However, it is possible to anticipate part of the economic impact at this time, since a 50% reduction of trolling boat fishing effort was observed in the 2020 Atlantic salmon fishing season in the Baltic. However, increased fishing effort in freshwater fisheries and potential subsequent increased expenditures for this sector may have compensated the reductions in expenditures for marine recreational fisheries as most of the recreational fishing effort in Germany is exerted in freshwater fisheries.

Although social impacts are difficult to anticipate, consulted experts speculate that since some of the marine recreational fishers started fishing in local freshwater facilities, expected health and well-being benefits derived from the practice of their activity could have partially remained. On the other hand, there are expected higher social impacts on fishers more specialized in marine recreational fishing. Moreover, some negative effects due to the restrictions regarding social distancing could be expected, since fishing competitions and team angling could not be performed, and neither meetings in fishing clubs nor fishing outings with people from different households. This might particularly impact on the social well-being of older people living alone.

### Greece

In Greece, the COVID-19 crisis began in March 2020, when a complete lockdown was imposed in the country, and mobility of the population was restricted to essential activities. Shore and boat angling was not allowed until May 2020, while spearfishing until June 2020, affecting the 700,000 resident recreational fishers. In November 2020, the country was put into a second lockdown. Marine recreational fishers were again not allowed to fish, except between December 2020 and January 2021, until the end of March 2021. Recreational fishing was allowed again in April 2021 with some restrictions. International tourism was restricted for some months, but even when it was allowed again numbers decreased remarkably (up to 90% in some cases) compared to 2019, especially in northern Greece, where half of recreational fishers are foreigners (mainly from Bulgaria). Apart from very isolated areas where control and enforcement are difficult, compliance was high during the first lockdown, whereas it was reduced during the second lockdown, with some illegal fishing exposed by the press (e.g., Creta24, 2021; Kavalapost, 2021; Ypaithros, 2021).

The consulted experts expect some improvements in the conservation state of the Greek marine ecosystems and fisheries due to the reduction of human presence and lower fishing mortality. However, these benefits will not be of much importance because the fishing activity of commercial fleets has not greatly decreased. The highest impact on the fishing sector was found in the small-scale fisheries, as the fishes caught are sold at ports and not through the wholesale markets, and consumers could not easily reach the ports due to mobility restrictions. To compensate the commercial small-scale fishers the Government offered some economic support to the sector (Greek Government Decision 94/165904). The consumption of seafood by residents did not compensate for the lack of activity in the restauration, which largely depend on tourism.

The consulted experts anticipate that the recreational fishing industry faces an important reduction in sales and revenue, e.g., shops specialized in selling fishing tackle and baits, and boat services, including mechanical repairs and equipment sales and maintenance. Severe lockdowns led to reduction of production of different goods, difficulties in their distribution, and employment losses. In the mid-long term, the crisis might lead to business closures. On the other hand, although in the Northern provinces of Macedonia and Thrace fishing tourism is important, the economic impact of border closures is not expected to be high because the expenses and investments of these tourists are not high in general.

Greeks are very sociable people and imposed measures for social distancing are affecting well-being across the country. Furthermore, recreational fishing is in many cases an activity sought to reduce stress in everyday life. Frustration derived from the imposition of social distancing measures, added to the prohibition of recreational fishing, triggered social protests throughout the country (e.g., Simera, 2021; Solaris, 2021). Economic crisis caused by the pandemic is expected to have more impact on the most vulnerable segments of recreational fishing. Coastal communities highly dependent on recreational fishing activities are expected to suffer from unemployment, poverty, and thereby social disruption. Although the pandemic affects all population segments, it is particularly detrimental to members of those social groups living in most vulnerable conditions, such as people living in poverty, older people, refugees, migrants, and other sensitive social groups that largely fish not for leisure purposes but for food. These vulnerable groups are highly engaged in recreational fishing and expected to be adversely affected by the pandemic.

### Italy

In Italy, the first social confinement was between March and May 2020, and included a ban on recreational fishing. After this severe lockdown recreational fishing was allowed again in the country. Other regional lockdowns with restrictions to recreational fishing followed during 2020 and 2021, in a very dynamic scenario following the development of the pandemic in each region.

Although consulted Italian experts considered that the period in which recreational fishing effort was restricted or banned was too short to cause relevant ecological changes, the reduced fishing effort would have allowed some species to have more effective reproductive seasons, especially those that spawn in spring. Reduction in human disturbances, including pollution and noise, would also have favored some fish species to occur in coastal habitats where they are usually not found.

Some loss of expenses directly related to recreational fishing would be expected in Italy (e.g., travel, food, or baits), but on the other hand, consulted experts noted that some fishers invested in buying new fishing gear through online commerce during lockdown. The summer tourist season, including recreational fishing activities, was relatively normal, and it is also expected that more people will access the fishery after the pandemic because they value more contact with nature than before the lockdowns, with a consequent increase in their investments and running costs for recreational fishing.

In Italy a general decrease of well-being in almost all strata of the population is expected, in many cases because of the loss of contact with nature and reduced social contacts. Recreational fishers are especially sensitive to these aspects, because they practice their activities in blue areas, they fish with friends in many cases, and get involved in competitions and club activities. In addition, they face the consequences of having less opportunities to eat their catches. Health and well-being impacts derived from less seafood intake could be very important for semi-subsistence fishers, and for fishers with higher culinary motivations to access the fishery.

### Latvia

No strict lockdown was applied in Latvia in the spring of 2020. On the contrary, the Government asked people to spend more time outdoors, while restrictions to indoor activities were imposed, e.g., in shops, bars and restaurants. As a result, more access to recreational fishing was observed, further driven by closures of schools and home office. Boat crews were restricted to two fishers, but compliance and enforcement of this rule was not high. Although popular competitions were cancelled, in spring of 2020 numbers of sea anglers targeting Atlantic herring, garfish *Belone belone*, and the invasive round goby *Neogobius melanostomus* were much higher than in previous years.

The consulted experts do not expect major changes in the marine ecosystem status of the Latvian Baltic Sea. Recreational fishing mortality is usually low compared to commercial fishing. Moreover, although commercial fishing effort was lower due to less demand during the COVID-19 crisis, due to reductions of the most important quotas in 2020, commercial fishers managed to meet their fishing opportunities, even with the fleet moored in the harbors for some months.

In Latvia most recreational fisheries are accessed by individual fishers, and there were no restrictions for that. However, some companies offer boat fishing trips, especially for fishers from Lithuania targeting Atlantic salmon and sea trout, and those were most probably impacted due to loss of tourism opportunities during the 2020 autumn season. Fishing tackle shops in big shopping malls were closed only on weekends, while small shops remained open.

In Latvia, the lockdown was quite mild in 2020, and therefore the impact of COVID-19 on social peace, well-being and public health could be lower compared to other countries. There was some debate about cancelling some restrictions for recreational fishing and lowering the prices of licenses to increase the time people spent outdoors, but they were not finally implemented.

### The Netherlands

In the Netherlands there was a moderate lockdown starting in March 2020. Many people worked at home, while schools, bars, restaurants, camping facilities, and sport clubs, etc., were closed. On the other hand, outdoor activities keeping some social distance were allowed, including recreational fishing. Since keeping social distance was difficult, charter fishing boats were not allowed to operate, and competitions and popular fishing events were cancelled. There is no licensing or registration required for sea angling in the Netherlands. Therefore, it is difficult to quantify changes in access and effort. In recent years recreational angling has declined in the country (van der Hammen and Chen, 2020), however, since sales of mandatory freshwater licenses showed a steep increase, it is expected that shore angling also increased. Good weather, lack of alternative leisure activities, more free time, and children at home must have promoted access to recreational fishing. On the other hand, although this is a minoritarian option compared to shore angling, capacity restrictions (only two fishers allowed) to private boats have probably limited their access. Moreover, parking lots close to the beaches were closed, so beaches were difficult to access for people living far from the coast. A second lockdown, starting in December 2020 through 2021 was stricter, as it included curfews, meeting capacity limitations, and shop closures, and worse weather conditions to spend time outdoors, all of which could have reduced interest in recreational fishing.

Although the increase in fishing effort could have been relevant in the case of shore anglers, the consulted experts do not expect significant effects on the marine ecosystems of the Netherlands, if compared to the strong reduction of the landings of the commercial fleet shown during the first months of the COVID-19 pandemic.

The worst economic impact has been borne by commercial charter boats based on the coasts of the Netherlands. However, tackle shops selling fishing gears, equipment, and baits, and angling associations selling fishing licenses took advantage of the increased recreational fishing demand in both marine and freshwater environments during the pandemic, especially during the first lockdown.

Consulted experts expect lower social impacts of COVID-19 in the Netherlands during the first lockdown compared to other countries because people could spend time outdoors, including recreational fishing. The results of the second, stricter lockdown must have been similar to those of other neighboring countries.

### Norway

Marine recreational fisheries in Norway are exploited by both residents and tourists (Vølstad et al., 2020). Since March 2020, when the pandemic arrived in the country, main recreational fisheries regulations have not changed, except some changes in the export limit of fish for marine angling tourists. However, other measures had a direct impact on marine recreational fishing. These measures evolved, adapting to the different national and international health scenarios. The most negatively affected sector in the Norwegian marine recreational fisheries was the marine angling tourism sector, as this fishery is dominated by foreign anglers. From March 2020, access to Norway from other countries was restricted. During late spring and early summer these measures were relaxed for some time, but strict quarantine regulations were still in place, hampering the access of foreign tourists to the country. Quarantine was lifted for a time for some European countries but imposed again as infection numbers increased during autumn 2020. As a result of this scenario, the access of foreign marine angling tourists was dramatically reduced in 2020 compared to previous years. On the other hand, with increased unemployment rate and reduced holiday travel opportunities to other countries due to COVID-19 measures, residents had more time to spend fishing in Norway. Therefore, local access to the fishery was increased during the COVID-19 pandemic. There is no license required for sea angling, but a 23% increase in mandatory licenses to enter the European lobster *Homarus gammarus* fishery was observed in 2020, compared to 2019 (Directorate of Fisheries, 2021b). The sales of boats also increased substantially in 2020 compared to 2019 (Berglihn, 2020).

Although there are many other factors that impact marine ecosystems, sea angling tourism may have some impacts on local fish populations (Vølstad et al., 2011), and a decrease in their catches could, in theory, have had a positive effect. The mandatory catch reporting to the Norwegian Directorate of Fisheries showed that the overall catches of saithe *Pollachius virens*, Atlantic cod, Atlantic halibut *Hippoglossus hippoglossus*, Atlantic wolffish *Anarhichas lupus* and redfish *Sebastes* spp. in the marine angling tourism industry were reduced by ca. 75% in 2020 compared to 2019 (Directorate of Fisheries, 2021a). On the other hand, Norwegian residents seemed to have increased their fishing effort compared to previous years, which might have counterbalanced the decrease in tourist fishing mortality to some extent.

The COVID-19 measures had a substantial negative impact on the tourist fishing industry as many foreign visitors were never able to access the country. However, economic investments of residents in the fishery seemed to have increased, including the purchase of fishing tackle and new boats (Berglihn, 2020). For example, a market analysis conducted by Klarna (2020) showed that one of the largest online recreational fishing equipment stores in the European Nordic countries had an 87% increase in sales of recreational fishing gear in the period between March and September 2020, compared to the same period in 2019.

Norway has a low population density compared to many other countries, and there are several options of outdoor activities available to the local population. Indeed, fishing is one of the most popular leisure activities in Norway, with one third of the population fishing in the sea at least once a year (Vølstad et al., 2020). Even though there have been several lockdowns in Norway during 2020, many outdoor activities were not specially affected. In fact, while meeting friends indoors was restricted from time to time, people could meet outside, e.g., during fishing, keeping some social distance. Thus, recreational fishing may have been one of the activities which contributed to support social well-being during the COVID-19 pandemic.

### Poland

People in Poland were in a mandatory complete lockdown from March to April 2020. Non-essential activities, including recreational fishing were prohibited by law.

The lower fishing mortality and reduced disturbances derived from the absence of recreational fishers may have been positive for local fish stocks during the lockdown in spring 2020, especially because it affected the prime fishing season for Atlantic salmon and sea trout in Poland. On the other hand, Polish anglers rapidly resumed their normal activity, so the closure has been relatively short.

The lockdown imposed during spring 2020 that affected the fishing season for Atlantic salmon and sea trout in the Baltic Sea had a high negative impact on fishing tourism. The lack of economic flow originated by the recreational fishers, including both private and commercial companies that provide fishing services is important to local economies, very dependent on tourism.

The consulted experts do not expect relevant impacts on social peace, well-being, and public health because of mandatory or voluntary lockdowns, or new habits related to recreational fishing due to social distance.

## Portugal

In Portugal, the first COVID-19 cases were reported in early March 2020, and the first peak in the number of cases was observed at the end of the same month. As part of the implemented lockdowns, Portugal banned all types of recreational fishing activities in the mainland and Atlantic archipelagos between March (April in the Azores Islands) and May 2020. Only essential activities such as working, buying food, etc., were allowed. Overall, many recreational fishers did not support the temporary fishing closure, and there are records of some noncompliance, especially by shore anglers and spear fishers in rural and remote areas where there is low enforcement. The available evidence collected by the experts suggests that compliance with the fishing ban was higher among boat anglers because they are easily controlled by the authorities, and boat anglers agreed that it would be difficult to keep social distance onboard.

During the COVID-19 crisis most recreational marine activities were severely reduced, and they were completely banned during the lockdown of spring 2020. Given commercial fleets continued fishing (commercial fishing was considered an essential activity), and recreational activities were only forbidden during a relatively short period, the consulted experts do not expect important reductions in overall fishing mortality. Nevertheless, some spear fishers reported increases in the abundance of crevice-dwelling fish species (e.g., European conger *Conger conger* or forkbeard *Phycis phycis*), and limpets *Patella aspera*, but not in the case of important recreational species like parrot fish *Sparisoma cretense*. Consulted boat and shore anglers did not report relevant changes compared to the previous year. On the other hand, a recovery would be expected for the white seabream *Diplodus sargus*. This is one of the most targeted species by local shore anglers and spear fishers at the SW coast of Portugal during the winter and early spring, when this fish aggregates to spawn and is more vulnerable and accessible to fishing (Veiga et al., 2010). Although there was a temporary closure for this fishery in place between February and March, the lockdown provided an extended closure. Moreover, reductions in the commercial landings of about 40% with respect to previous years (Instituto nacional de Estatística, 2021) may have resulted in greater benefits to marine ecosystems than those that result from the reductions of recreational fishing effort, especially during the winter-spring spawning season of many of the most important recreational and commercial coastal species. In addition, reduction of human use of intertidal ecosystems, e.g., digging for bait, that impacts on seagrass meadows, and of other recreational activities like sailing, swimming, or surfing, may also have had some positive effects on sensitive species, including seabirds. Furthermore, the decrease in tourism due to travel restrictions may have improved water quality by reducing urban wastewaters dumped into the sea. On the other hand, the increase of pandemic-related unemployment in the Azores is expected to increase commercial fishing effort on, e.g., limpets, common octopus *Octopus vulgaris*, and others. Poaching and non-compliance of limpet protection zones are also supposed to have increased, as happened in the past (Diogo et al., 2016).

In Portugal, bait sales, tackle shops, boat maintenance companies, and restaurant facilities at marinas suffered important economic losses during the complete lockdown. Another relevant negative economic impact to recreational fisheries is expected to affect touristic fisheries, especially to charter boats and head-boats involved in coastal and Big Game fishing, since this activity is heavily dependent on foreign tourists. In 2020, the pandemic had a major impact on the number of tourists visiting Portugal, and consequently on Big Game fishing tours, especially in the Algarve and the Atlantic islands of Madeira and Azores. For example, the international Big Game fishing competition of Madeira, which attracts many foreign visitors and participants, was canceled in 2020. As an indicator of tourism reduction, apartment's overnight stays showed a 67% decrease from January to November 2020, when compared to 2019 (Instituto nacional de Estatística, 2021). On the other hand, resident recreational fishers seem to have increased their number of fishing trips during the summer of 2020, which together with online purchase of fishing tackle, could help to revert some of the previous economic losses. Furthermore, some measures were implemented to stimulate local tourism to compensate for losses of foreign visitors, e.g., in the Azores, which could have a positive impact on the recreational fishing sector.

The rise in unemployment, limitations of social interactions and events, and changes of habits are increasing the stress, anxiety and social inequalities in the Portuguese society, especially in vulnerable and aged people (Silva Moreira et al., 2021). In this sense, in the Azores, and probably in some other areas of the country, some low-income residents that go fishing for food could have reduced their access to healthy food at low cost through the lockdown. Furthermore, new measures of social distancing are especially difficult for Portuguese people because they are used to close human contact. On the other hand, COVID-19 helped many people to adopt healthier habits, such as spending more time outdoors, either exercising, relaxing, or socializing. For recreational fishers in particular, experts consulted do not anticipate stronger impacts compared to other people because they were able to practice the activity soon after the ban was lifted. Although some fishers felt discriminated because other recreational activities were allowed during certain lockdown periods, such as surfing, among others, their return to fishing, each with their individual motivations, e.g., contact with nature, friends, and family, or to catch some fish, could have helped them to temper potential negative effects of the lockdown on their physical and psychological health, and well-being.

## Spain

The Spanish population was confined in their homes between March and April 2020, after which the mandatory national lockdown was progressively withdrawn across the country. Essential activities such as some jobs, food shopping and health care continued under strict sanitary conditions, while other important activities like face-to-face education suffered severe restrictions. Non-essential activities were strictly forbidden, including recreational fishing. In general, recreational fishing ban was respected by Spanish fishers. After this strict lockdown, marine recreational fishing was progressively authorized, with differences between autonomous regions, provinces, municipalities, and even between sanitary areas. However, throughout the following months of 2020 and early 2021 different restrictions to peoples' mobility were put into force, including travels, curfews, partial confinements, and border closures, which made full access to fishing difficult in practice, especially for foreign tourists and for residents of non-coastal areas. Access to the fishery can be assessed by the acquisition of compulsory fishing licenses in Spain. In some regions the volume of licenses increased during this period. For instance, in the Balearic Islands, consulted experts noted an increase in the licenses issued just after the main lockdown compared to previous years, especially for shore angling, which is the modality that requires less expenses in equipment and mobility. This could be explained to a certain degree by a renovated interest in outdoor activities, which may have developed during social distance. The increase could also be caused by a growing interest in catch consumption, which is an important fishers' motivation in Spain (Morales-Nin et al., 2015), and could feasibly have been reinforced by economic difficulties experienced by some people because of the pandemic.

Although commercial fisheries reduced their landings in the first months of the pandemic, with some differences between fleets segments, they never stopped fishing in Spain (Coll et al., 2021). Recreational fisheries were completely closed for a relatively short period during the 2020 spring. Therefore, in general, consulted experts do not expect major changes in marine ecosystems. On the other hand, the effects of the spring 2020 lockdown on Spanish fish stocks may have been somewhat positive due to reduced effort and fishing mortality. For example, in the Catalonian Mediterranean Sea, it was estimated that ca. 110,000 shore angling, 42,000 boat angling, and 10,000 spearfishing fishing trips have not been conducted. The overall reduction in recreational catches during this period could have contributed to protecting the reproductive period of some highly targeted species, especially Atlantic horse mackerel *Trachurus trachurus*, Atlantic mackerel *Scomber scomber*, annular seabream *Diplodus annularis*, comber *Serranus cabrilla*, Mediterranean rainbow wrasse *Coris julis*, surmullet *Mullus surmuletus,* and white seabream (Dedeu et al., 2019; ICATMAR, 2020). The reproduction of other important species in the Spanish Atlantic, such as the European seabass *Dicentrarchus labrax* in the North, or dusky grouper *Epinephelus marginatus* and rubberlip grunt *Plectorhinchus mediterraneus* in the South (Pita et al., 2020), may also have been favored. Reductions in local and foreign tourism contributed to lower pollution of coastal waters due to less discharge of urban wastewater. Also, lower human disturbances during the 2020 spring contributed to greater presence of some species, such as Atlantic bluefin tuna *Thunnus thynnus* and marine mammals, very close to the coastline. On the other hand, the post-social confinement phase could have contributed to a general increase in fishing effort due to increased demand for outdoor leisure activities, especially near the most populated areas due to mobility restrictions (e.g., Lloret, 2020). Thus, while human pressure in the best-preserved areas may have decreased in the months after the lockdown of spring 2020, pressure on the most degraded peri-urban areas would have increased.

The inclusion of recreational fishing as a non-essential activity during the first lockdown in Spain, and throughout subsequent restrictions of people's mobility, including tourism, have impacted the value chain that indirectly depends on this activity, affecting restaurants, hotels, guided fishing tours and charter boats, retail shops of fishing tackle, and fuel consumption. Although investments derived from recreational fishing may have been mostly unaffected, since they are related to multi-year expenses, short-term expenses have probably been affected to a greater extent. In this sense, running costs to cover travel expenses of the fishers tend to have a considerable weight within their total annual expenditure in Spain (García-de-la-Fuente et al., 2020). Based on seasonal average expenditure per fishing day of recreational fishers, consulted experts estimated a potential reduction of direct and indirect expenditures on transportation, meals, tackle and other related expenses, reaching five million euros in 2020, only in Catalonia (ICATMAR, 2020). Furthermore, services related to recreational tourism activities faced high loss of reserves and financial resources at an unprecedented scale, especially affecting the Mediterranean coast, and the Canary Islands, which are highly dependent on tourism. The economic activity related to the modalities that need higher investments, such as boat angling and spear fishing, have probably been affected the most. In fact, although there has been an increase in recreational nautical activity in some places, since the maintenance of recreational boats is expensive, especially in a context of global economic crisis, some of the consulted experts indicated that sales of second-hand boats increased during 2020. On the other hand, shore angling, which is a less expensive modality, could have seen an increase motivated by fishing for consumption resulting in reduced costs for food, particularly among the sectors of the population most affected by the health and economic crises. However, according to interviews carried out by the consulted experts with tackle shops managers, the sales related to the increase in the access to recreational fishing that followed the social lockdown did not cover the economic losses suffered during the spring 2020 fishing ban and the subsequent restrictions on mobility (online sales were not considered).

Recreational fishers were somewhat amenable to the first lockdown in the spring of 2020, but showed some frustration when some other outdoor recreational activities were progressively allowed, e.g., swimming in the sea, or surfing, while recreational fishing continued to be banned (FEPyC, 2020; Jara y Sedal, 2020). A period where contradictory regulations at the national, regional, and municipal levels were in place contributed to the confusion and frustration of the fishers. In Spain, close social contact and outdoor social activities are important, so the impact of social distancing on the well-being of the population is probably higher than in other countries. In fact, recreational fishing is mainly a social activity in Spain, where most fishers seek the company of friends or family when fishing (Pita et al., 2018a; ICATMAR, 2020). Although during the first phase of the crisis, with the ban on fishing, many social encounters were prevented, during the de-escalation phase, even with different restrictions on mobility, consulted experts agreed that an increase was observed in the access to recreational fishing, probably promoted by the difficulty of accessing other leisure activities (cinemas, theaters, museums, bars, and restaurants were closed, or with very small capacity during the pandemic). The main reason indicated by the fishers interviewed by the experts was to obtain psychological benefits to cope with the lack of activity during the health crisis. The stress derived from the confinement situation and of the restrictions to access their preferred recreational activity, has probably most affected avid fishers, and those living in non-coastal regions. On the other hand, the COVID-19 pandemic has probably contributed to widening the social gap by mainly affecting vulnerable groups that obtained part of their food from fishing, or even illegally sell their catches, especially people with low incomes.

### United Kingdom

Sea angling is the main form of marine recreational fishing in the United Kingdom. The number and duration of lockdowns, and the associated restrictions regarding sea angling varied between the different countries and were complex. For example, the first lockdown in United Kingdom meant that sea angling was not possible from the end of March until early May 2020. From May, Wales allowed sea angling within five miles of peoples' homes, but this was not possible in Scotland, Northern Ireland, or England until later. Fishing was a permitted activity for most of the summer across most of the United Kingdom, although some regions and cities had additional restrictions that prevented it. For example, there was a tiered approach based on the levels of COVID-19 that resulted in variation in restrictions. Depending on the location, this may have restricted sea angler's ability to travel to fish, engage in angling tourism, and participate in competitions. Subsequent lockdowns in the autumn and winter prevented angling for a time in England, but it was then allowed if undertaken locally with one other person. Access to charter and hire boats was also restricted for some periods.

There is limited evidence on the impact of COVID-19 on sea angling access, and derived ecological impacts across the United Kingdom, because there is no requirement to have a license to fish in the sea. The number of mandatory licenses sold for freshwater angling in England was higher in 2020 than previous years, suggesting that more individuals were angling. It is likely that sea angling has seen a similar increase, but this did not necessarily mean that there was more effort as some sea anglers were prevented from fishing. As angling was initially not allowed during the first lockdown in the 2020 spring, effort will have been lower, but this was at a time during the year where angling effort is usually low. As recreational fishing was one of the few allowable recreational activities toward the end of the first lockdown, it is likely that effort increased, especially as many people were working from home or were not able to work, so had more opportunity and free time to go angling.

Consulted experts expect that the impact of COVID-19 on the economy has been mixed. Online sales of fishing gear increased, but tackle shops were not able to open during lockdown or were only able to provide click and collect services, reducing local expenditure. Restrictions on access and travel are likely to have reduced the overall trip expenditure, as fishing has been more local. In addition, charter boats were only able to operate with reduced capacity if at all to maintain social distancing. This, along with limited government support, has impacted on the charter boat sector.

Consulted experts expect that reduced access to fishing could have a negative impact on physical health and well-being. Angling in the United Kingdom has been shown to be important as a source of physical activity, relaxation, and socializing. In addition, some people retain fish to eat, so it may also have reduced the benefits of fish consumption in the United Kingdom.

### Uruguay

In Uruguay, a health emergency was declared due to COVID-19 in March 2020. Although there was no mandatory social lockdown, the Government asked the population to avoid crowds in public spaces, promoting voluntary social distancing. Recreational fishing was directly affected because ports were closed for recreational boats until May 2020, while fishing from docks and beaches decreased because of the voluntary social distancing measures, and the vigilance of the authorities to avoid overcrowding. During the voluntary social distancing period, most recreational fishers complied with the measures proposed by the government, and the experts consulted observed a reduction in recreational fishing effort of 25% compared to 2019. In May 2020 fishers began to gradually resume the activity, both from boats and from the coast.

Fishing effort exerted in the different recreational fisheries decreased in Uruguay due to social distancing and the closure of recreational ports. Consequently, it is expected that targeted and non-targeted species will benefit from the reduction of human disturbances and fishing mortality. Although consulted experts noted a 40% decrease in total recreational fisheries catches in 2020, compared to 2019, the period of reduction in activity was too short to produce benefits on ecosystems in the long term. The species that benefited the most from the reduction in catches were broadnose sevengill shark *Notorynchus cepedianus* and South American silver porgy *Diplodus argenteus*. On the other hand, commercial fishing fleets operated as usual, targeting some species that are also commonly caught in the marine recreational fisheries.

The COVID-19 pandemic has caused a deep economic crisis in Uruguay due to the closure of many companies. Tourism was one of the most affected economic activities due to the closure of borders. During the first 3 months since the start of the health emergency (i.e., from March to June 2020), investments and running costs related to recreational fishing decreased, due to the closure of ports and voluntary social distancing. After this period, recreational activity began to resume, but with little economic investment due to the economic crisis. The experts consulted found that imports of recreational fishing goods fell by 15% compared to the year before the pandemic.

Although the voluntary confinement and social distancing in Uruguay prevented infections and deaths during the first months of the COVID-19 pandemic, it has probably affected psychological health and well-being across the country, as reported by consulted experts. Restrictions to socialize and carry out leisure outdoor activities, including recreational fishing, could have specifically contributed to some loss of social well-being.

## Online Survey to Fishers

We obtained 5,998 answers in the different online questionnaires from recreational fishers from 15 countries of America (406 answers), Asia (2), Europe (5,573), and Oceania (17; **Figure 1**). Shore angling was the most popular modality (54% of the respondents reported using this platform and gear), followed by boat angling (45%), shore spearfishing (29%), boat spearfishing (21%), shell fishing (7%), and recreational fishing operating with nets and commercial-like gears (1%; **Table 1**).

Most fishers were men (98%), with an overall mean age of 44.52 ± 12.82 years, and a mean BMI of 26.61 ± 3.94, which is equivalent to moderate overweight (CDC, 2021). On average, fishers lived in a household with 2.95 ± 1.28 members and showed an intermediate income level[3]. More than half of the fishers finished secondary school education (59%), followed by those that obtained a university degree (22%), and those who only finished primary school (19%). Most fishers were married or lived with a partner (74%), followed by singles (19%), divorced, or separated persons (6%), and widowers (1%; **Table 1**).

The answers of the respondents (4,788 after excluding incomplete cases) to the seven questions designed to capture fishers' heterogeneity suggested the existence of some clusters in the data ($H$ = 0.238), with an optimal number of two clusters ($S$ = 0.465). Most fishers were included in Group 1 (98% of total; **Figure 1**), with similar ratios in all countries, except in Australia, Denmark, New Zealand, Turkey, United Kingdom, and United States, where all fishers were included in the main cluster. All access platforms and fishing gears showed higher allocation of fishers to Group 1, with similar ratios. Fishers operating with nets and commercial-like gear were all included in Group 1.

Age and BMI of fishers in Group 1 was lower than in Group 2, while fishers of Group 2 showed lower socioeconomic status, with lower income and education levels. Thus, up to 27% of fishers in Group 2 only completed primary school (only 13% in Group 1), while only 12% obtained a university degree (up to 23% in Group 1). Furthermore, the ratio of widowers and divorcees or separated was higher among Group 2 fishers. Finally, while family size was similar between the two clusters, the relative proportion of women included in Group 2 (9% of fishers in Group 2) was higher than in Group 1 (2%; **Table 1**).

The SIMPER analysis showed some variability in the contribution of the different questions used to define the clusters. Consumption preferences of the catch, followed by centrality to lifestyle of recreational fishing, and catch preferences contributed most to differences between clusters. Attendance at fishing competitions, self-reported fishing skills and know-how, and number of target species showed a medium contribution, while C&R practices showed the least contribution (**Table 2**).

[3]Between € 1000 and € 2000 of monthly net income for the households of fishers in developed countries, and between € 600 and € 1000 in the case of developing countries.

**TABLE 1** | Description of the participants in the online survey distributed to marine recreational fishers, including details of each cluster of fishers (incomplete cases were excluded; BMI stands for Body Mass Index).

| Fishers' characteristics | | All | Group 1 | Group 2 |
|---|---|---|---|---|
| **Gear and platform (*N*)** | | | | |
| | Shore angling | 3,223 | 2,177 | 36 |
| | Boat angling | 2,711 | 2,279 | 34 |
| | Shore spearfishing | 1,756 | 1,546 | 26 |
| | Boat spearfishing | 1,252 | 1,139 | 19 |
| | Nets | 31 | 31 | 0 |
| | Shell fishing | 423 | 360 | 4 |
| **Country (*N*)** | | | | |
| | Argentina | 254 | 248 | 3 |
| | Australia | 16 | 16 | 0 |
| | Belgium | 150 | 149 | 1 |
| | Brazil | 57 | 56 | 1 |
| | Denmark | 1 | 1 | 0 |
| | France | 932 | 921 | 11 |
| | Greece | 100 | 97 | 2 |
| | Italy | 1,194 | 1,157 | 22 |
| | New Zealand | 1 | 1 | 0 |
| | Portugal | 1675 | 493 | 6 |
| | Spain | 1,520 | 1,481 | 25 |
| | Turkey | 2 | 2 | 0 |
| | United Kingdom | 1 | 1 | 0 |
| | Uruguay | 92 | 89 | 2 |
| | United States | 3 | 3 | 0 |
| **Age (years)** | | | | |
| | Mean | 44.52 ± 12.82 | 43.79 ± 12.60 | 47.93 ± 14.76 |
| **Gender (*N*)** | | | | |
| | Men | 5,850 | 4,602 | 64 |
| | Women | 107 | 84 | 6 |
| **Civil status (*N*)** | | | | |
| | Divorced or separated | 376 | 281 | 7 |
| | Married/living with a partner | 4,421 | 3,501 | 44 |
| | Single | 1,148 | 900 | 20 |
| | Widower | 49 | 33 | 2 |
| **Household members (*N*)** | | | | |
| | Mean | 2.95 ± 1.28 | 2.96 ± 1.28 | 3.0 ± 1.57 |
| **Education (*N*)** | | | | |
| | Primary | 1,155 | 620 | 20 |
| | Secondary | 3,504 | 3,007 | 44 |
| | University | 1,316 | 1,085 | 9 |
| **Income (level)** | | | | |
| | Mean | 2.38 ± 0.81 | 2.45 ± 0.80 | 2.25 ± 0.93 |
| **BMI** | | | | |
| | Mean | 26.61 ± 3.94 | 26.59 ± 3.95 | 27.24 ± 5.0 |

The two clusters showed significant differences regarding the scores given by the fishers to the seven questions designed to capture fishers' heterogeneity, both separately in the unadjusted models, as well as the final adjusted model (**Table 3**). The

**TABLE 2 |** Output of a SIMPER procedure showing the average contribution to the groupings of each of the seven questions designed to capture fishers' heterogeneity of the online survey participants (see text and **Supplementary Appendix A** for further details of the questions).

| Attribute | Contribution |
|---|---|
| Consumption preferences | 0.0997795 |
| Centrality to lifestyle | 0.0817971 |
| Catch preferences | 0.0806974 |
| Competition's attendance | 0.0582528 |
| Skills and know how | 0.0485037 |
| Target species | 0.0468437 |
| Catch and release | 0.0445635 |

**TABLE 3 |** Outputs of the binomial generalized linear model (GLM) fitted to the two groups of fishers.

| Outcome | Predictor | Coefficient | P value | Goodness of fit ($R^2$) | AIC |
|---|---|---|---|---|---|
| Group | Catch and release | −1.1167 | 0.0085 | 0.0103 | 752 |
| Group | Catch preferences | −2.0360 | < 0.0001 | 0.3907 | 464 |
| Group | Competition's attendance | 1.2338 | < 0.0001 | 0.0541 | 719 |
| Group | Consumption preferences | −2.1094 | < 0.0001 | 0.4816 | 396 |
| Group | Centrality to lifestyle | −2.0878 | < 0.0001 | 0.4218 | 441 |
| Group | Skills and know how | −1.6425 | < 0.0001 | 0.1166 | 672 |
| Group | Target species | 1.0799 | 0.0576 | 0.0049 | 756 |
| Group | Catch and release | −1.1768 | 0.0167 | 0.8355 | 140 |
| | Catch preferences | −1.6194 | < 0.0001 | | |
| | Competition's attendance | 1.4757 | < 0.0001 | | |
| | Consumption preferences | −2.1502 | < 0.0001 | | |
| | Centrality to lifestyle | −1.9035 | < 0.0001 | | |
| | Skills and know how | −1.2408 | 0.0272 | | |
| | Target species | 1.1656 | 0.0364 | | |

*We show the estimated model coefficients (compared to Group 1) and p-values for the predictors (seven questions designed to capture fishers' heterogeneity, see text and **Supplementary Appendix A** for further details of the questions) of unadjusted, and of final adjusted models. The error structure (family), values of Akaike's information criterion (AIC), and goodness of fit ($R^2$), are also provided.*

adjusted model ($R^2$ = 0.836) showed that fishers in Group 1 consumed more of their catches ($p < 0.001$), fishing was more important for their lifestyle ($p < 0.001$), showed a preference to catch (few) larger fish than (many) little fish ($p < 0.001$), attended less fishing competitions ($p < 0.001$), considered their fishing skills and know-how to be greater ($p = 0.027$), practiced C&R more ($p = 0.017$), and were more selective in terms of their target species ($p = 0.036$; **Figure 3**). From now on we will call the fishers of Group 1 *advanced*, and those of group 2 *basic*, in reference to the theoretically expected progress made during recreational activity careers (Bryan, 1977; Scott and Shafer, 2001).

## Impacts of COVID-19 on the Ecosystems

We found evidence in both unadjusted and final adjusted models that fishers of the two clusters differed in their perception of the expected changes in ecosystems due to variations in the recreational and commercial fishing effort because of the COVID-19 pandemic (**Supplementary Table 1**). *Advanced* fishers did not expect increases in fish abundances because of potential reductions in recreational fishing effort during the pandemic, while the positioning of *basic* fishers was neutral ($p = 0.012$, final adjusted GLM, $R^2$ = 0.036; **Supplementary Figure 1**). In contrast, *advanced* fishers did expect important increases in fish abundances after (even low) reductions in commercial fishing effort, while *basic* fishers did not ($p < 0.001$, $R^2$ = 0.034; **Supplementary Figure 2** and **Figure 4**).

In addition to some differences between countries, fishers that were older ($p = 0.001$), and with higher education level ($p = 0.047$ and $p < 0.001$, comparing secondary and university studies with primary school, respectively) were more skeptical of the benefits to the ecosystems derived from reductions in recreational fishing effort during the pandemic. However, the same group of fishers expected greater benefits to fish stocks from reduced commercial fishing effort ($p = 0.028$ in the case of age, and $p = 0.006$ comparing university with primary education; **Supplementary Table 1** and **Supplementary Figures 1, 2**).

## Impacts of COVID-19 on Fishers' Well-Being

Concern about self-perceived health conditions related to the COVID-19 pandemic was very high among *advanced* fishers, while much lower for *basic* fishers ($p < 0.001$ in the final adjusted GLM, $R^2$ = 0.094). In addition to some differences between countries, concerns about health increased with age ($p = 0.001$) and BMI of the fishers ($p = 0.011$), while decreased with economic status ($p < 0.001$; **Supplementary Table 1**, **Figure 4**, and **Supplementary Figure 3**).

The perceived negative affect of *advanced* fishers was very high because of the COVID-19 pandemic, while it remained stable for *basic* fishers ($p < 0.001$, $R^2$ = 0.038). Some differences between countries were found in relation to the emotional stability of fishers, while overall fishers' mood improved with age ($p < 0.001$), and economic status ($p = 0.018$; **Supplementary Table 1**, **Figure 4**, and **Supplementary Figure 4**).

Quality of night sleep was poorer during the COVID-19 crises for *advanced* fishers, whereas it remained unchanged for *basic* fishers ($p < 0.001$, $R^2$ = 0.032). We also found differences between countries in terms of the reported quality of sleep. Moreover, satisfaction with night rest improved with age ($p < 0.001$) and economic status ($p = 0.018$), decreased with family size ($p = 0.036$), it was better for men than for women ($p < 0.001$), and for married and single than for divorced persons ($p = 0.007$ and $p = 0.022$, respectively; **Supplementary Table 1**, **Figure 4**, and **Supplementary Figure 5**).

Fishers reported in general much lower fish intake than before the COVID-19 crises, either because they fished less, or because they bought less fish (**Figure 4**). *Advanced* fishers showed the greater reduction in fish consumption habits ($p < 0.001$, $R^2$ = 0.031). Fish consumption varied among fishers

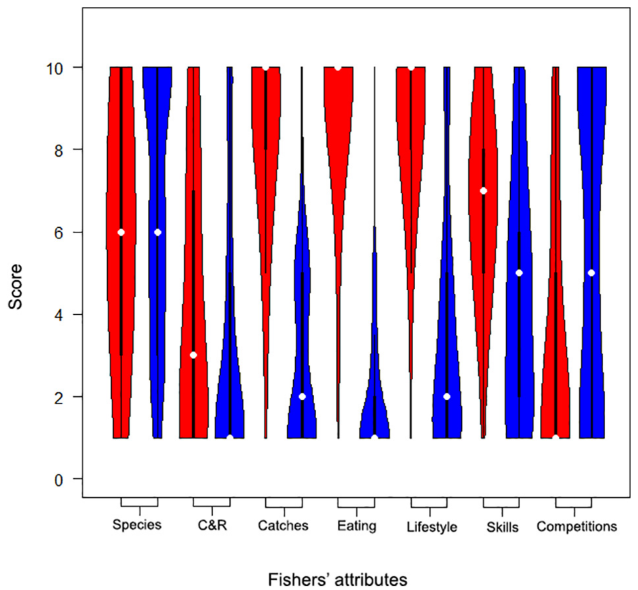


**FIGURE 3 |** Scores by a cluster of fishers (in red Group 1 -*advanced*-, in blue Group 2 -*basic*-) obtained in seven questions designed to capture fishers' heterogeneity during the online survey. It is shown the mean value of fishers' scores when asked about the number of target species ("species"), scored between "1," meaning one species, and "10," meaning no preferences; catch and release of live fish practices ("C&R"), scored between "1," meaning no fish are released, and "10," meaning all fish are released; catch preferences ("Catches"), scored between "1," meaning a preference for (many) little fish, and "10," meaning a preference for (few) large fish; consumption preferences ("eating"), scored between "1," meaning that the caught fish is not consumed, and "10," meaning that all catches are consumed; centrality to lifestyle of recreational fishing ("lifestyle"), scored between "1," meaning not at all important, and "10," meaning very important; fishing skills and know-how ("skills"), scored between "1," meaning poor, and "10," meaning high; and attendance to competitions ("competitions"), scored between "1," meaning never attending, and "10," meaning participating in all competitions (see text in section "Study Design," and **Supplementary Appendix A** for further details of the questions). The top and bottom of the thick black lines correspond to the first and third quartiles of the data, the thin black lines extend to 1.5 times the interquartile range, and the median is indicated with a white dot. A two-side rotated kernel density estimation of each distribution is also shown.

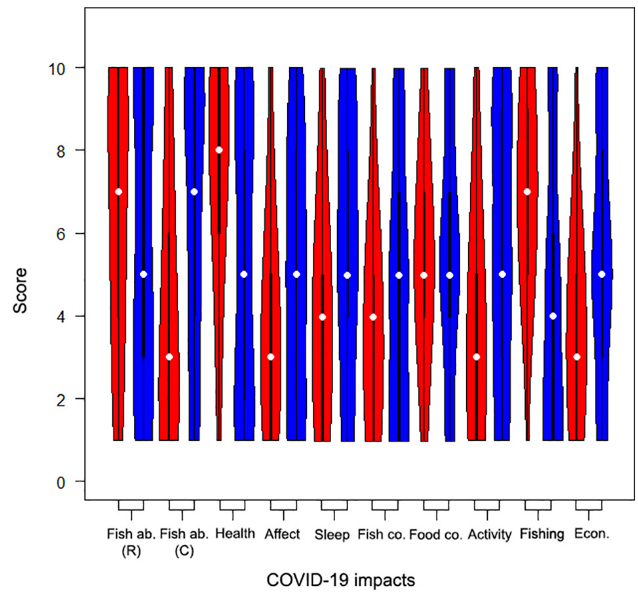


**FIGURE 4 |** Results of the online survey about impacts of COVID-19 in marine recreational fisheries by cluster of fishers (in red *advanced* fishers, in blue *basic* fishers). It is shown the mean value of fishers' scores, between "1," meaning strongly agree, and "10," meaning strongly disagree, when asked about expected increases in fish abundances ("fish ab.") because reductions in recreational fishing access ("R"); and when asked if they expect little changes in fish abundances because commercial fishing effort was not significantly reduced ("C"). It is also shown their perceived health condition ("health"), scored between "1," meaning not worried, and "10," meaning very concerned; their perceived negative affect ("affect"), scored between "1," meaning sadder, restless, irritated, or disgusted, and "10," meaning less sad, restless, irritated, or disgusted; their perceived quality of night sleep ("sleep"), scored between "1," meaning much worse, and "10," meaning much better; their fish consumption ("fish co."), scored between "1," meaning lower, and "10," meaning higher; their overall healthy food habits ("food co."), scored between "1," meaning less intake of fresh fruit and vegetables, and "10," meaning more fresh fruits and vegetables in diet; their physical activity ("activity"), scored between "1," meaning much less exercise, and "10," meaning much more exercise; their planned fishing activity ("fishing"), scored between "1," meaning expected reductions in fishing access, and "10," meaning expecting more time fishing; and their perception on the economic ("econ.") situation, scored between "1," meaning expecting very negative trends, and "10," meaning expecting very positive trends. The top and bottom of the thick black lines correspond to the first and third quartiles of the data, the thin black lines extend to 1.5 times the interquartile range, and the median is indicated with a white dot. A two-side rotated kernel density estimation of each distribution is also shown.

living in the different countries and increased with fishers' age ($p < 0.001$) and economic status ($p = 0.009$; **Supplementary Table 1** and **Supplementary Figure 6**). On the contrary, overall healthy diet habits remained unchanged (**Figure 4**), without differences between the two clusters of fishers ($p = 0.715$ in the unadjusted GLM). However, we found some differences between countries, age, and BMI, with healthier food consumed by older fishers ($p < 0.001$), and unhealthier food consumed by people with higher BMI ($p = 0.002$; **Supplementary Table 1** and **Supplementary Figure 7**).

*Advanced* fishers reported a step decrease in physical activity during the pandemic, while exercise habits of *basic* fishers did not vary ($p < 0.001$, $R^2 = 0.049$; **Figure 4**). Fishers reported different levels of activity in each country, while in general, exercise moderately increased with age ($p = 0.001$) and income ($p = 0.008$), and strongly decreased with BMI ($p = \ < 0.001$; **Supplementary Table 1** and **Supplementary Figure 8**). Moreover, *advanced* fishers anticipated strong increases in their recreational fishing effort, while *basic* fishers expected to go fishing a little less in the future ($p < 0.001$, $R^2 = 0.062$; **Figure 4**). There were some differences between countries and education levels regarding expected recreational fishing effort after the pandemic. Also, older fishers ($p < 0.001$) with bigger families ($p = 0.007$) believed that they will reduce time devoted to fishing in the future, while people with higher BMI expect to go fishing more often ($p = 0.001$; **Supplementary Table 1** and **Supplementary Figure 9**).

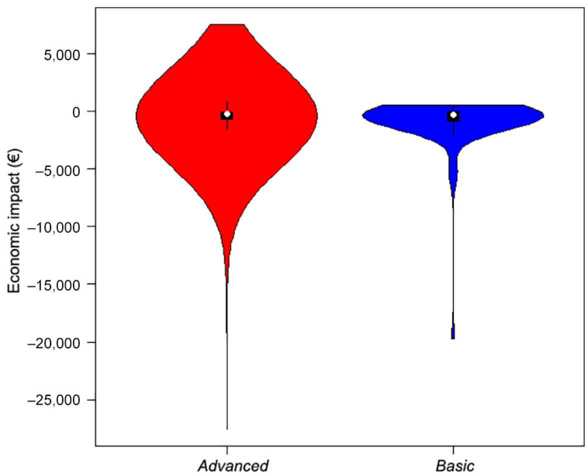


**FIGURE 5 |** Economic impact of COVID-19 on each recreational fisher obtained in an online survey. It is shown the mean reported change in expenses (Euros·fisher$^{-1}$) by cluster of fishers. The top and bottom of the thick black lines correspond to the first and third quartiles of the data, the thin black lines extend to 1.5 times the interquartile range, and the median is indicated with a white dot. A two-side rotated kernel density estimation of each distribution is also shown.

### Economic Impacts of COVID-19

Advanced fishers were very pessimistic about overall economic perspectives after the COVID-19 pandemic. In contrast, *basic* fishers did not expect economic changes in either direction ($p < 0.001$, $R^2 = 0.051$; **Figure 4**). Fishers' perception of the economic scenarios because of the pandemic differed between countries and improved with age ($p = 0.011$) and economic situation ($p < 0.001$), while worsened with family size ($p = 0.004$; **Supplementary Table 1** and **Supplementary Figure 10**).

Mean overall economic impact derived from the loss of investments and running costs during the first months of the pandemic was estimated at 504.74 ± 1244.05 €·fisher.[1] However, up to 17% of respondents did not show changes in their expenses related to recreational fishing, while 4% of fishers increased them (all of them *advanced* fishers). Reported economic reductions were somewhat higher for *basic* fishers ($p = 0.029$, $R^2 = 0.037$), as none of them showed increases in their expenses, unlike *advanced* fishers (**Figure 5**). In addition to differences between countries, negative economic growth was more relevant for fishers with higher incomes ($p < 0.001$; **Supplementary Table 1** and **Supplementary Figure 11**).

## DISCUSSION

The experts consulted in this study concluded that marine recreational fishing access was reduced during the first year of the COVID-19 pandemic, especially during temporal lockdowns imposed in most countries. According to this, recreational fishers reported in the online survey that they reduced their physical activity and fish consumption, especially in the case of *advanced* fishers, for whom recreational fishing is central for their lifestyle, and the consumption of the catch is very important. The restrictions affecting recreational fishing access intensified the important negative effects of the pandemic on the perceived health and well-being of recreational fishers. Thus, *advanced* fishers experienced a poorer night rest, and consequently showed higher concerns about their health status, and worsened mood. Furthermore, both the consulted experts and *advanced* fishers agreed that the economic impact derived from the limitations imposed on recreational fishing was highly relevant, with average economic losses derived from the decrease in expenses of the fishers during the first months of the pandemic of 505 €·fisher.[1] On the other hand, both experts consulted, and surveyed fishers expected some benefits for marine ecosystems derived from reductions of human impacts during the COVID-19 pandemic. In general, they agreed that the reductions on commercial fishing effort were more beneficial to fish stocks and marine ecosystems than reduced recreational fishing effort.

### Global Importance

Results of the survey to recreational fishers and of the expert consultation showed that it is expected that global fish stocks could benefit from the reduction of the impacts of commercial fisheries during the COVID-19 pandemic, in line with what was found in recent studies (e.g., Kemp et al., 2020; Coll et al., 2021; Ferrer et al., 2021; White et al., 2021a). Whether reductions of recreational fishing effort will accrue similar benefits is less clear for recreational fishers, especially in the case of older and more educated fishers. However, as already pointed out by Cooke et al. (2021) in global freshwater recreational fisheries, consulted experts identified some benefits derived from reduced marine recreational fishing pressure, especially on highly vulnerable target species like Argentinian sandperch or broadnose sevengill shark in America, and Atlantic cod, Atlantic halibut, Atlantic salmon, Atlantic wolffish, dusky grouper, European seabass, redfish, rubberlip grunt, saithe, or white seabream in Europe. Furthermore, the experts indicated that overall reductions in human disturbances, including pollution and noise, led to an increase in the abundance of infrequent species near the coast, which resulted in an increase in recreational fishing opportunities (see e.g., Edward et al., 2021). However, experts also noted that recreational human pressure on marine ecosystems near large population hubs was increased after lockdowns, when people were allowed to practice outdoor activities, including fishing, while activities in closed spaces and travels were restricted, or banned. The greater free time of people due to rising unemployment may also have contributed to increased human pressure on these areas. Consequently, human impacts escalated in the already most ecologically degraded areas, as it was found in different marine ecosystems (China et al., 2021; Gundelund and Skov, 2021). Furthermore, some of the experts consulted in this study confirmed that more recreational fishing licenses were issued in many countries during the COVID-19 pandemic, which suggests an increase in the number of fishers. Although restrictions affecting access and mobility of recreational fishers prevented increases in the overall fishing effort, newcomers may have caused greater fishing mortality, because these fishers tend to retain more fish (Gundelund and Skov, 2021). We also showed a similar pattern in our results, with *advanced* fishers practicing more C&R. In consequence, the consulted experts showed some concerns regarding higher retention rates of fish species with key ecological roles, like billfishes and groupers.

The overall reduction in the access to recreational fisheries has also had a significant economic impact, as recognized by the experts consulted and by the fishers in the surveys. This was particularly the case for those fishers with greater economic power, who reduced their expenses to a greater extent. As a rough estimate, taking into account the loss of investments and running costs indicated by the fishers (505€ on average), and the numbers of marine recreational fishers operating worldwide estimated by Cisneros-Montemayor and Sumaila (2010), the economic impact of the first year of the COVID-19 pandemic on global marine recreational fisheries would be around 29 billion €, approximately half of the annual investments generated by recreational fishers globally.[4]

In addition to the economic impacts derived from the reduced activity of recreational fishers in many countries during the COVID-19 pandemic, the consulted experts highlighted important indirect effects on fishers' health and well-being. Experts anticipated a greater importance of these types of impacts in countries where social relevance of fishing is deeply rooted (see Cohen and Lemay, 2007; Rosenquist et al., 2011), such as in southern European countries (Pita et al., 2018b, 2020), and lower impacts in those countries that imposed fewer restrictions on outdoor leisure activities, including recreational fishing, such as Latvia, the Netherlands, Norway, or Uruguay. As a result of restrictions affecting access to the fishery, recreational fishers in general, and especially *advanced* fishers, showed lower physical activity and lower fish consumption. Recent studies on the impacts of the COVID-19 pandemic on different recreational activities also showed results like those found in our study; e.g., Howarth et al. (2021) noted that fish consumption was lower among recreational fishers during the pandemic, while Curtis et al. (2021) concluded that the physical activity of the population decreased. Consequently, it is not surprising that the fishers surveyed in this study reported poor night rest, worse mood, and concerns about their health condition, especially in the case of *advanced* fishers.

Many of the consulted experts highlighted the unequal distribution of the socioeconomic impacts derived from the loss of access to recreational fishing, affecting more seriously coastal populations highly dependent on tourism, and vulnerable people dependent on fishing for food (Nieman et al., 2021). Therefore, unemployed, or poor persons, refugees, immigrants, ethnic minority groups, and other sensitive social groups would be the most impacted (Lee and Miller, 2020). In fact, we showed that fishers' concerns of the economic situation due to the pandemic improved with economic status, while a comfortable economic situation mitigated the main negative impacts on their health and well-being.

## Limitations of the Study

The consultation of experts in marine recreational fishing had a good coverage in Europe but it was limited in other areas, most probably because of the early involvement of the Spanish working group, and of the higher proportion of Europeans in the ICES WGRFS. Similarly, although the online survey of fishers had a greater geographic coverage than the expert consultation, including all continents (except Africa), a higher number of responses were also obtained from Europe and South America. The limited information gathered for North America and Oceania is more important than for Africa and Asia, where marine recreational fishing is relatively less prominent (Potts et al., 2019). However, despite limitations regarding coverage, our results provide a reasonable diagnosis of the COVID-19 pandemic impacts on global marine recreational fishing.

We obtained a convenience, non-random sample by using a self-administrated questionnaire in the online survey distributed to marine recreational fishers. Despite efforts to promote the existence of the online survey, including an international marketing campaign, many fishers either did not know about the survey or did not respond for some reason. Therefore, this sample may not be representative of the world population of marine recreational fishers or even of individual surveyed countries (Fisher, 1996; Venes, 2017). Spear fishers are probably overrepresented in the sample, likely due to the high number of responses obtained in countries of southern Europe, where this fishing modality has a greater relative importance than in other areas (Pita et al., 2017).

It is not possible to determine whether the ratio between groupings obtained in our survey, i.e., *advanced* (with up to 98% of fishers) versus *basic* (2%), could be globally escalated. Taking into account the four "personas" identified by Bryan's (1977) seminal work on typologies of trout anglers, our *advanced* fishers would include Bryan's "technique specialists" and "technique setting specialists," while our *basic* fishers would include Bryan's "occasional" and "generalists." Considering that we identified only two groups of fishers, it could be argued that our sampling may not have fully captured the heterogeneity of global marine recreational fishers. However, the groupings found by other studies with marine fishers are relatively similar to those identified by us. Thus, Beardmore et al. (2013), e.g., found two main groups of German anglers: a majority group (ca. 60% of total anglers) consisting of anglers with equivalent characteristics to our *advanced* fishers, and a much smaller one (ca. 30%) integrated by *basic*-like anglers. Furthermore, the questions that we used to group the fishers showed, in general, a similar performance than the ones used by Beardmore et al. (2013). In both studies centrality to lifestyle and catch preferences were very important to predict the typologies of fishers; skills and know-how were of moderate importance, while C&R practice was less relevant. Conversely, consumption preferences were the most important attribute for our groupings, while it was of much less importance in the case of German anglers. A greater variability in our sample in relation to the consumption of catches by fishers could explain the differences, which suggests that our sample is reasonably heterogeneous, at least in relation to this dimension. Nevertheless, in the absence of specific

[4] Cisneros-Montemayor and Sumaila (2010) estimated that globally there are about 58 million marine recreational fishers that in 2003 generated 39.7 billion USD in expenditures, which is equivalent to 64 billion € in current money. In our estimate we did not take into account multiplier effects of fishers' expenses on the economies, especially in touristic areas.

studies on large populations of marine recreational fishers, it is not possible to determine to what extent our sample reflected the heterogeneity of worldwide marine recreational fishers. In this sense, due to the different characteristics of recreational fisheries in industrialized countries (Arlinghaus et al., 2014), a greater representation of countries in Northern Europe and North America, as well as the most developed countries in Oceania, would perhaps result in changes in the groupings identified in our study. However, although we acknowledge these limitations, we did not make inferences or extrapolations to the overall population. Instead, we exclusively use the results to make comparisons between the two groups of fishers identified: *advanced* versus *basic*.

Recall and declaration biases (Pollock et al., 1994) could also have affected both the experts consulted and the fishers surveyed. However, since our recall period was limited to the previous months (3 months in the online survey) it is not expected that the responses are affected by substantial recall bias. It cannot be ruled out that some of the experts and fishers surveyed have answered some questions idiosyncratically according to their convenience, or to accommodate to their preconceptions. We hope that the size of the sample, that includes a high degree of redundancy in the case of expert consultations, may have contributed to limiting this bias.

### Governing Marine Recreational Fishing in Future Pandemics

Policy makers are generally not aware of the enormous diversity of attitudes of recreational fishers (Johnston et al., 2010; Knoche and Lupi, 2016; Magee et al., 2018), and how they influence their interaction with other components of socio-ecological systems (Fenichel et al., 2013; Hunt et al., 2019; Matsumura et al., 2019). Although this study showed the importance of recreational fishing for the health and well-being of all practitioners involved, we demonstrated that the COVID-19 pandemic had a greater impact on *advanced* fishers.

During the COVID-19 socioeconomic crises, policy makers sometimes were not able to clearly define which activities should be considered essential during lockdowns, with important differences within and among countries (Storr et al., 2021). We highlighted important spatiotemporal differences regarding the possibility of practicing marine recreational fishing, varying according to the development of the pandemic between countries, and even regions within countries. Thus, while in most countries recreational outdoor activities, including marine recreational fishing, were not allowed for some periods, in some countries (e.g., Denmark, Latvia, the Netherlands, Norway, or Uruguay in our study), or the United States (Paradis et al., 2021), governments encouraged outdoor activities keeping social distances.

Social restrictions imposed in many countries led to an increase in the global demand of the population for the outdoors (Ding et al., 2020), and the more *advanced* recreational fishers particularly suffered from a lack of access to blue areas, especially for those living in urban areas (Rice et al., 2020; Venter et al., 2020; Herman and Drozda, 2021; White et al., 2021b). As a result of the frustration of fishers with restriction measures imposed to recreational fishing access there were some protests, e.g., in France, or Greece, at a time of great uncertainty.

Individual outdoor leisure activities facilitate social distancing and indirectly mitigate the spread of COVID-19 (Güzel et al., 2020), especially when practiced in natural areas (Venter et al., 2020). In this work, as also found by other authors (e.g., Howarth et al., 2021), we show that the practice of marine recreational fishing improves the perceived health and well-being of the population during a pandemic. Allowing access of marine recreational fishers would significantly contribute to reducing important socioeconomic impacts, especially on the most vulnerable population groups. Following Freeman and Eykelbosh (2020) distance between recreational fishers should be maximized to minimize interactions, e.g., limiting access to popular fishing spots, restricting the number of fishers on boats, or enabling temporal access restrictions to different groups of people to avoid overcrowding.

As we also demonstrated in this study, the benefits derived from lower human disturbances, among other impacts, on marine ecosystems should not be overlooked (see also Cooke et al., 2020). However, the main human impacts on global marine ecosystems are far from being reduced (Ripple et al., 2017). It is unlikely that the health of the world's marine ecosystems will show sustained improvement once the COVID-19 pandemic has been brought under control (see Corlett et al., 2020; Soga et al., 2021). Therefore, as suggested by other authors (e.g., China et al., 2021), in the event of a new pandemic in which recreational activities are not restricted in natural areas, it would be advisable to limit peoples' impacts in the more degraded peri-urban areas, favoring the dispersion of the population in larger areas to limit the excessive concentration of their impacts.

## DATA AVAILABILITY STATEMENT

The datasets presented in this article are not readily available because most of questionnaires are property of different agencies and institutes. They could be asked individually to get the data. Requests to access the datasets should be directed to PP, pablo.pita@usc.es.

## AUTHOR CONTRIBUTIONS

All authors listed have made a substantial, direct and intellectual contribution to the work, and approved it for publication.

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## SUPPLEMENTARY MATERIAL

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fmars.2021.735741/full#supplementary-material

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# Impacts of COVID-19 on the Catch of Small-Scale Fishers and Their Families Due to Restriction Policies in Davao Gulf, Philippines

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COVID-19 was declared a global pandemic by the World Health Organization in 2020 with countries putting up several measures to mitigate and flatten the curve of hospitalizations and death from travel bans to home confinements and local lockdowns. This pandemic created health and economic crises, leading to increased incidence of poverty and food crisis especially on both agriculture and the fisheries in many developing nations including the Philippines. The specific objectives of this study were to assess the impact of COVID-19 restrictions on the catch per unit effort (CPUE) of small-scale fishers and to determine what factors could influence the volume of their catch during this time of pandemic. Moreover, this also investigated the impact of COVID-19 restrictions to fishers and their families. To do that we surveyed $N = 200$ small-scale fishers around the Davao gulf using semi-structured questionnaire and inquired on the impact of the COVID-19 to their fishing operation, catch, fishing costs, and their families. The collected socioeconomic variables, including emotional responses to the pandemic were then related to the CPUE and the volume of catch. The results show that fishers were highly affected by the pandemic due to the lockdown policy imposed in the fishing villages during the earlier phases of restrictions by the government. Fishers were affected in terms of the volume of their catch, also fishing costs, and emotionally as they were also frustrated due to the impacts of the hard lockdown. The restricted fishing access was found to have important and major set-back on the fishing operations of fishers and the same was experienced also by the middlemen given the low fish price and reduced mobility of the fish traders. COVID-19 also impacted the fishers, and their families through lack of mobility, food inadequacy, travel restrictions and their children's education.

**Keywords: COVID-19, Davao Gulf, education, fishers, fisheries management, health, small-scale fisheries (SSF)**

# INTRODUCTION

## COVID-19 and Impact on Fisheries

In 2020, COVID-19 was declared a global pandemic by the World Health Organization (WHO, 2020). Countries worldwide have taken several measures to mitigate and flatten the curve of hospitalization and death through travel bans, home confinement, social distancing, local lockdowns, and business closure methods were implemented by governments all over the world (Jomitol et al., 2020; UN, 2020). This pandemic created health and economic crises, leading to increased incidence of poverty and food crisis especially on both agriculture and the fisheries (Sumner et al., 2020). Southeast Asian nations were also affected by the pandemic slowly taking over each country including the Philippines (Ferrer et al., 2021). With an island-dwelling population of more than 100 million and more than 7,100 islands, the Philippines is considered a major fishing nation with 1.6 million Filipino fishers; of these, an estimated 957,551 fishers use traditional hooks and lines, and gillnets for their daily fishing on small boats (<3 gross tons) (BFAR, 2015). The small-scale or municipal fisheries in the Philippines play a critical role in the livelihoods and food security of coastal communities and the nation (Perez et al., 2012). The drastic implications of COVID-19 lockdown in small-scale fisheries (SSF) have become evident, manifestations include, closing down of fishing operations, closed market stalls affecting food security (Béné et al., 2015; Gregorio and Ancog, 2020; Ferrer et al., 2021). Past pandemics show that quarantines and panic not only affect human activities and economic growth but it also affects fisheries supply chains, tourism, and agricultural activities that induces hunger and malnutrition as well as psychological impacts (Bermejo, 2004; Cullen et al., 2020; Sunny et al., 2021).

## COVID-19 and Movement Restrictions

Enhanced Community Quarantine (ECQ) started in mid-March 2020 in response to the COVID-19 pandemic. The ECQ meant "stay at home" as mobility and transportation (air, water, and land) were restricted (Ferrer et al., 2021). It affected people's daily activity patterns or regular movements and habits from jogging, walking to dining in restaurants, which were previously thought normal or usual (Simunek et al., 2021). In the fisheries, movement restrictions significantly affected the fishers and also affected fish supply and demand, including fish distribution, labor and production of fish (Love et al., 2020; Belton et al., 2021). It is estimated that 10% of the global population depends on SSF for their livelihood, resulting in rising food insecurity among fishing communities (Sunny et al., 2021). In Sabah, Malaysia, researchers found that mobility control procedures negatively affected fish trading of small-scale fishers (Jomitol et al., 2020).

Further, crowding at fish landing sites in Ghana suggested the potential for spreading COVID-19 within the fisheries sector (Okyere et al., 2020). In the case of Wuhan and Shenzhen in China they imposed a draconian measure of travel restrictions and mobility limitations to evaluate whether this will help control the rapid spread of the virus (Chinazzi et al., 2020; Zhou et al., 2020). Responses to COVID-19 pandemic varied from one place to another, some countries are reopening workplaces, schools and social gatherings to adapt to their economies and others are suppressing transmission through restricting business industries, and schools while waiting for the vaccines (Abolfotouh et al., 2021).

## COVID-19 and Disruptions on Families of Fishers

This pandemic had affected almost every aspect of life, including fishers and their families (Bennett et al., 2020; Demirci et al., 2020). During the pandemic, the price of fish decreased due to restrictions making it more difficult for fishing families to conduct their daily activities (Hidayati et al., 2021). Even though the situation has disrupted the fishers' economy, most of them still fished every day and ignored its possible effect on their health and fishing costs (Kaewnuratchadasorn et al., 2020). This is because they have no alternative livelihood (Avtar et al., 2021). The closing of educational institutions also appears to be a problem for the fisher's family (Chaturvedi et al., 2021). With the school closures implemented, a rapid transition from physical to digital sphere of learning emerged (Kapasia et al., 2020). Online learning has now become an alternative to conventional learning (Bestiantono et al., 2020). Due to this abrupt change, students from less privilege homes experienced a more significant negative impact due to reduction of family income caused by the COVID-19 outbreak; this also made it more challenging to have access to digital resources such as costly internet connection (Aucejo et al., 2020; Lee, 2020). Because of the preceding reasons, fishers need to make a tough decision by risking themselves to feed their family although by continuing to operate their fishing ventures makes them vulnerable to the disease (FAO, 2020a). This study aimed to understand and assess the impact of COVID-19 to small-scale fishers of Davao Gulf, Mindanao. The specific objectives of this study were to assess the impact of COVID-19 restrictions on the catch per unit effort (CPUE) of small-scale fishers and to determine what factors could influence the volume of their catch during this time of pandemic. Moreover, this also investigated the impact of COVID-19 restrictions to fishers and their families.

# METHODOLOGY

## Description of the Study Area

The study was conducted in Davao Gulf, located in southern Philippines on the Island of Mindanao (**Figure 1**). It lies approximately between 6°30′00′′ North longitude and 125°58′35′′ East latitude. The water surface area is about 3,087 $km^2$ and tide in the area is predominantly semi-diurnal, with two high and two low water levels occurring in a day. Fisheries production in Davao Gulf was dominated by commercial fishing having an annual average catch percentage of 88% compared to municipal fishing (SSF) which only comprised 12% of the average catch in past years (Villanueva, 2018).

The different study sites include Governor Generoso, San Isidro, Pantukan, Mabini, Toril in Davao City, Samal Island, Sta Cruz, Sta Maria, and Malita. These areas were mainly agricultural producing towns with known products such as banana, coconuts,

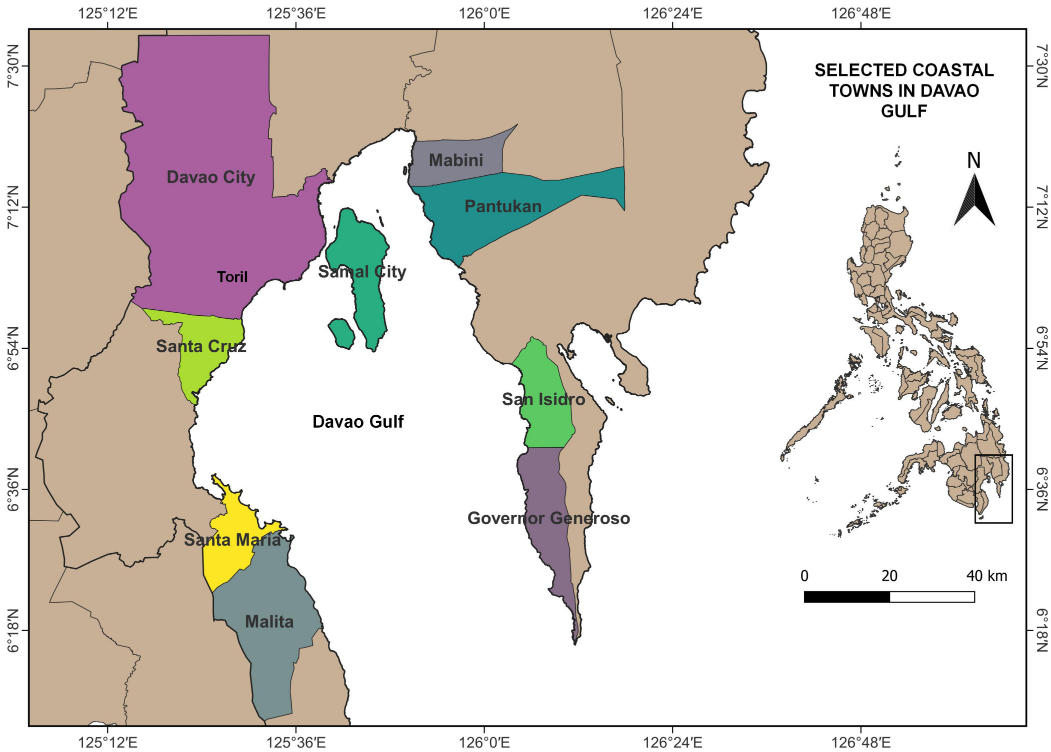


**FIGURE 1 |** The study sites around the Davao Gulf where the impact of COVID-19 surveys were conducted with small-scale fishers (SSF) and their families.

cacao, durian, and pomelo, and harboring rich fishing grounds. Some of these sites have well-paved roads, irrigation and farm-to-market roads, food terminals and fish ports, access to micro-credits, and rural banks and cooperatives (see **Table 1**). However, the lack of centralized market depot for agricultural and fish products logistics are missing even in Davao City. Normally, small-scale fishers use hooks and lines, traps, spear fishing, longlines, gillnets, and payaos in their fishing activities (Macusi, 2017). Common catch species in the area include bigeye scad, roundscad, frigate tuna, bullet tuna, bali sardines, skipjack tuna, yellowfin tuna, groupers, and other coral reef fish species (Macusi et al., 2021). Other marine life forms found in the Davao Gulf include sea turtles and other cetaceans that face the brunt of climate change impacts and marine pollution (Abreo, 2016; Abreo et al., 2016).

## Data Collection

A survey interview was conducted using the semi-structured questionnaire which contained both close-ended and open-ended questions in order to obtain information from the respondents. The information obtained included the names of fishers, their residence area, age, household size, fishing hours, fishing frequency and fishing areas, catch composition, fish prices, fishing costs, and their reactions to the impact of the COVID-19 restrictions. The respondents of the study were 90% boat owners which was also the same as in the study of Macusi et al. (2021) on SSF in Davao Gulf. Fishers ($N$ = 200 respondents) were randomly selected from various study sites and they were engaged in fishing and fishing-related activities for at least a year or full-time. They use simple fishing gears such as hook and line, multiple hook and line and gill nets. According to the Bureau of Fisheries and Aquatic Resources (BFAR), vessel with the capacity of 3 tons below is considered to be small-scale fishing boats in the Philippines. The interview lasted for 15–20 mins, and was conducted one-to-one while the interviewer listed down the answers of the respondents. The interview was carried out at the homes of the respondents, near the community fish port and barangay halls. Before the interview, permission letters were sent to the office of the barangay captain and repeated visits required also the same courtesy call to the local government because of the present pandemic.

## Data Analyses

### Statistical Analysis

After the interview, all data were encoded in Microsoft excel 2016 and subsequently a preliminary analysis was done using Analyse-it excel add-on software. All possible dependent variables were checked for their normality and homogeneity, with the catch and CPUE in particular and plotted on graphs for visualizations [The CPUE was derived from the average reported catch (kg) and from the number of fishing hours (hr) spent by the fisher when fishing]. This data was then $\log_{10}$ transformed when it violated the assumptions of ANOVA. To analyze the data on the influence of various factors on the CPUE of the small-scale fishers during the time of COVID-19, we reduced the number of factors into four variables namely fisheries (fishing frequency, fish hold

**TABLE 1 |** Number of population and registered fishers and their livelihood in the various study sites around Davao Gulf.

| Profile | Governor Generoso | San Isidro | Pantukan | Mabini | Samal | Davao City | Sta Maria | Sta Cruz | Malita |
|---|---|---|---|---|---|---|---|---|---|
| Population | 55,109 | 36,032 | 85,899 | 41,102 | 1,04,123 | 1.63M | 53,671 | 90,987 | 1,17,746 |
| Registered Fishers | 2,300 | 1,551 | 1,904 | 1,067 | 5,936 | 5,510 | 3,200 | 4,011 | 800 |
| Average Farm Area (h) | 2.7 | | 2.5 | | 2.7 | 4.5 | | 3 | |
| Annual Municipal Fisheries Production (mt) | 9.38 | | 1.43 | | 4.98 | 16.09 | | 13.66 | |
| Agricultural sources of livelihood | Fishing, farming (coconut and banana), mining, community fish port, and services | Fishing, farming (coconut and banana), tourism, and services | Fishing, farming (coconut and banana), tourism, mining, and services | Fishing, farming (banana), services, shipping, and tourism | Fishing, farming, tourism, port, and services | Fishing, farming (coconut, cacao and banana), banking services, shipping, and ports | Fishing, farming, services, and makeshift fish port | Fishing, farming, industrial, services, makeshift fish port, and ice plant | Fishing, farming (coconut and banana) community fish port |
| Infrastructure | Ice plants, community fish port, and paved roads | Ice plants, community fish port, paved roads, and small public market | paved roads, small public markets, and recreation centers | paved roads, small public market, and recreation centers | Ice plants, community fish port, paved roads, parks, and recreation | Ice plants, industrial area, community fish port, paved roads, parks, and recreation | Ice plants, community fish port | Ice plants, community fish port, paved roads, and recreation centers | Ice plants, community fish port, and paved roads |

capacity, and proportion of catch sold), emotional (frustrating, anger, fear, and hope), sociodemographic (age, household size, number of years fishing, and years of education), and financial variables (revenue, gear maintenance, boat maintenance, and total fish costs) using PCA (principal component analysis). This was similar to the method used in our previous manuscripts for variable reduction (Macusi et al., 2020, 2021). The obtained variables were then used as predictors for what mainly influences the CPUE (dependent variable) using a multiple linear regression. Aiming to further analyze the data on which factors were highly influencing the volume of catch during the time of pandemic (on whether it causes a reduction of the volume or it remains the same as the pre-pandemic volume of catch), a binary logistic regression was done and different factors were related to the response variable. These variables are shown in **Table 2** which shows their description and mean, fishing hours, proportion catch sold, fishing costs (Php), fish hold capacity (kg), fishing frequency, age (years), education (years), household size, number of years fishing, revenue (Php), emotions (frustrating, anger, fear, and hope). All data analyses were conducted using MINITAB 17.0 (State College, PA, United States).

### Qualitative Data Analysis

Qualitative data analyses were conducted using the coding method (Dey, 2005) where specific words that are often repeated by respondents were counted, classified and then discussed. To do that, a general and bigger category or theme was identified based on the responses regarding impacts of COVID-19 that is about 15 groups and then reduced to 10 categories or themes for frequently cited impacts of the COVID-19 restrictions, and the challenges that the particular fishers and their families faced during the height of the pandemic in 2020. These were subjective groupings and frequently influenced by previous readings on the current impacts of COVID-19. The resulting frequency was visualized and refined further, and the final result was organized on a table.

## RESULTS

### Socio-Demographic Profile

Results show that the average age of fishers in the study sites: San Isidro (48 years old), Samal (47 years old) and Toril (46 years old) were highest; this was followed by Pantukan (43 years old), Mabini (42 years old), Governor Generoso and Sta Cruz (41 years old), while Malita (39 years old) and Sta Maria (36 years old) were the lowest in age (**Figure 2A**). Toril (Davao City) had the highest average fishing experience of 28 years followed by San Isidro with 26, Samal and Pantukan with 25, Sta Cruz with 21, Malita with 20 while Governor Generoso and Mabini shared the same fishing experience of 19 years and Sta Maria with 12 years of fishing experience had the lowest (**Figure 2B**). The highest number of respondents mentioned elementary level as their highest level of education with a percentage of 33% followed by elementary graduate with 28%, high school with 20%, high

**TABLE 2 |** Mean and range of variables used in the data analysis.

| Variables | Definition | Mean (min, max) |
|---|---|---|
| Age (years) | Age of individual fishers | 42 (15, 82) |
| Education (years) | Number of years of fishing experience of fisher | 6 (0, 13) |
| Household size | Number of individual members of the family | 4 (1, 14) |
| Number of years fishing (years) | Number of years of fishing experience | 21 (1, 62) |
| Catch per trip (kg/trip) | The volume or amount of fish catch per fishing trip | 9.84 (0.4, 40) |
| Number of fishing hours | Number of fishing hours from the time of arrival in the fishing ground up to the last fish catch | 9.64 (1, 48) |
| Catch per unit effort (CPUE; kg/hr) | Catch per unit effort based on the volume of fish catch (kg) per trip divided by the number of fishing hours | 1.28 (0.03, 7) |
| Fishing frequency | The number of times that fishers go out and fish in a week | 5 (1, 7) |
| Fish cost (Php) | The combined costs of fishing per trip, e.g., cost of bait, ice, foodpacks, and fuel | 425 (0, 8,500) |
| Proportion catch sold | The percentage or amount of fish catch sold after the portion for their families or crew members are separated | 93 (20, 100) |
| Fish price (Php) | The average fish price of all species caught by individual fishers | 135 (3, 300) |
| Fish-hold capacity (kg) | The average fish holding capacity of individual boats | 200 (35, 1,000) |
| Revenue (Php) | The amount of total fish catch (kg) multiplied by the average fish price (Php) for the fishing trip | 1300 (40, 8,700) |
| Electric bill (Php) | Latest electric bill paid during the time of pandemic (October–November 2020) | 400 (0, 3,000) |
| Water bill (Php) | Latest water bill paid during the time of pandemic (October–November 2020) | 82 (0, 600) |

school graduates with 16%, and 3% were able to reach college level and finish their vocational courses. About 1% of the fishers have no educational attainment, 0.5% for senior high level and no college graduate (**Figure 2C**). In terms of the number of household size, Governor Generoso, Mabini, and Pantukan have an average of five members, followed by Samal, San Isidro, Sta Maria, Sta Cruz, and Malita with an average of four members, overall the number of the household size was from 1 to 13 (**Figure 2D**). The dominant fish species caught were: Island mackerel (*Rastrelliger faughni*) with a frequency of 33 followed by Bali Sardines (*Sardinella lemuru*) with 31, Bigeye scad (*Selar crumenophthalmus*) with 27, roundscad (*Decapterus macrosoma*) with 18 and Frigate tuna (*Auxis thazard*) with 16 together with common squid (*Sepioteuthis lessoniana*) of the same frequency (**Figure 2E**). Out of this volume of fish catch, 52% will go to the financiers and traders, 23% will go directly to buyers, while 11% will be sold to their neighbors, 7% for family consumption, and 6% for the local markets (**Figure 2F**).

## Impact on the Catch Per Unit Effort of Fishers and Influencing Factors

Results of the multiple linear regression show that the CPUE was highly influenced by the fisheries factors (df = 4, MS = 1.63, $F = 10.40$, $p \leq 0.0001$). These fisheries factors were mainly: fish hold capacity of the boat, proportion of fish catch sold, fishing frequency, revenue and fishing costs more than any other variable such as sociodemographic (age, household size, education, and fishing experience), financial (electric and water bills) or emotional response (frustration, anger, fear, and hope). There is no relationship between the CPUE of fishers and their emotion or sociodemographic profile or bills to pay during the time of pandemic. But in terms of analyses of the influencing factors on the volume of catch (whether the volume remained the same or decreased due to the pandemic), both economic (proportion of catch sold and total fishing costs) and the emotional factor, frustration, played key roles. The logistic regression equation was highly significant (df = 14, $X^2 = 32.98$, $p < 0.003$), showing that COVID-19 highly affected the volume of catch and particularly influenced by the variables "proportion of catch sold" [$B = 0.035$ (SE = 0.0173), Wald = 4.45, df = 1, $p = 0.035$], and "fishing costs" [$B = -0.0006$ (SE = 0.0003), Wald = 4.99, df = 1, $p = 0.026$] and the emotional factor "frustration" [B = 1.425 (SE = 0.55), Wald = 7.78, df = 1, $p = 0.005$; See **Table 3**].

## Challenges Due to COVID-19 Impact in the Fisheries

The consistently high percentage ratings of restricted fishing areas (32% in Mabini and 16% in Pantukan and Malita, 11% in San Isidro and Samal, 5% in Governor Generoso, 4% in Toril and Sta Maria and 2% in Sta Cruz or an overall percentage of 36%) have shown that this was the main impact to the fisheries operation. While having a low fish price was also a similar problem (29% in Governor Generoso, 24% in Samal, 22% in Malita, 20% in San Isidro, and 2% in Malita and Sta Maria or an overall percentage of 29%). This was followed by reduced mobility by fish traders (22% in Sta Maria, and Sta Maria, 13% in Governor Generoso, Mabini and Samal, 9% in San Isidro, and 4% in Toril and Sta Cruz or an overall percentage of 15%) and travel restrictions (38% in Mabini, 22% in Malita, 15% in Sta Maria and Sta Cruz, and 8% in Samal and San Isidro or an overall percentage of 8%) (**Table 4**).

## Challenges Due to COVID-19 Impact to Fishers' Families

Results show that the high percentage ratings of lack of mobility (21% in for Governor Generoso, 17% in Malita, 15% in Samal, 11% in San Isidro, 4% in Sta Cruz, and 2% in Davao City or an overall percentage of 46%) was the main impact experienced by the fishers' families. While food inadequacy was also a similar problem (45% in Malita, 16% in Samal, 13% in San Isidro and Davao City, 10% in Mabini and 2% Sta Maria and Sta Cruz or an overall percentage of 30%). This was followed by travel restrictions (40% in Mabini, 33% in San Isidro, 20% in Sta Maria, and 7% in Samal or an overall percentage of 15%) and education

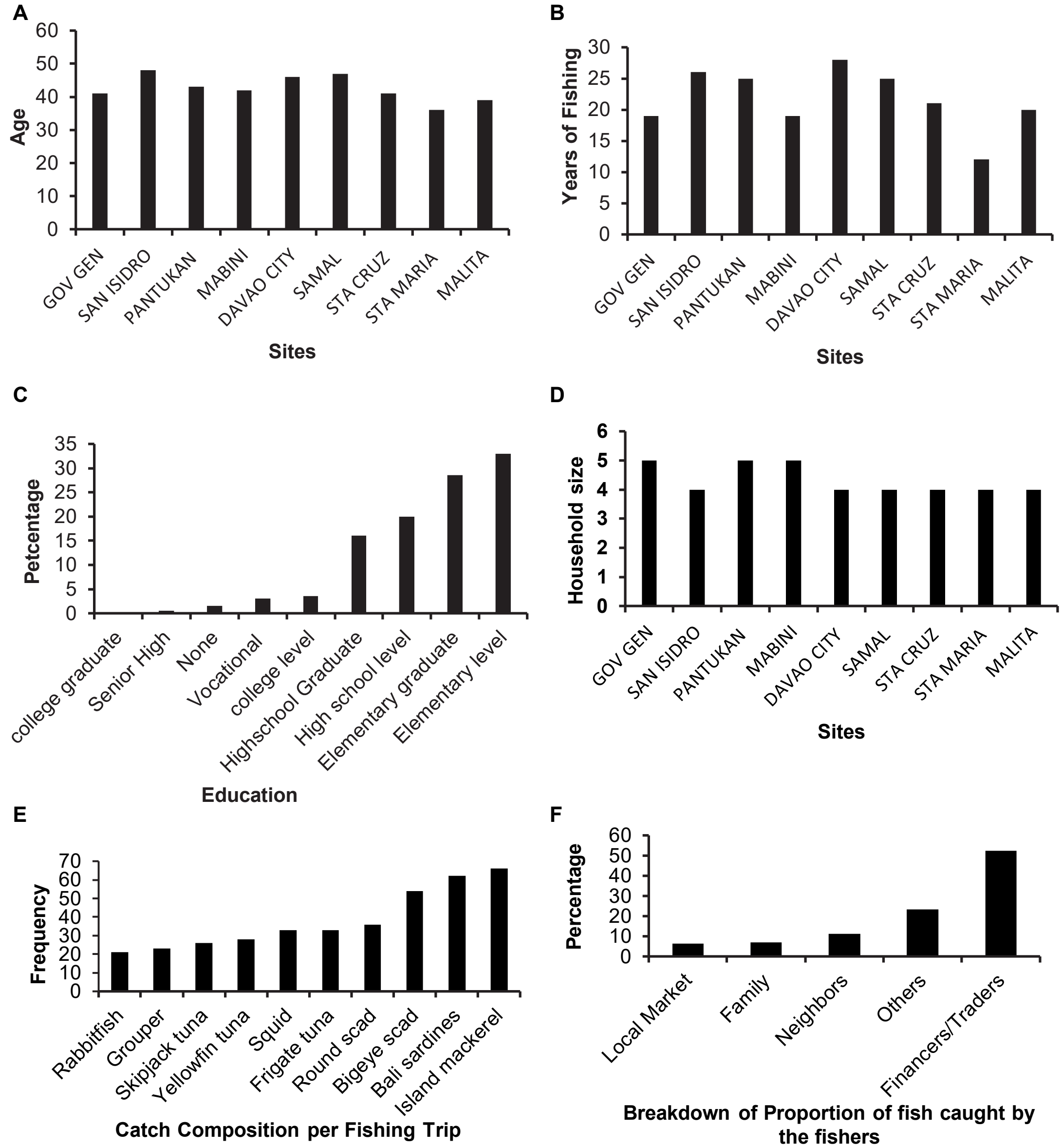


**FIGURE 2 |** Age of respondents **(A)**, household size **(B)**, years of education and **(C)** years of fishing **(D)**, catch composition **(E)**, and breakdown of proportion of fish caught by fishers **(F)**.

of their children (30% in Samal and 10% in Mabini, San Isidro, Davao City, Governor Generoso, Sta Maria, Sta Cruz, and Malita or an overall percentage of 10%) (see **Table 5**).

# DISCUSSION

## Impacts of COVID-19 Restrictions on the Fisheries

This study revealed that there is a struggle among the fishers during the first three months of the lockdown (March–May 2020). Children stopped going to school thus, giving the burden of teaching to their parents while staying at home and also working from home for these mothers. Many of the women also struggled to find jobs because they had completely stopped working to attend to their children at home. In addition, the impacts of COVID-19 was expected to take a significant toll on global fisheries with predictions of potentially negative consequences for the livelihood and income of the SSF in developing countries (Bennett et al., 2020; FAO, 2020b). Small-scale fisheries contribute to coastal communities' social and economic development as they provide food, livelihood, and income to the poor, vulnerable and marginal sectors (FAO, 2020a; Ferrer et al., 2021). However, severe implications of COVID-19 for the SSF have become more obvious (Simunek et al., 2021). Fishing area restrictions due to the implementation

**TABLE 3 |** Factors that are influencing the change in the volume of fish catch during the time of Pandemic in Davao Gulf (Significantly different factors are in bold).

| Variables | B (SE) | Odds ratio | 95% Confidence Interval for odds ratio | |
|---|---|---|---|---|
| | | | Lower | Upper |
| Fish Price (Php) | –0.003 (0.003) | 0.997 | 0.992 | 1.003 |
| Number of fishing hours | 0.0179 (0.027) | 1.018 | 0.965 | 1.074 |
| Proportion of catch sold (kg) | **0.0350 (0.017)*** | 1.036 | 1.001 | 1.071 |
| Fishing costs (Php) | **–0.00064 (0.0003)*** | 0.999 | 0.999 | 1 |
| Fish hold capacity | 0.00016 (0.001) | 1 | 0.998 | 1.002 |
| Fishing frequency | –0.017 (0.085) | 0.983 | 0.832 | 1.162 |
| Age (years) | –0.007 (0.018) | 0.992 | 0.958 | 1.028 |
| Education (years) | –0.0196 (0.0610) | 0.981 | 0.87 | 1.105 |
| Household size | 0.0757 (0.077) | 1.079 | 0.928 | 1.253 |
| Fishing experience (years) | –0.0278 (0.018) | 0.973 | 0.939 | 1.007 |
| Frustration | **1.425 (0.550)**** | 4.159 | 1.415 | 12.223 |
| Anger | 0.119 (0.590) | 1.127 | 0.354 | 3.581 |
| Fear | –0.325 (0.349) | 0.723 | 0.365 | 1.432 |
| Hope | 0.557 (0.364) | 1.745 | 0.856 | 3.558 |
| Constant | –2.16 (1.85) | 1.32 | | |

*Cox and Snell $R^2$ = 0.153; Nagelkerke $R^2$ = 0.205; Model $X^2$ = 32.99, p = < 0.003.*
*$^*p < 0.05$.*
*$^{**}p < 0.001$.*

of border lockdowns was a major problem experienced by the fishers in Davao Gulf (Jomitol et al., 2020), complete shutdowns of fisheries were also experienced, stay-at-home orders preventing travel to and within fishing areas during imposition of draconian measures of lockdown (Okyere et al., 2020). Aside from these, there was a heightened apprehension in which fishing communities are at high risk of COVID-19 due to their migratory and clustering behavior, making fishing communities potential hotspots for rapid spread of the virus (FAO, 2020a). Moreover, the reduction in market demands of fish products resulted in lower prices of fish products; for this reason many fishers reduced their fishing activities and some have completely stopped as their work have become unprofitable (FAO, 2021). In some cases, quotas were not attained due to low demand and lack of storage for a perishable product which makes them desperate to sell their catch immediately (White et al., 2021).

## Impacts of COVID-19 Restrictions on Fisher Families

A fisher's struggle also reflects the struggles of his family. When fishing becomes difficult for them, it will also be difficult to put food on their tables and feed their families. This can result to inadequate food and later manifest as malnutrition. For this study alone, one of the statistically significant factors was the fisheries variable, on a previous work by Macusi et al. (2021), it was found that some factors that had an effect on the CPUE were years of fishing, revenue and catch left for the family (during closed fishing season in the same area). Even though revenue was not found significant in this study, the financial factor mainly, fishing cost was nonetheless present and was the main thing in the minds of fishers as they were anxious for their profitability and food security (Fabinyi et al., 2017). In addition, fishers were not exempted from the impacts of lockdowns and with their inability to go outside their homes during the earlier phases of the lockdown (non-essential workers were not allowed outside their homes or to conduct other activities), survival was a challenge (February to May 2020). The longer they stayed at home to stay safe from the virus, the longer they worried about feeding their families (Ercilla et al., 2021). Lack of mobility resulted in food inadequacy (Workie et al., 2020). During this pandemic, food supply declined because of the disrupted food supply chain and prices for common goods skyrocketed (FAO, 2021). Since fishers were prevented from fishing, this frustrated the family as they cannot do anything about their situation other than to wait for foodpacks from the local government (Mukhtar, 2020). During this time (February 2020–May 2020), travel restrictions were implemented preventing the movement or travel of workers seeking to go from their residence to their work sites, or offices. This was a big challenge for the fishers' families because according to many of them, their other family members capable of finding jobs or already working outside their place of residence were not able to travel due to the tight policy restrictions from border to border (Simunek et al., 2021). In addition, the closing of the educational institutions (basic education to college level) was not very helpful for the fishers' families, as this has the unintended effect of some of the families unable to cope up with the sudden change in the education system (Chaturvedi et al., 2021). There was a real struggle to teach their children at home since they could not teach their children the lessons because of their very low educational attainment (Aucejo et al., 2020). This abrupt change was a great challenge to most, especially to the less privilege

**TABLE 4 |** Cross-tabulation of challenges experienced by fishers during COVID-19 pandemic.

| Challenges | Governor Generoso | San Isidro | Pantukan | Mabini | Davao City | Samal | Sta Cruz | Sta Maria | Malita |
|---|---|---|---|---|---|---|---|---|---|
| Restricted market | 0 | 1 (14%) | 0 | 0 | 0 | 0 | 0 | 3 (43%) | 3 (43%) |
| Lack of fish buyers | 0 | 0 | 0 | 1 (33%) | 0 | 0 | 2 (67%) | 0 | 0 |
| Reduced income | 0 | 0 | 0 | 0 | 2 (22%) | 0 | 1 (11%) | 5 (56%) | 1 (11%) |
| Restricted fishing areas | 3 (5%) | 6 (11%) | 9 (16%) | 18 (32%) | 2 (4%) | 6 (11%) | 1 (2%) | 2 (4%) | 9 (16%) |
| Reduced mobility for fish traders | 3 (13%) | 2 (9%) | 0 | 3 (13%) | 1 (4%) | 3 (13%) | 1 (4%) | 5 (22%) | 5 (22%) |
| Travel restrictions | 0 | 1 (8%) | 0 | 5 (38%) | 0 | 1 (8%) | 2 (15%) | 2 (15%) | 2 (15%) |
| Low fish price | 13 (29%) | 9 (20%) | 0 | 1 (2%) | 0 | 11 (24%) | 0 | 1 (2%) | 10 (22%) |

**TABLE 5 |** Cross-tabulation of challenges experienced by fisher's family during COVID-19 pandemic.

| Challenges | Governor Generoso | San Isidro | Pantukan | Mabini | Davao City | Samal | Sta Cruz | Sta Maria | Malita |
|---|---|---|---|---|---|---|---|---|---|
| Lack of mobility | 10 (21%) | 5 (11%) | 4 (9%) | 10 (21%) | 1 (2%) | 7 (15%) | 2 (4%) | 0 | 8 (17%) |
| Food inadequacy | 0 | 4 (13%) | 0 | 3 (10%) | 1 (3%) | 5 (16%) | 2 (6%) | 2 (6%) | 14 (45%) |
| Education (modular and online) | 1 (10%) | 1 (10%) | 0 | 1 (10%) | 1 (10%) | 3 (30%) | 1 (10%) | 1 (10%) | 1 (10%) |
| Travel restrictions | 0 | 5 (33%) | 0 | 6 (40%) | 0 | 1 (7%) | 0 | 3 (20%) | 0 |

homes such as the fishers. Their income cannot cope up to access the digital resources and costly internet connections available (Lee, 2020).

## Impacts of COVID-19 and the Challenges of Policy Restrictions

Policy restrictions during COVID-19 brought about several problems toward the fishing communities of Davao Gulf. A struggle to find someone to lend them money to fish was found out to impact their fishing activities during the COVID-19 pandemic. Fishing costs or capital used by the fishers and the prices of fish they caught were influenced by middlemen (Jomitol et al., 2020), often times middlemen do not only direct fish buyers but also, act as financiers that for their fishing operation. The fishers will then tacitly agree to sell their fish catch to them instead of other middlemen in return for the money lent (Surtida, 2000). Financiers often act as middlemen and perform important functions such as, delivery of fishes from one fishing site to another, processing fish or selling them directly to the local buyers and bigger public markets (Crona et al., 2010; Arya et al., 2015). Additionally, financiers and middlemen make it convenient for the fishers to market their catch in which they find difficult to do due to their limited education, knowledge in trading and negotiation as well as limited market network (Ruddle, 2011). Thus, they are forced to rely on financial assurance provided by the middlemen during fishing periods, especially in periods with low catches (Tháy et al., 2019). As some of the fishers lack fishing assets like boats, fishing gears due to poverty, this put them at a disadvantage when applying for a loan from a rural or agricultural bank because they lack collateral security (Nazir et al., 2018). In order to compensate the financial needs of the fishers, informal credits occur (Asogwa and Asogwa, 2019). These informal credits provided by the financiers and other microcredit lending schemes help to dispose and sell their catch without delay and provide them flexible loan without cumbersome formalities (Palanivelu and Malarvizhi, 2019). In return for the financiers help, a steady and substantial supply of fish is of crucial importance, these concerns form into a situation where financiers are ready to meet the needs of the fishers to the best possible extent (Asante et al., 2021). However, this system has a number of disadvantages for the fishers such as high interest rates and exploitative terms and conditions regarding the disposal and price of fish, also informal credit sources are limited and unequally distributed (Apituley et al., 2019). In addition, COVID-19 has disrupted the fish market supply due to the fragmented operation by the financiers and middlemen that resulted to lesser or limited lending for the fishers as they also struggled to dispose/sell the fish catches due to the consequences punitive travel restrictions (Ruddle, 2011; Asante et al., 2021). On the other hand, the COVID-19 pandemic caused a major emotional distress to the fishers (Terry et al., 2020). They were worried on how to provide for their family and at the same time afraid of acquiring the virus, some fishers tried other jobs just to provide food in their table and some still go out to the sea despite the warnings from authorities to stay home (Bollido and Irene, 2020). The pandemic-related restraints such as social-distancing, home quarantine and isolation have impacted the economic sustainability and well-being of the fishers and their families. This has induced negative emotions like sadness, worry, fear, anger, annoyance, helplessness, loneliness and frustration (Auriemma and Iannaccone, 2020; Mamun et al., 2020; Bhuiyan et al., 2021). These negative emotions experienced due to the current situation are common amongst marginalized sectors such as these fishers, yet if only the government can provide stable financial and food support, then the fishers will heed the warnings of authorities and stay home (Sheek-Hussein et al., 2021). This study will help us in the next pandemic that essential workers such as fishers should not be included in lockdowns for food security. Moreover, about 30–50% of animal protein of Filipinos comes from seafoods (Macusi et al., 2011) provided by the fisheries sector, when hindered it will decrease the protein source and affect the food security of the nation.

## CONCLUSION

The impacts of COVID-19 are both direct and indirect, the fishers were affected directly due to lack of financiers and middlemen to transport their products, their families suffer inadequate food and could barely teach their children at home both due to lack of knowledge and also lack of additional finances for internet connection. This occurred largely during the first few months (February to May 2020) of the restriction imposed by the government (Ferrer et al., 2021). Further, our study revealed that COVID-19 highly affected the fishers and their fish catch economically and socially. The restricted fishing access was found to have important and major set-back on the fishing operations of fishers and the same was experienced also by the middlemen given the low fish price and reduced mobility of the fish traders. COVID-19 also impacted the fishers, and their families through lack of mobility, food inadequacy, travel restrictions and their children's education. Despite all these challenges of policy restrictions imposed upon the fishers during the pandemic's early period, they again began to operate when the enhanced community quarantine classification of the Davao region was lifted (around June 2020). It took a pandemic to highlight the importance of the fisheries, emphasizing the fishers' role in maintaining food supply amid crisis (Ferrer et al., 2021). Despite their income and livelihood disruptions, the local fishers remained positive and hopeful to weather this pandemic.

## DATA AVAILABILITY STATEMENT

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

## ETHICS STATEMENT

The studies involving human participants were reviewed and approved by Emily Antonio.

## AUTHOR CONTRIBUTIONS

EdM, ErM, and LD designed and conceptualized the study. EdM, SS, and MaB wrote the original draft of the manuscript. EdM, MC, MiB, and SS conducted the fieldwork. MaB, SS, and EdM analyzed and visualized the data. LD did overall supervision of the study. All authors contributed to the article and approved the submitted version.

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# Defend as You Can, React Quickly: The Effects of the COVID-19 Shock on a Large Fishery of the Mediterranean Sea

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This paper presents an analysis of the effect of SARS-CoV-2 coronavirus pandemic and related restrictive measures on the activity of the Italian fleet of trawlers, which represents one of the most important fisheries in the Mediterranean Sea. We integrated multiple sources of information including: (1) Fleet activity data from Vessel Monitoring System, the most important satellite-based tracking device; (2) vessel-specific landing data disaggregated by species; (3) market and economic drivers affecting the effort variation during the lockdown and in the related fishing strategies; (4) monthly landings of demersal species in the main Italian harbors. These data sources are combined to: (1) Assess the absolute and relative changes of trawling effort in the geographical sub-areas surrounding the Italian coasts; (2) integrate and compare these changes with the market and economic drivers in order to explain the observed changes in fishing effort and strategy; (3) analyze the changes of the fishing effort on the Landing-per-unit-effort (LPUE) in order to further understand the strategy adopted by fishers during this crisis and to infer the potential consequence for the different stocks. The results provide an overview of the effects of the "COVID-19 shock," in terms of fishing activity and socio-economic drivers, demonstrating that the consequences of the pandemic have been very varied. Although the COVID-19 shock has caused a marked overall reduction in activity in the first semester of 2020, in some cases the strategies adopted by fishermen and the commercial network linked to their activity have significantly reduced the impact of the emergency and taken back catch and effort to levels similar to those of previous years. These results could provide insights for management measures based on temporal stops of fishing activities. In particular, if no limits to the fishing effort after the restart of fishing activities are adopted, the benefits of fishing pressure reduction on fishery resources could be nullified. On the other hands, when fishing activities restart, and in the absence of catch control, effort tends to increase on coastal bottoms characterized by greater abundance of resources and longer effective fishing time.

**Keywords: COVID-19, sustainability, trawl fisheries, marine ecology, Vessel Monitoring System, landings, economics, strategy**

## INTRODUCTION

Since its appearance in China in December 2019, the spread of SARS-CoV-2 coronavirus responsible for the well-known COVID-19 pandemic has heavily affected the entire world throughout the year 2020 and it still represents an important global problem. At the end of January 2020, the outbreak of COVID-19 was recognized as a Public Health Emergency of International Concern (PHEIC) by the World Health Organization (WHO) who, on March 11, 2020 announced the global pandemic. For facing such an emergency, human activities have been suddenly and considerably modified and adjusted, namely "shocked"—being a "shock," in the context of economy, a single event that is neither expected nor predicted that breeds instability (Link et al., 2021). In the urgency of containing the early phases of the contagion, countries have adopted severe strategies and management measurements, such as lockdowns. In this context, the Italian government has been one of the first worldwide to apply important restrictions of human activities and, more generally, of the overall society. In particular, a lockdown period was imposed from March 11, 2020 until May 17, 2020 (GU, 2020a,b) and, after this, restrictions have been relaxed but not completely removed until summer. These restrictions have limited, and even completely blocked, a large number of professional activities, e.g., hotels, restaurants and caterings (Coll et al., 2021) and, although the restrictions did not specifically affect primary economic sector including fishing activities, they altered the domestic demand for many products, including fresh fish. The analysis of the effects of such policies on marine fisheries may represent a huge and quite unique experiment from which to learn a vital lesson.

Recently, a growing number of researchers investigated the impacts of the shock induced by COVID-19 on fishing and fishers (FAO, 2020; Eugui et al., 2021; White et al., 2021). These studies documented varied effects on different aspects of fisheries. In some cases, as the countries implemented lockdown, many fishing activities faced complete shutdowns, e.g., in Namibia (Béné et al., 2015). Indeed, industrial fishing activity at global level has decreased by 6.5% at the end of April 2020 compared to April 2019 (Clavelle, 2020), while at regional level the reduction of activity was substantially different depending on both the local strategies and the spreading of the SARS-CoV-2. For instance, as highlighted in Coll et al. (2021), in the Exclusive Economic Zones of China the fishing activity decreased (overall in the year 2020) as much as 40%, while in Peru it dropped by 80%. At a smaller spatial scale, Coll et al. (2021) analyzed the effect of the reduction in fishing pressure in the Catalan Sea, Spanish Mediterranean. The authors showed that during the period of the lockdown (March–May 2020) fishing effort dropped by 34%, landings decreased by 49% and revenues declined by 39% in comparison with the same period in 2017–2019. On the other hand, Coll et al. (2021) did not detect a significant change in Landing-Per-Unit-of-Efforts (LPUEs). Similarly, Russo et al. (2021) by comparing the fishing activities in three periods (before, during, and after the lockdown) of 2019 and 2020 highlighted a reduction of about 50% of fishing effort in the Northern and Central Adriatic Sea. Before lockdown period the analysis showed a slight increase of the trawling activities at the Geographical Sub Area (GSA) 17 level in 2020, reflecting in a higher number of active vessels, days at sea, and, more in general, of the fishing effort. Moreover, the high-resolution maps of the difference of the fishing effort between 2019 and 2020 highlighted a similar distribution of the fishing grounds in the period before the lockdown, confirming the already pointed out non-random behavior of the fishers in the Northern and Central Adriatic Sea (Russo et al., 2021). By analyzing the data on landings, Russo et al. (2021) also pointed out a strong decrease in profits ranging from -30%, for the small-scale fisheries, to -85%, for the small bottom otter trawl, essentially as a consequence of the decrease in the fishing activity.

The restrictions also strongly changed the maritime traffic during the first half of 2020. March et al. (2021), using Automatic Identification System (AIS) data, provided a large-scale assessment on the global change in marine traffic revealing a general decline of 1.4%. When compared to the baselines, i.e., equivalent periods of 2019, the Western Mediterranean Sea was one the areas with the highest reduction in shipping activities (March et al., 2021). In particular, the number of vessels sharply decreased in the first days of mobility restrictions, reaching an overall median drop of 51% during the initial national lockdowns in Spain, France and Italy. Yet, after relaxing restrictions, the fishing vessels returned close to baseline values (March et al., 2021). This happened often very fast, with most of the fleets rebounding their activity from mid-July until mid-September (March et al., 2021).

Although the missing data of half of 2020 could potentially affect modeling or imputation methods, especially for time series analyses (Link et al., 2021), the shock-induced by COVID-19 might provide an opportunity to advance in a sustainable fisheries policy, especially "when there is a political will to do so" (Kemp et al., 2020). This means that the COVID-19 shock represents an opportunity to grasp insights on how to modify fisheries management while the industry is subjected to a crisis, i.e., using a "strategic opportunism" (Isenberg, 1987).

Notwithstanding the glaring negative impact of the pandemic in terms of death, suffering, increasing individual and social inequalities and psychological hardship, the restrictions of human activities showed positive effects on marine ecosystems. China et al. (2021), for example, pointed out an increase in species richness in Israel Gulf of Aqaba, predominantly influenced by increased evenness without changes in total abundances. The authors underlined that the short-term reduction in human activity during lockdown had similar effects to long-term, i.e., year-round, restrictions stressing the importance of limiting such activities to well-designated spatial areas for minimizing the human-induced impacts (China et al., 2021). Similarly, in the Gulf of Mannar (India) an increase in fish abundance (based on direct estimation of population size) has been detected as a direct result of the absence of fishing activities, in particular trap fishing in reef areas, and shore seine and gill net operations near the reef areas (Patterson Edward et al., 2021). Although the period with strongest restrictions lasted only a few months, these studies suggest that the impact of such a strong reduction in human activity may have consequences for ecosystems in terms of population size and pollution (Patterson Edward et al., 2021). Moreover, a general improvement of the health of the coastal environment following a decrease in turbidity, nutrient and macroplastic concentration had been pointed out, along with an enhancement in dissolved oxygen levels, phytoplankton and fish densities (Patterson Edward et al., 2021).

In this paper, we try to address the following issues: (1) What were the effect of the restrictions related to the SARS-CoV-2 coronavirus pandemic, "**COVID-19 shock**" hereafter, on the trawling activity in the different seas surrounding the Italian coasts, during first part of the year 2020, which represented the critical phase of the pandemic; (2) what were the effects of this COVID-19 shock after the end of the pandemic-related restrictions; (3) what were the effects of the COVID-19 shock on the LPUE of the main demersal species exploited by trawlers, including the ones monitored and managed through specific plans; (4) what were the market and economic drivers that indirectly amplified the effort variation in the lockdown and in the subsequent period.

We think that the analysis of the COVID-19 shock, like unwanted broad fisheries ban experiment, could provide insights useful for tuning of future fisheries management policies which are based on temporal closures of fishing activities.

## MATERIALS AND METHODS

### VMS Data Sources and Processing

Vessel Monitoring System (VMS) data for the portion of the trawling fleet equipped with this tracking device were provided by the Italian Ministry for Agriculture, Food and Forestry (MIPAAF), within the scientific activities related to the Italian National Program for the Data Collection in the Fisheries Sector (INPDCF). Namely, 1297 trawlers (over the total 1,349 forming the whole Italian fleet of trawlers with length-over-all greater than 15 m) were considered in this study. VMS data were used to reconstruct the fishing activity for each Italian trawler using the VMSbase R package (Russo et al., 2011a,b, 2014). VMS data are a series of consecutive pings (signals) sent by each vessel at regular time intervals. VMS pings belonging to the same vessel can thus be partitioned into fishing trips and interpolated to increase the temporal frequency to 10 min and align the vessels to the same temporal grid (Russo et al., 2011a). The procedure is based on the detection of in-harbor positions as the VMS pings with speed values near to zero and within a defined buffer distance from the harbor. The high-frequency interpolated (10 min in this study) VMS pings are inspected, and fishing set positions are identified using combined speed and depth filters. At the end of this analysis, the following information is obtained: (I) Positions and time length of the hauls for each fishing trip of each vessel and II) the respective harbor of landing.

### Fishing Effort

The reference 30 × 30 nautical miles grid (**Figure 1**) established by the General Fisheries Commission for the Mediterranean (GFCM)[1] was used to quantify the:

1. The total monthly trawling effort in fishing hours by cell. This value, based on the analysis of VMS data described above, was aimed at capturing only the effective fishing effort, excluding steaming or other activities;
2. The total monthly trawling effort in fishing days by cell. This value, based on the analysis of VMS data described above, was aimed at providing a more common measure of fishing effort.

The fishing effort was then computed for each vessel $v$, for each cell $c$ of the grid and for each month $t$. Then, the total trawling effort at a monthly scale was assessed as:

$$\begin{aligned} H_{t,c} &= \sum_{v=1}^{V} H_{t,c,v} \\ D_{t,c} &= \sum_{v=1}^{v} D_{t,c,v} \end{aligned}$$

Where $H_{t,c}$ is the total trawling effort in hours in the cell $c$ during the month $t$, while $D_{t,c}$ is the total trawling effort in fishing days in the cell $c$ during the month $t$ considering the fleet composed by $V$ vessels.

In order to simplify the analysis of the results, and to provide results potentially useful for management, each cell of the grid was uniquely associated with the main GSA in terms of spatial overlap. In this way, it was possible to obtain the values of $H_{t,c}$ and $D_{t,c}$ by GSA summing up the sets of cells belonging to each GSA. Monthly temporal series of values for both $H_{t,c}$ and $D_{t,c}$ by GSA were obtained at the end of this procedure. Considering that almost all the fishing activity of the Italian trawlers falls within the GSA 9, 10, 11.1, 11.2, 13, 15, 16, 17, 18, 19, and 21 (Russo et al., 2019; De Angelis et al., 2020), only these GSAs were considered and, to simplify the analyses, GSAs 11.1 and 11.2 were merged into GSA 11 (**Figure 1**). In addition, it is important to note that GSAs 13, 15, and 21 are not adjacent to the Italian coast so they do not contain ports. For this reason, these GSAs do not appear in the results relating to Landings and socio-economic analysis (see below). The effect of the COVID-19 shock on the fishing

[1] https://www.fao.org/gfcm/data/maps/grid/en/

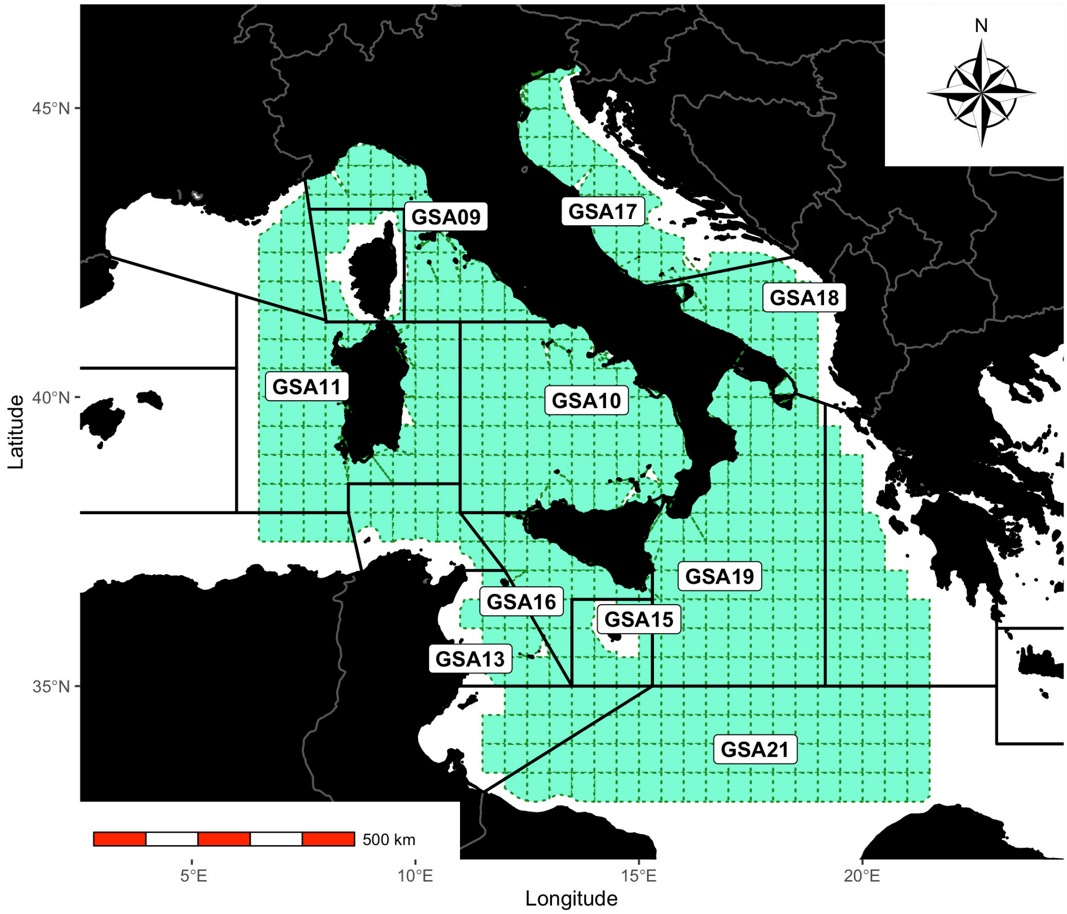


**FIGURE 1 |** Spatial domain of the study and 30 × 30 nautical miles grid established by the GFCM (). The Geographical Sub Areas (GSA) of the Mediterranean Sea considered in this study are also represented.

activity was investigated comparing the mean monthly value of fishing effort (both as Fishing Hours and Fishing Days) in the years 2015–2019, which were assumed as the reference baseline, with the monthly values during the year 2020. The values of the ratio between Fishing Days and Fishing Hours, here defined as **"Strategy" (S)**, was defined for capturing the tendency to reduce the displacements (navigation), for example excluding distant fishing grounds, to the advantage of the effective fishing time. In different Italian seas this is a critical aspect related to management (De Angelis et al., 2020).

A four-way ANOVA (analysis of variance) was used to test the differences in the values of Fishing effort (both as Fishing Days and Fishing Hours) and the Strategy in relation to GSA, Month, Year and the COVID-19 shock defined as a binary factor equal to one when the year is 2020.

## Landings

The data related to the total monthly landings of demersal species in a sample of the main ports of each GSA (**Table 1**) have been analyzed for the first 6 months of the years 2019 and 2020 (data for the second semester of the year 2020 were not available during the preparation of this paper), and compared in order to verify the effects of the COVID-19 shock on the production of the fleet.

## Landings-Per-Unit-of-Effort

Monthly landings data for the vessels equipped with VMS were also obtained from the monitoring activities planned in the INPDCF. These data were cross-linked at the scale of single vessels in order to reconstruct the monthly activity (in terms of spatial allocation of fishing effort) and corresponding landings by species. A non-negative least square regression (Russo et al., 2018) was used to reconstruct spatial origin of these landings and to estimate the monthly value of Landings-Per-Unit-of-Effort (LPUE) by cell for the main demersal species exploited by Italian trawlers.

These selected species (**Table 2**) account for around 65% of the whole landings of the Italian trawlers per year in the period 2015–2020, and comprises essentially all the demersal species of fishes, crustaceans and mollusks which are important for direct human consumption. The effect of the COVID-19 shock factor on LPUE was also tested using the same approach, i.e., four-way ANOVA, described for Fishing Effort.

**TABLE 1 |** Harbors and corresponding GSA for which the total monthly landings of demersal species in the years 2019–2020 were compared.

| Harbor | GSA |
|---|---|
| ANZIO | GSA09 |
| FIUMICINO | |
| LA SPEZIA | |
| SESTRI LEVANTE | |
| LIVORNO | |
| PIOMBINO | |
| PORTO SANTO STEFANO | |
| VIAREGGIO | |
| VIBO VALENTIA | GSA10 |
| POZZUOLI | |
| SALERNO | |
| PORTICELLO | |
| TERRASINI | |
| CAGLIARI | GSA11 |
| CALASETTA | |
| SANT'ANTIOCO | |
| MARSALA | GSA16 |
| MAZARA DEL VALLO | |
| PORTOPALO DI CAPO PASSERO | |
| SCIACCA | |
| TRAPANI | |
| GIULIANOVA | GSA17 |
| ORTONA | |
| PESCARA | |
| CATTOLICA | |
| CESENATICO | |
| GORO | |
| PORTO GARIBALDI | |
| RAVENNA | |
| RIMINI | |
| ANCONA | |
| CIVITANOVA MARCHE | |
| FANO | |
| PORTO SAN GIORGIO | |
| SAN BENEDETTO DEL TRONTO | |
| SENIGALLIA | |
| TERMOLI | |
| CAORLE | |
| CHIOGGIA | |
| PORTO TOLLE | |
| BISCEGLIE | GSA18 |
| MANFREDONIA | |
| VIESTE | |
| CORIGLIANO CALABRO | GSA19 |
| CROTONE | |
| GALLIPOLI | |
| RIPOSTO | |

**TABLE 2 |** List of the investigated species, i.e., $N = 11$.

| Species name | Common name | FAO 3 alpha code | Mean% of the total landings for demersal species |
|---|---|---|---|
| *Parapenaeus longirostris* | Deep-water rose shrimp | DPS | 16.96 |
| *Merluccius merluccius* | European hake | HKE | 10.28 |
| *Eledone moschata* | Musky octopus | EDT | 9.12 |
| *Aristaeomorpha foliacea* | Giant red shrimp | ARS | 6.49 |
| *Mullus barbatus* | Red mullet | MUT | 6.25 |
| *Eledone cirrhosa* | Horned octopus | EOI | 4.58 |
| *Sepia officinalis* | Common cuttlefish | CTC | 3.43 |
| *Illex coindetii* | Broadtail shortfin squid | SQM | 3.13 |
| *Nephrops norvegicus* | Norway lobster | NEP | 2.45 |
| *Mullus surmuletus* | Surmullet | MUR | 1.67 |
| *Aristeus antennatus* | Blue and red shrimp | ARA | 1.46 |

**TABLE 3 |** Number of vessels participating in the study according to GSA.

| Geographical sub-area | Number of interviews |
|---|---|
| GSA 09—Northern Tyrrhenian Sea | 31 |
| GSA 10—Southern and Central Tyrrhenian Sea | 27 |
| GSA 11—Sardinia | 18 |
| GSA 16—Southern Sicily | 46 |
| GSA 17—Northern Adriatic Sea | 57 |
| GSA 18—Southern Adriatic Sea | 27 |
| GSA 19—Western Ionian Sea | 16 |
| Total | **222** |

## Market and Economic Drivers

The market and economic drivers that indirectly amplified the effort variation during the lockdown and in the subsequent period have been assessed by administering a questionnaire to a representative vessel sample through a web platform. The sample was composed of 222 demersal trawlers randomly selected over the whole fleet. To establish whether the impact of the lockdown differed in the different areas, the sample was further stratified according to GSA, thus identifying 27 segments. The number of participating vessels is reported in **Table 3** according to their GSA. The fleet segment of demersal trawlers in Italy account for about 2,149 vessels (European Commission et al., 2019), and the survey involved 10% of the whole fleet segment.

The questionnaire consisted of six closed-ended questions. Two questions collected qualitative information directed at establishing:

- The main factors that induced a stop or reduction of fishing activities in the weeks from March 9th 2020 to May 31st 2020.
- The measures that were adopted by fishers to mitigate the adverse effects of the pandemic.

## RESULTS

The following subsections present the results of the analyses on Fishing Effort, Fishing Strategy and LPUE (that represents an index of the fishing efficiency and targets) of the Italian fleet during the years 2015–2020, and in particular the values of the year 2020 (affected by the SARS-CoV-2 pandemic) are contrasted with the values in the period 2015–2019. Average monthly values before and during the COVID-19 year (2020) were compared in order to detect (if any) the effect of the COVID-19 shock regardless of any other seasonal variability factor or any natural seasonal variability.

## Fishing Effort in Days

The comparison (**Figure 2**) between monthly Fishing Days per GSA during the years 2015–2019, and the corresponding values during the year 2020, indicates that all the predictors (GSA, Year, Month and COVID-19 shock) have a statistically significant effect on this indicator (**Table 4**—ANOVA Results). In some cases (e.g., from January to March in GSA15, in the months of February and March for the GSAs 10, 13, and 21), the values are significantly

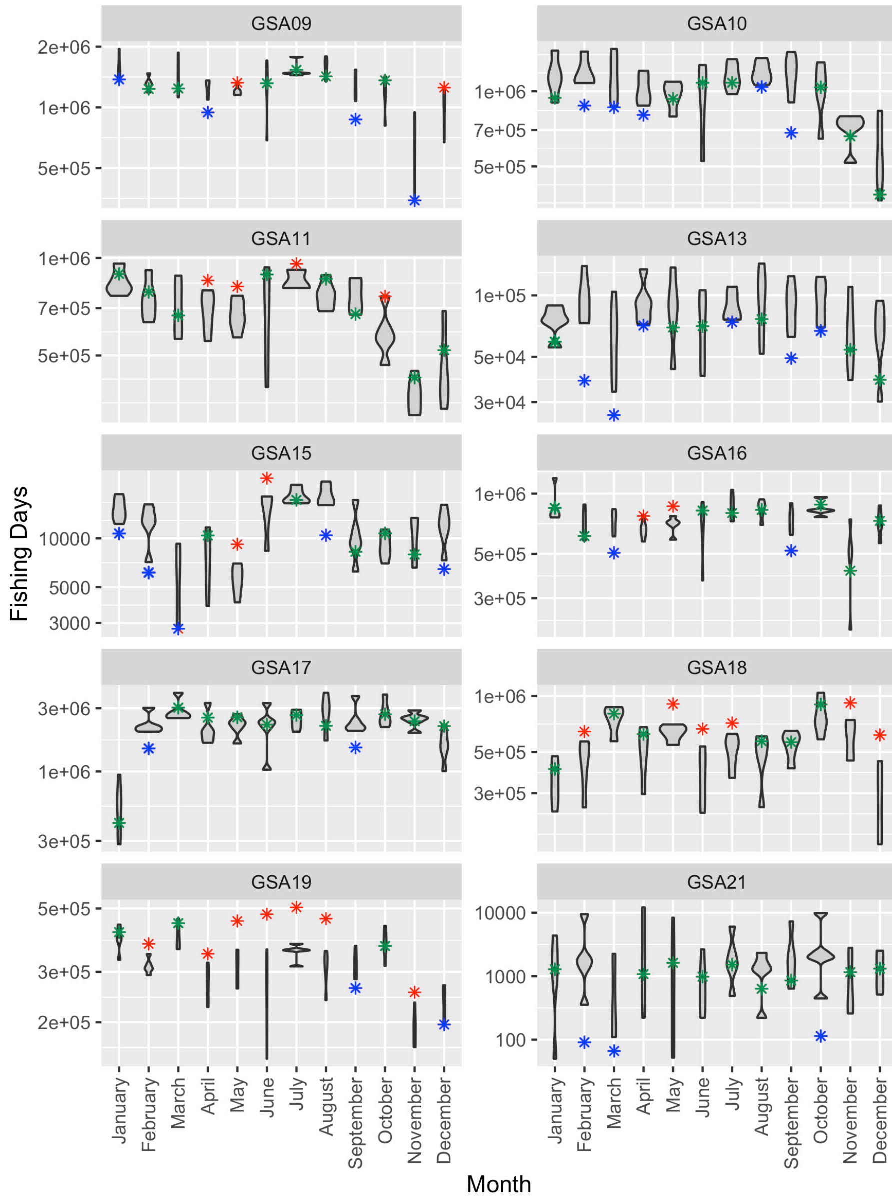


**FIGURE 2 |** Violin plot of the values of total Fishing Effort (in Days) by month and GSA. The values of the years 2015–2019 are represented by the violin, while those of the year 2020 (during the pandemic) are represented as asterisks colored in red when significantly higher than those in the reference period, in blue when significantly lower than those in the reference period and in green when coherent with those in the reference period. A violin plot is a plotting method similar to a box plot, since it shows the probability density of the data at different values, smoothed by a kernel density estimator.

**TABLE 4 |** Results of the ANOVA applied on the different indicators (Fishing Days, Fishing Hours, Strategy, LPUE).

| Dependant variable | Predictor | Sum of squares | Deg. of freedom | *F*-value | *p*-value |
|---|---|---|---|---|---|
| Fishing days | GSA | 1.614e + 14 | 9 | | < 2e-16*** |
| | Month | 3.770e + 12 | 11 | 8.189 | 1.58e-13*** |
| | Year | 2.675e + 11 | 1 | 6.392 | 0.0117* |
| | Covid shock | 2.220e + 11 | 1 | 5.305 | 0.0216* |
| Fishing hours | GSA | 6.759e + 09 | 9 | 3393.025 | <2e-16*** |
| | Month | 1.371e + 07 | 11 | 6.881 | 5.21e-11*** |
| | Year | 1.931e + 07 | 1 | 9.694 | 0.00193** |
| | Covid shock | 1.541e + 07 | 1 | 7.737 | 0.00557** |
| Strategy | GSA | 0.11243 | 9 | 175.830 | < 2e-16*** |
| | Month | 0.00692 | 11 | 8.850 | 9.15e-15*** |
| | Year | 0.00071 | 1 | 9.971 | 0.00166** |
| | Covid shock | 0.00043 | 1 | 5.990 | 0.01465* |
| LPUE | Species | 40.7 | 10 | 49.688 | < 2e-16*** |
| | GSA | 24.4 | 9 | 49.525 | < 2e-16*** |
| | Month | 2.8 | 11 | 3.126 | 0.000323*** |
| | Year | 2.4 | 1 | 29.099 | 7.18e-08*** |
| | Covid shock | 0.6 | 1 | 7.149 | 0.007523** |

** < 0.05, ** < 0.01, *** < 0.001.*

lower than the ones observed in the baseline distribution. These abnormally low values are found especially in February (five over 10 GSAs: 10, 13, 15, 17, and 21), March (five over 10 GSAs: 10, 13, 15, 16, and 21), and September (six over 10 GSAs: 9, 10, 13, 16, 17, and 19). In other cases, the values observed during the year 2020 are significantly higher than those in the reference distribution. This can be observed in April (three GSAs over 10: GSA 11, 16, and 19), in May (seven GSAs over 10: GSA 9, 11, 15, 16, 18, and 19), and in June (three GSAs over 10: GSA 15, 18, and 19). In some GSAs (e.g., GSA 9, 10,13, 17, and 21), the values in the year 2020 never exceed those observed in the reference distributions.

## Fishing Effort in Hours

The comparison (**Figure 3**) between the recent values of monthly Fishing Hours per GSA during the years 2015–2019 and the corresponding value during the year 2020, indicates that all the predictors (GSA, Year, Month and COVID-19 shock) have statistically significant effect (**Table 4**—ANOVA Results). In a few cases, the values are almost all significantly lower than the ones observed in the baseline distribution. These abnormally low values are found in January (GSA 15), February (GSAs 10, 13, 15, and 21), March (GSAs 13, 16, and 21), April (GSAs 9, 10, and 13), August (GSAs 9, 10, 15, and 16), September (GSAs 9, 10, 13, 15, and 16), October (GSA 21), and November (GSA15). In other cases, the values observed during the year 2020 are significantly higher than those in the reference distribution. This happens from April to July in GSA19, from May to July in GSA15, in March and May for GSA18, in April, July, October and November for GSA11, from September to December in GSA18, and in December/GSA21.

## Fishing Strategy

The comparison (**Figure 4**) between the recent values of S during the years 2015–2019 and the corresponding value during the year 2020 indicates that all the predictors (GSA, Year, Month and COVID-19 shock) have statistically significant effect (**Table 4—ANOVA** Results). The value of S was higher than the historical range in January (GSAs 10, 15, and 17), February (GSAs 10, 13, 15, 16, and 17), March (GSAs 10, 13, 15, and 16), April (GSAs 9 and 10), September (GSAs 10, 13, 16, 17, 19, and 21), from October to December (GSA 21), and in some other cases. This indicates that, in these areas/months, the trawlers spent less time steaming to allocate relatively more time on fishing. Conversely, the values of S were lower than expected in some blocks of months/GSA, e.g., in February and from May to July in GSA 18, from February to August and in November for GSA19, from April to June in GSA15 and GSA16, from February to July (excepting March) in GSA 18, in April/June/August in GSAs 11 and 19. Actually, in four GSAs (11, 16, 18, and 19) it is possible to observe at least 3 months, in spring/summer, characterized by small values of S. In these cases, the fleets allocated more time than usual to steaming. The analysis of the spatial pattern obtained for the GFCM standard grid allows us to inspect the internal pattern of each GSAs. **Figures 5**, **6** show the absolute change of the total monthly fishing effort between the year 2020 and the mean value for the period 2015–2019. In terms of Fishing Days (**Figure 5**), it is possible to see that the effort decreased by over 300 days per cell/month in some areas, especially GSAs 13 and 17 from March to June and GSA9 from February to June. Conversely, the Fishing Days increased off the southern coast of Sicily (GSA16) in January, June, September and November and in the coastal area between GSA17 and GSA18 (Adriatic Sea) in January, June, July and September. The corresponding pattern for Fishing Hours (**Figure 6**), is very similar, indicating that fishers decided, e.g., in the Adriatic sea during spring/summer, to concentrate their activity in few areas while, at the same time, other areas were partially abandoned. The case of the Adriatic Sea is coherent also with respect to the change in the Strategy, since a more coastal effort is likely to be more efficient in terms of ration between fishing time and steaming.

The effect of the COVID-19 shock on the fishing effort is finally summarized in **Figure 7**, in which the differences in percentage between the value of Fishing Hours in 2020 and the mean values during the years 2015–2019 is represented for each GSA. Here we present the global effect as a percentage of changes in the total yearly values of Fishing Days and Fishing Hours with respect to the reference period 2015–2019 (**Figure 7**). In most of the GSAs, the COVID-19 shock determined a reduction of the yearly effort. Actually, up to 62% (GSA 21), 27% (GSA 13), 15% (GSA15), 14% (GSA10), 8% (GSA17), and 7% (GSA9) of the Fishing Days were lost. However, in GSA11 (+ 12%), GSA18 (+ 23%) and GSA19 (+ 21%), the annual Fishing Days increased in 2020 with respect to the reference period. The corresponding analysis by GSA, Season and Depth stratum (**Supplementary Figures 2A,B**) showed that, in some areas where the effort decreased (GSAs 9, 10, 15, and 21), the reduction in fishing effort has affected all bathymetric strata

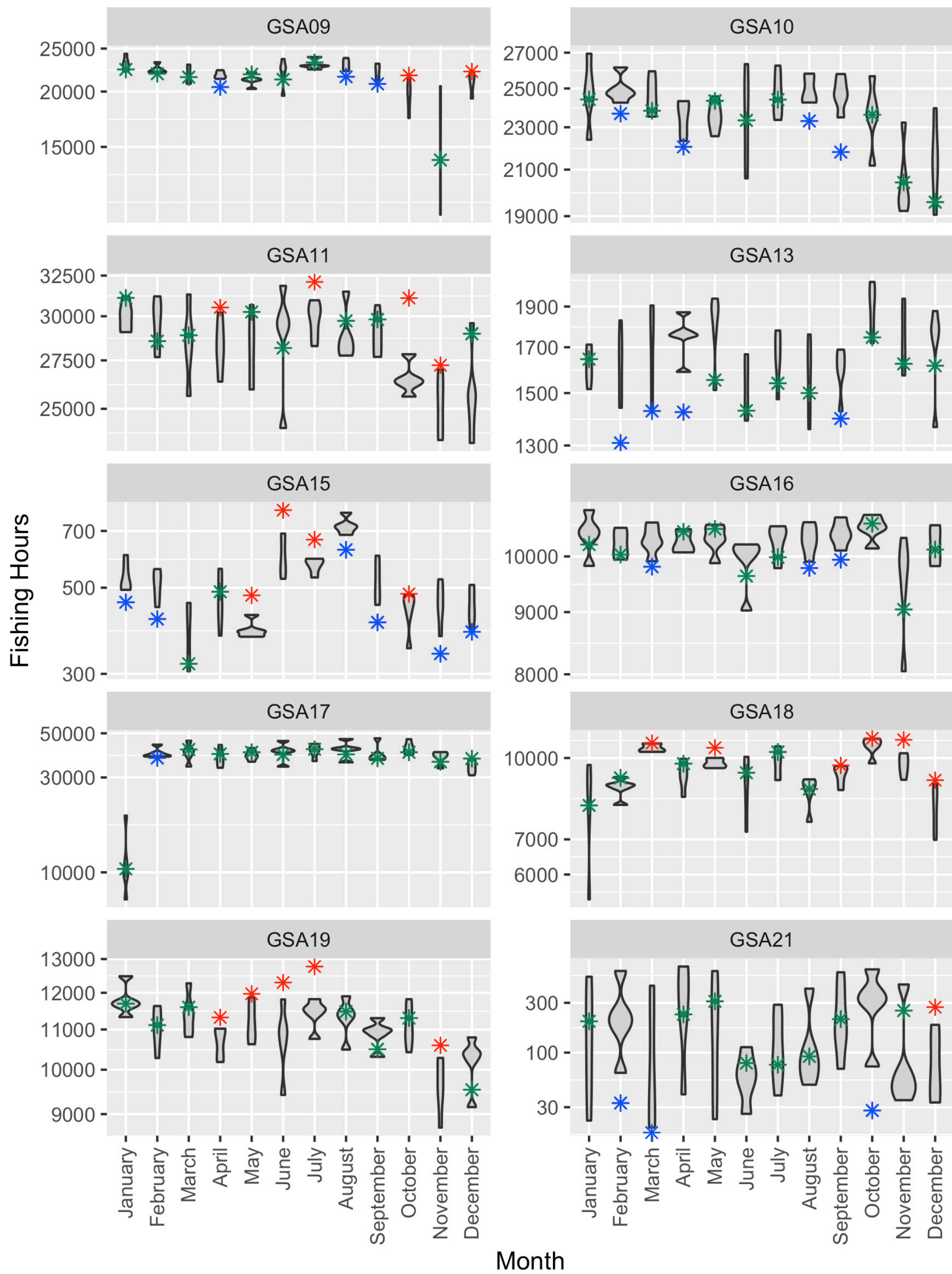


**FIGURE 3 |** Violin plot of the values of total Fishing Effort (in Hours) by month and GSA. The values of the years 2015–2019 are represented by the violin, while medians of the year 2020 (during the pandemic) are represented as asterisks colored in red when significantly higher than those in the reference period, in blue when significantly lower than those in the reference period and in green when coherent with those in the reference period.

during the winter. In other GSAs (11, 18, and 19) the Fishing Days increased, especially on the shallow waters, in winter. In all cases, the differences in percentage are larger during the first part of the year 2020, while they tend to be more dampened in the second half of the year. However, both for Fishing Days and Fishing Hours, negative values are larger for the strata (−500, −200] and (−1,000, −500], confirming that the fishers adopted a strategy oriented to the exploitation of species on the shelf.

## Landings

The analysis of the total monthly landings in the main harbors of each GSA (**Figure 8**) shows that, in all the GSAs with the exception of GSA11 and 18, the year 2020 had begun with an

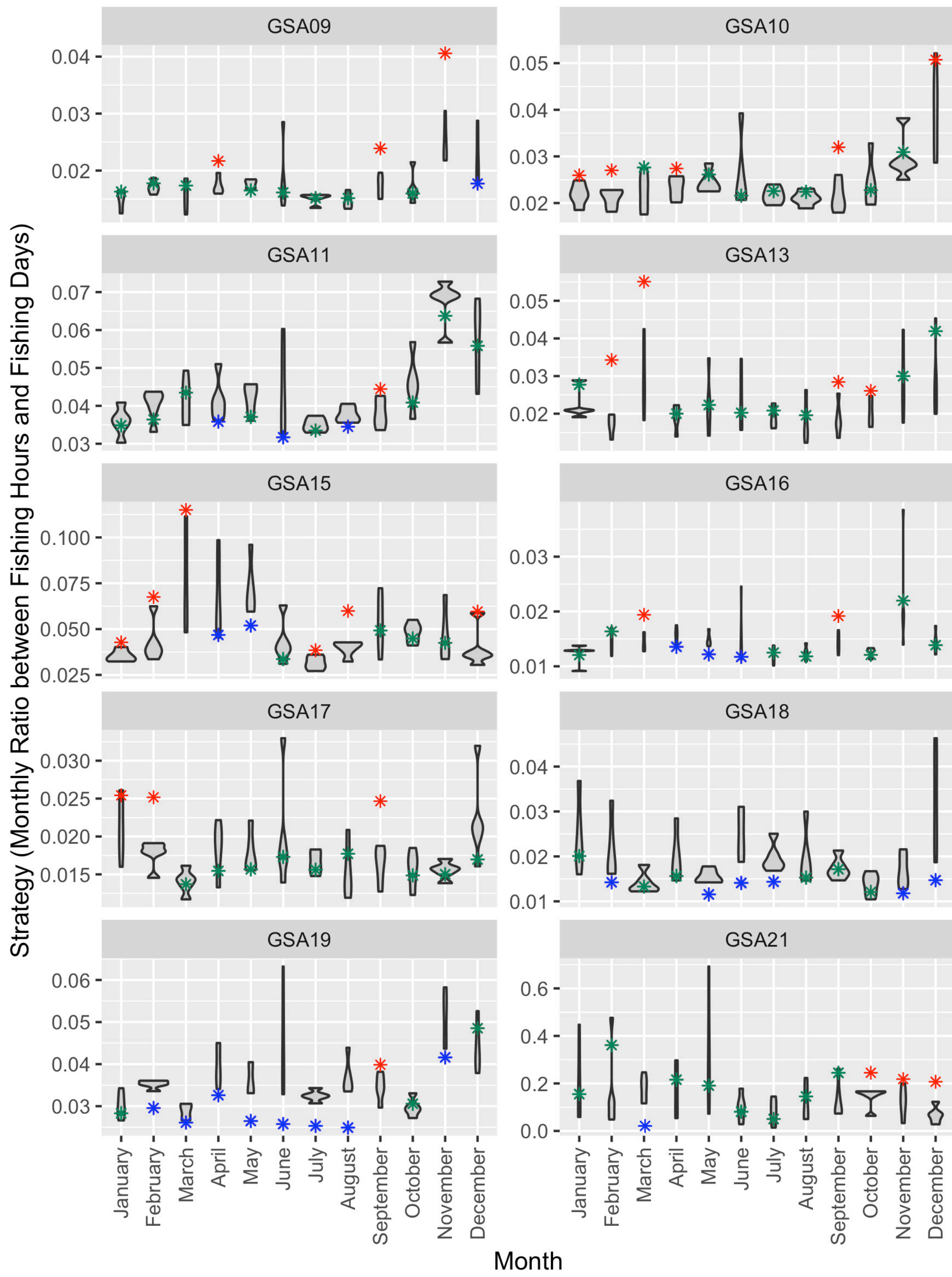


**FIGURE 4 |** Violin plot of the values of Strategy by month and GSA. The values of the years 2015–2019 are represented by the violin, while those of the year 2020 (during the pandemic) are represented as asterisks colored in red when significantly higher than those in the reference period, in blue when significantly lower than those in the reference period and in green when coherent with those in the reference period.

increasing production (January) with respect to the previous year (2019). From February, the situation changed greatly because in some GSAs (9 and 18) a collapse occurred whereas in other GSAs (11, 16, 17, and 19) the production remained stable and, finally, in the GSA10, it has continued to grow. March was the worst month in all GSAs in the year 2020 but the GSA19, with a decrease

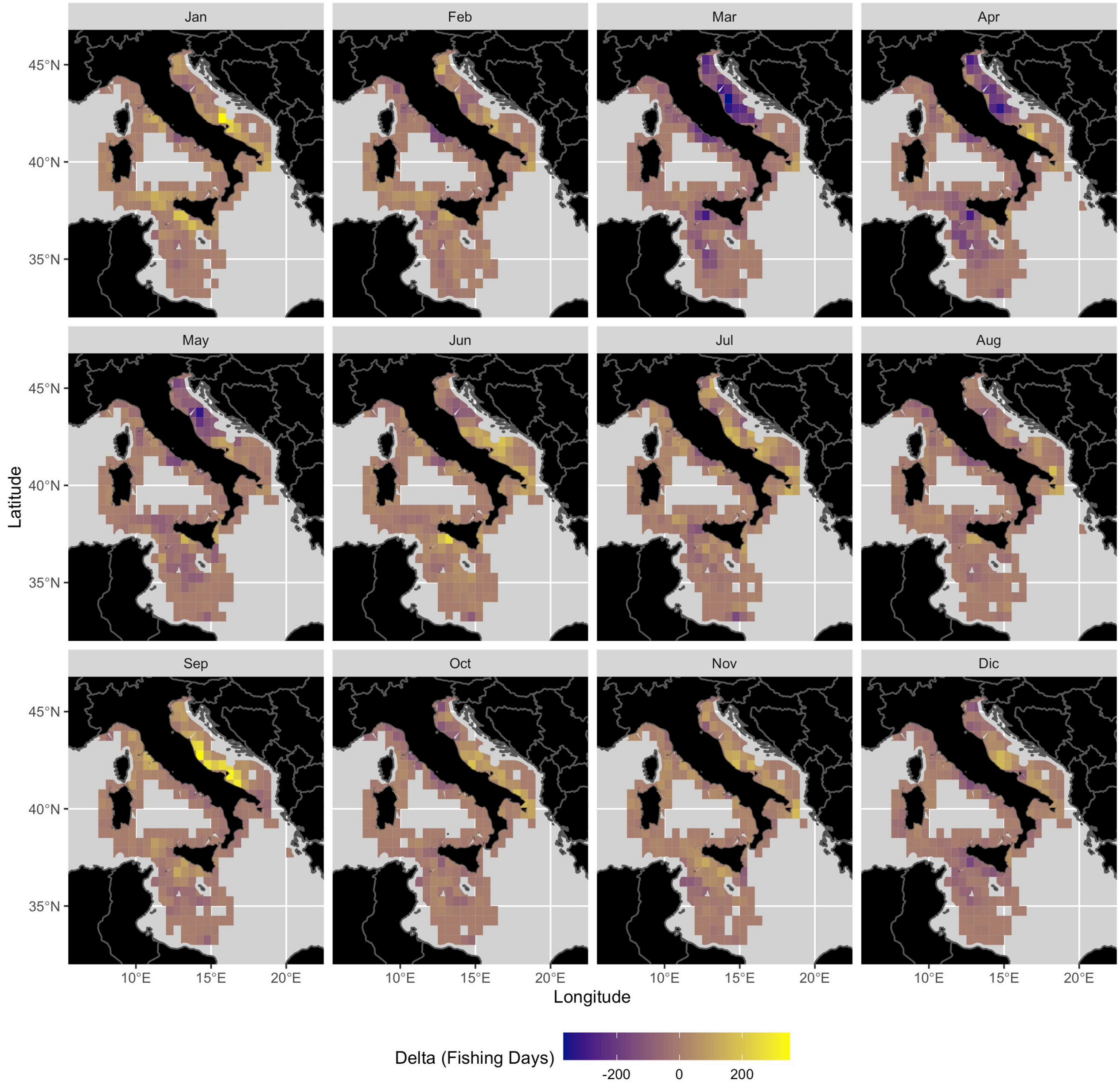


**FIGURE 5 |** Pattern of changes (difference in percentage between the value of Fishing Days in 2020 and the mean value during the years 2015–2019) over the-30 × 30 nautical miles grid established by the GFCM (https://www.fao.org/gfcm/data/maps/grid/en/).

of landing between 50% (GSA10) and 9% (GSA09). Actually, the pattern of GSA19 seems to be moved a month behind that of other GSAs. In the period between the months of April and June there is a gradual recovery with an increasing trend that, in several GSA (9, 11, 16, 18, and 19), brings the landing values to the same levels as the previous year. In the GSAs 18 and 19 the values of landings exceed those of the previous year, with an increase between 5 and 25%. While the changes are evaluated regardless of the GSA (**Figure 8**), it is clear that the reduction in the quantity of landings occurred mainly in March, followed by a slow recovery that brought the values around those of the previous year during the summer (although values for subsequent months were not available for this study).

## Landings-Per-Unit-of-Effort

The COVID-19 shock significantly modified the LPUE of the investigated species (**Table 2**). For the sake of conciseness, only the patterns for the four most important commercial species are represented in **Figure 9**. Those for the other seven species are visualized in the (**Supplementary Figure 1**). For some species

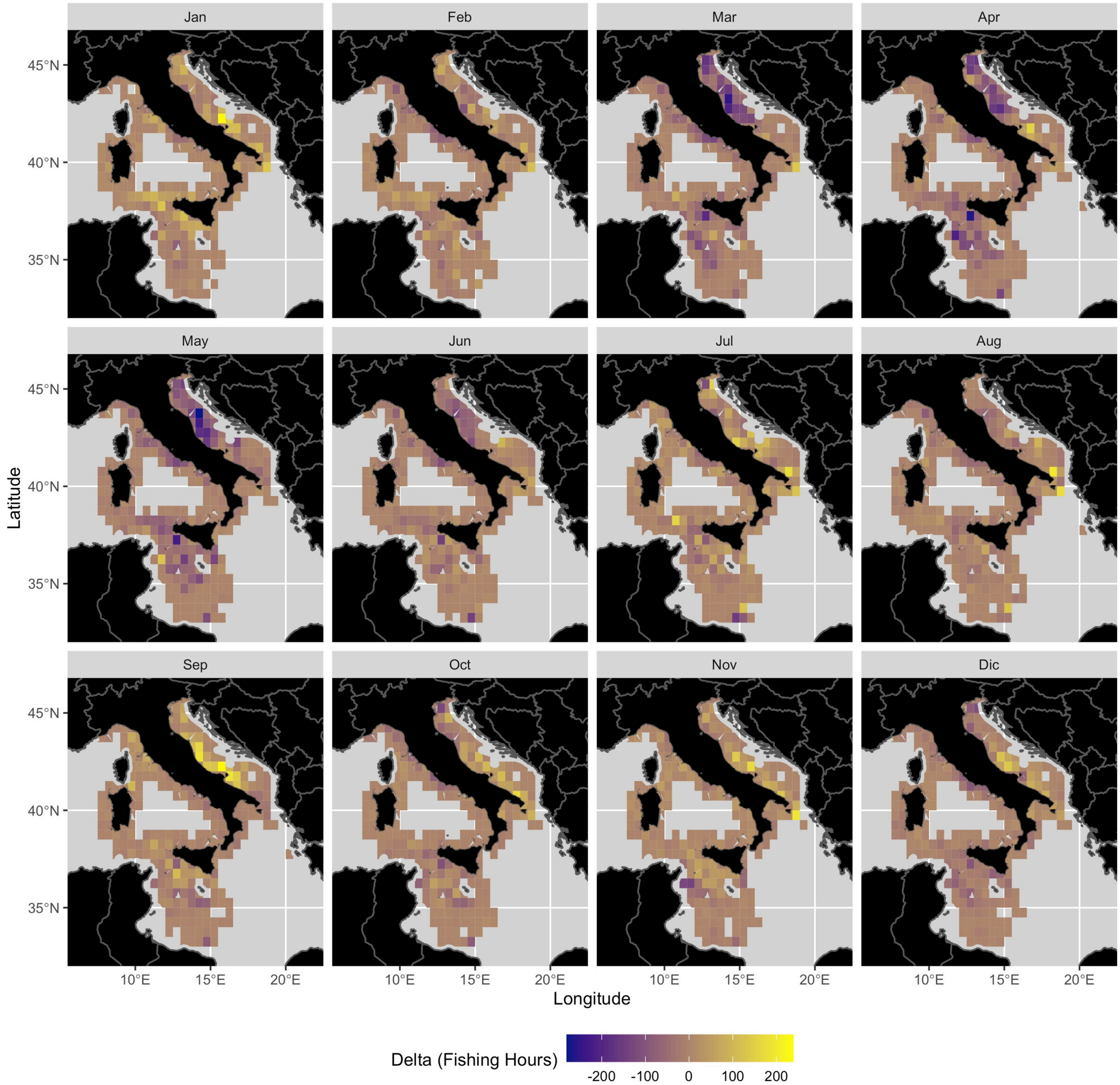


**FIGURE 6 |** Pattern of changes (difference in percentage between the value of Fishing Hours in 2020 and the mean values during the years 2015–2019) over the-30 × 30 nautical miles grid established by the GFCM (https://www.fao.org/gfcm/data/maps/grid/en/).

such as HKE and especially DPS, the values higher than expected (red asterisks) are much more frequent than those lower with respect to the reference period, suggesting that these species were more targeted than during the previous years. The situation is opposite for deep water species such as ARS and ARA, for which values lower than expected values far exceed, as a frequency, those with higher values than the reference period. The values of LPUE for NEP were higher than expected in different months for the GSAs 9, 10, 16, and 17, and in a few months for other GSAs.

## Market and Economic Drivers

The lockdown found the fishing sector wholly unprepared. The absence of alternative outlets, chiefly the restaurants, all but blocked the distribution network of the fishing sector. In fact, 88% of participants stated that during the lockdown they lost revenues due to a dramatic reduction of the sales they used to make through their usual channels (e.g., fish markets, wholesalers and restaurants). As a result of the absence of wholesalers at the landing sites, 92% of participants did not go fishing or reduced their level of activity.

Absence of wholesalers in the fishing harbor was mentioned by 37% of participants as the main cause of the stop of their activities in all the GSAs with the exception of the GSA 17 (**Figure 10**) where the reduction of the fish market trading was indicated as the main reason (37%). The closure of restaurants was mentioned by 26% of participants as the second cause of the stop of their activities (**Figure 10**). The closure of restaurants and mass caterers induced a domino effect on the activity of the

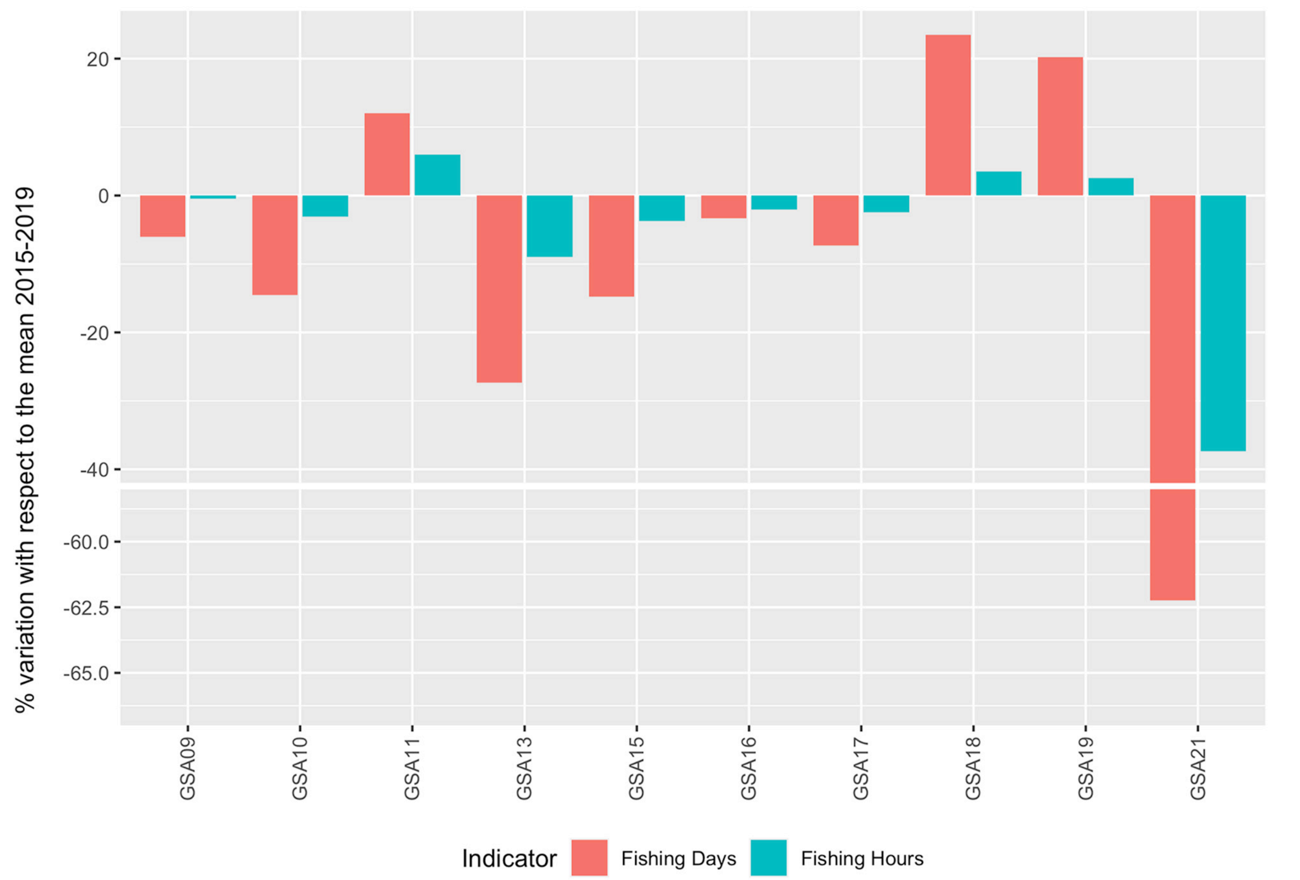


**FIGURE 7 |** Pattern of changes (difference in percentage between the total yearly value of Fishing Days and Fishing Hours in 2020 and the mean values during the years 2015–2019) for each GSA.

Italian fishing fleet, even though such effect was not uniform (e.g., in the Adriatic this was a reported reason with a proportion of 36% in GSA 17 and 31% in GSA 18). The closure of restaurants affects both directly and indirectly the sector. In several coastal areas, fishers traditionally supply the local restaurants directly, bypassing fish markets, wholesalers and local traders. This system is also favored by the large number of landing sites, some of which are quite distant from wholesale markets. The traditional direct sales to restaurants prevented the fishers from organizing alternative channels like online or door to door sales. In other fishing areas (mainly the Adriatic and Southern Sicily ones), wholesalers didn't purchase the most valuable species usually requested by restaurants. According to 19% of participants, the reduction of fish market trading limited their activity. Logistical problems were mentioned by 5% of participants, with a higher incidence in GSA18 and GSA19 (13 and 12%, respectively). In some regions, even though the fish markets were open daily, they could not be supplied due to the block of transport and movement of goods between regions. Finally, further causes of the total or partial reduction of activities—mentioned by the vessel owners as well as the crew—was the difficulty in ensuring social distancing on board. However, only 1% of vessels limited their activities for this reason. Since vessels have an average crew of four, often belonging to the same family unit, very few vessels, and only the largest, were affected by this problem. Reduction of the fishing effort (in terms of number of trips) is reported to be the more common action undertaken by fishers to mitigate the adverse effects of the lockdown (**Figure 10**). The predetermined volume of demand resulted in a significant reduction of activities (37% of participants); this action was the most important in all the fishing areas with the exception of GSA16 (Strait of Sicily); 74% of participants in the area chosen to freeze the landings (mainly crustaceans) and wait for a recovery of the seafood markets and prices. Only 10% of respondents stated they undertook actions to diversify their sales channels. This mitigated the loss of sales, even though the transport and movement restrictions reduced the consumer demand through reduced shopping frequency and the purchase of produce with a longer shelf-life (NISEA, 2020).

## DISCUSSION

The results of this paper clearly indicate that the pandemic and the related control measures have had a tangible and diversified effect on the Italian fleet of trawlers. In general, the lockdown

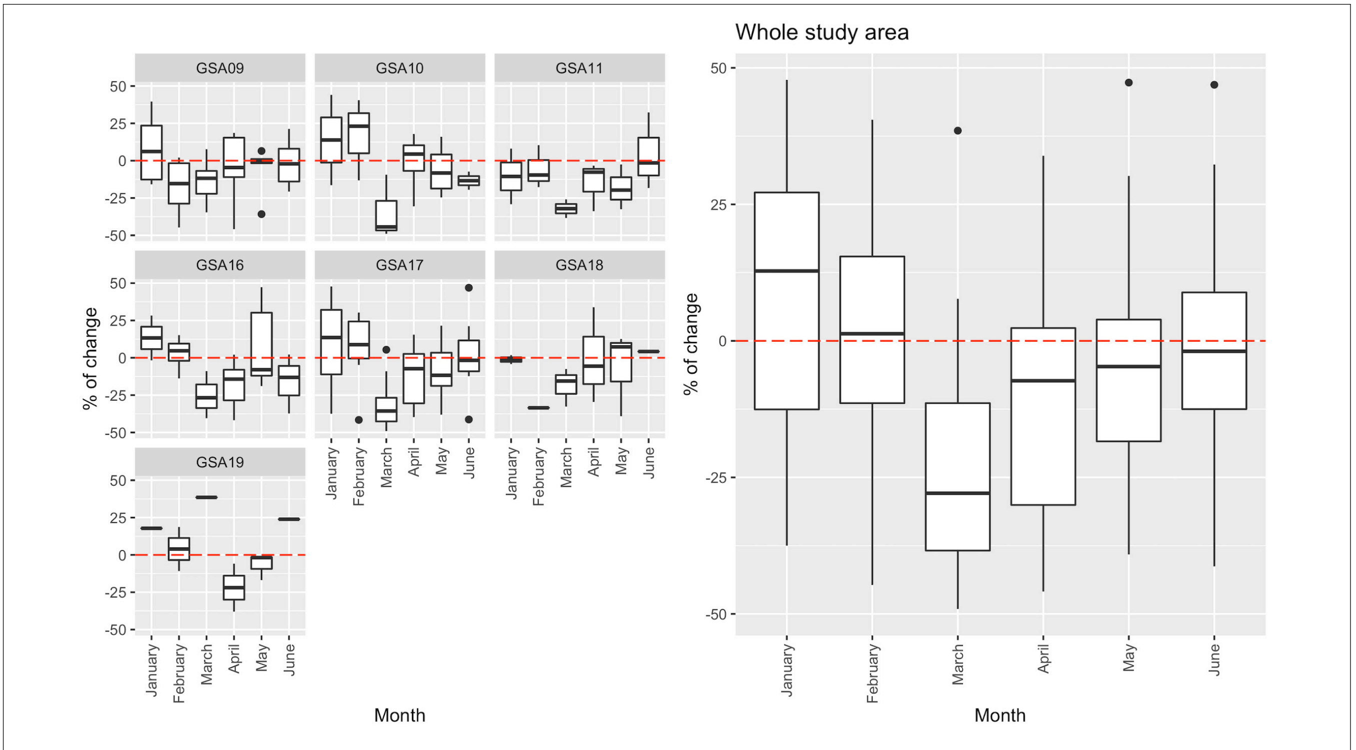


**FIGURE 8 |** Boxplot showing the variation (as percentages comparing values of the year 2020 and those of the 2019) in the total monthly landings of demersal species in the main harbors for each GSA.

measures have led, directly (because of closure of fish markets) or indirectly (because of lack or demand of restaurants), to a reduction in fishing effort. This reduction of the trawling effort occurred mainly in some areas, such as the GSA13, GSA15, and GSA21 (**Figure 1**), that host fishing grounds far from the Italian coast and, therefore, more difficult to exploit during the emergency (and the resulting confusion and uncertainty) caused by the pandemic. In addition to these geographically marginal areas, fishing effort has declined mainly in the Tyrrhenian Sea and especially in the northern Adriatic Sea for the months of March and April 2020 (**Figures 4**, **5**). Along the eastern coast of the Tyrrhenian Sea (GSA9 and 10), the fleet has reduced the activity both in terms of fishing hours and fishing days, without altering its strategy, that is the relative allocation of the fishing effort in both coastal or offshore fishing grounds. On the contrary, the effort around Sardinia Island (GSA11) increased probably because there the fishers have been particularly skilled and effective in reshaping their activities on specific requests by wholesalers (**Figure 9**). In the Adriatic Sea (GSA17 and 18) the situation was more heterogeneous: in the northern part (GSA17) the fishing days declined all year around (especially in February and September), but the fishing hours and, consequently, the strategy changed only in these 2 months. These results are in substantial agreement with previous studies (Russo et al., 2021—same special issue). The southern part of the Adriatic Sea (GSA18), together with the Ionian Sea (GSA19), have been the exception to the general trend of reduction of fishing activity. In fact, in these areas, the fishing days significantly increased in six over 12 months of the year 2020 (GSA18) or (GSA19, Ionian), both fishing hours and of fishing days reached values higher than expected. Finally, in the central Mediterranean (Strait of Sicily), the Italian trawlers concentrated their activity off the southern coast (GSA 16), reducing their fishing effort in distant fishing grounds located in GSA 13 and 15. According to De Angelis et al. (2020), it is possible to explain this behavior on the basis of two aspects: the reduced demand of the market (**Figure 10**) and the tendency to limit the costs and the risks associated with the deep-sea fishing. In other words, during an uncertain and complex period such as the pandemic, fishers may have taken a more cautious attitude in the selection of fishing grounds.

In almost all the GSAs, the effects of the pandemic were more evident during the first 6 months of the year 2020, whereas the fishing effort returned to levels similar to those of the reference period 2015–2019 during the second half of the year. The comparative analysis of landings in the main harbors of each GSA substantially confirms these observations (**Figure 10**).

Reasonably, the differences in the response to COVID-19 shock are the result of the great heterogeneity of the Italian fleet and its fishing grounds, but also of the commercial network for fishery products. During the lockdown weeks, the closure of restaurants and of several fishmongers and wholesale fish markets stopped the sales of fresh seafood. The economic fallout of the lockdown has variously affected the fishing sector, and a wide range of measures have been adopted to contrast the collapse of demand in the different areas and fisheries, such

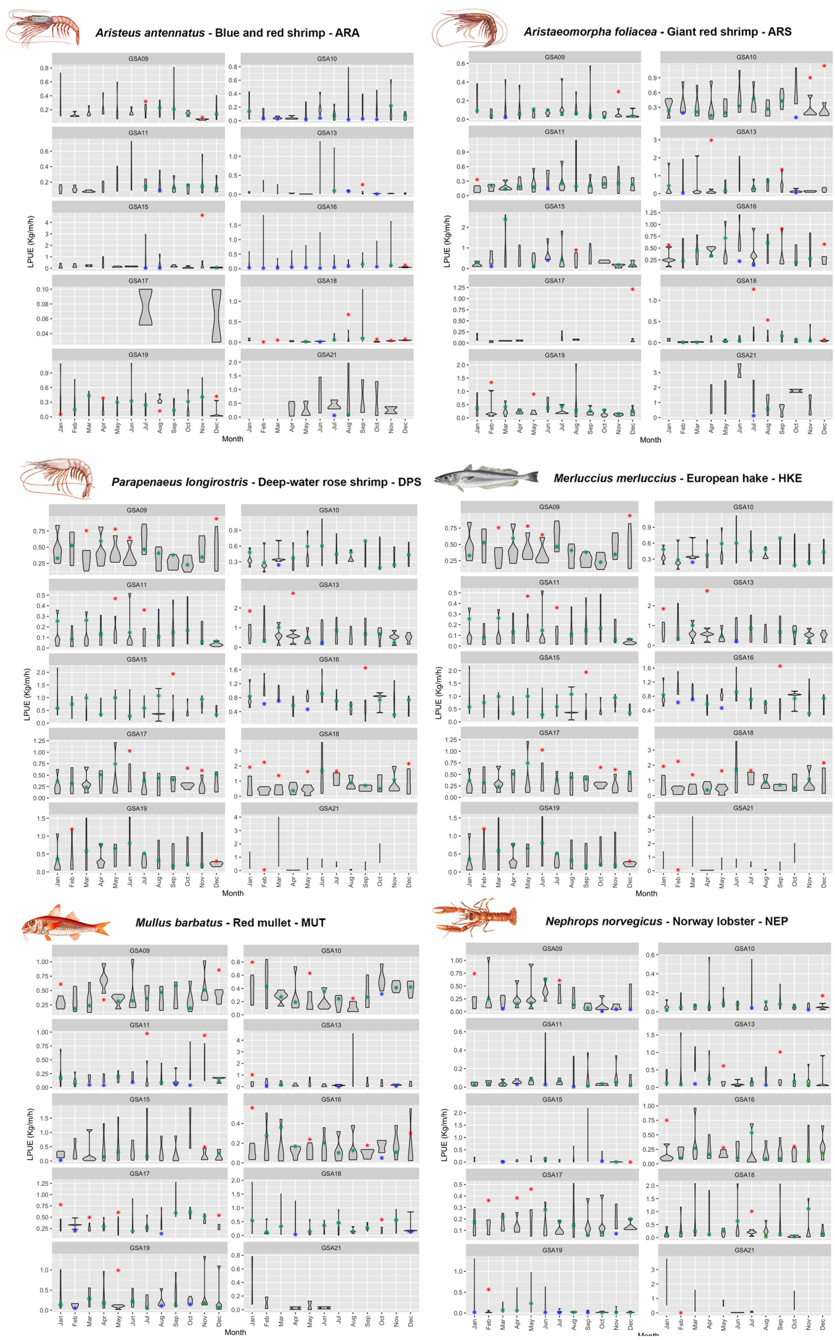


**FIGURE 9 |** Violin plot of the values of LPUE per species, month and GSA. The values of the years 2015–2019 are represented by the violin, while medians of the year 2020 (affected by the pandemic) are represented as red asterisks.

as new approach on the marketing side, with a focus on new channels (i.e., direct selling) and commercial agreements between the large-scale retailers and the fishing operators on a more local level (NISEA, 2020).

The negative economic impact driven by the pandemic was closely related to the fishing effort dynamics; indeed, with the exception of the first two lockdown weeks, fishing activities in some areas reverted to the average level of the period, whereas in others the stop lasted longer. The different behaviors were largely determined by the diverse local commercial structure and sales systems characterizing Italian fisheries. Clearly, in several ports (e.g., those located in Sicily, Apulia, and Campania) the closure of restaurants brought all fish trade to a halt. Some of the fishers who continued to work during the lockdown tried to deal with the situation by making changes to their sales channels, strengthening their collaboration with first sale

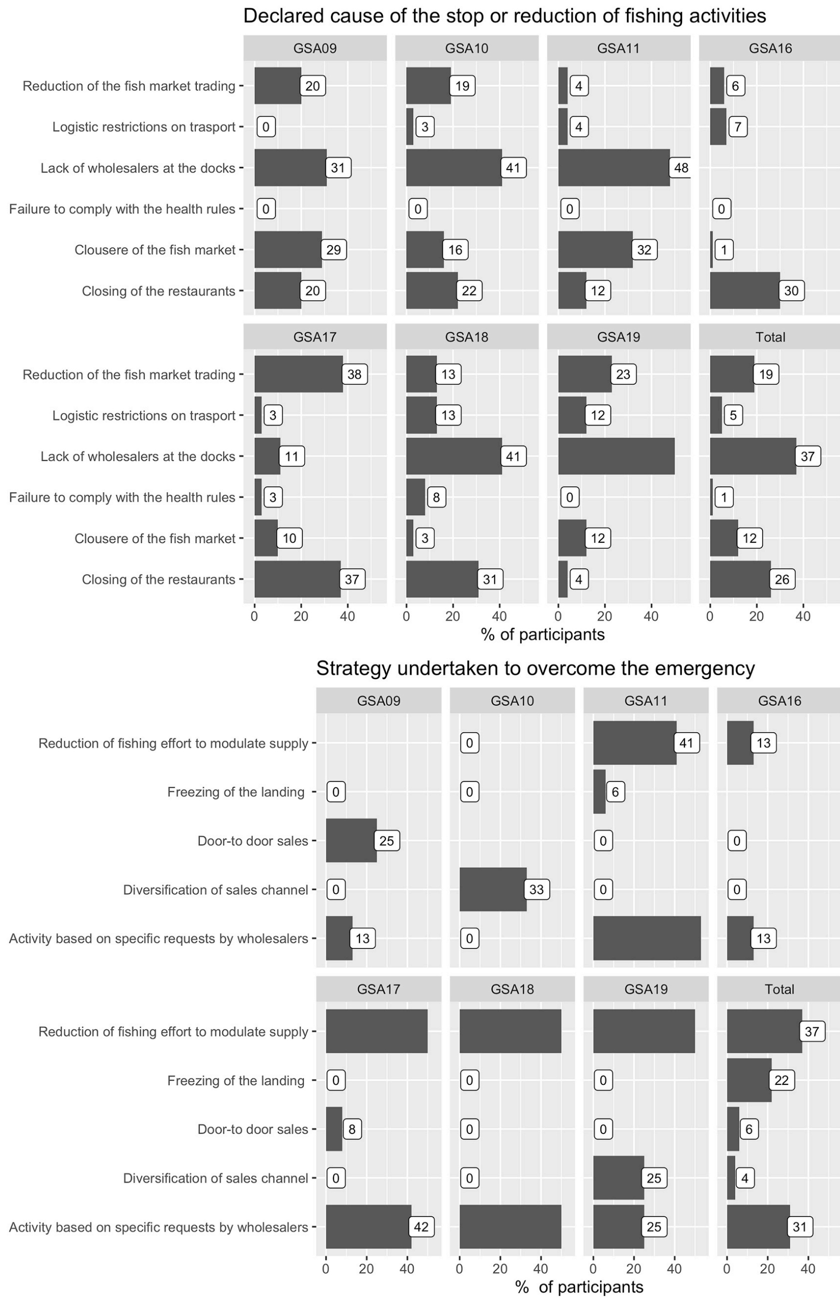


**FIGURE 10 |** Barplot showing the responses of the participants to the socio-economic questionnaire.

markets as well as local fishmongers. In March 2020 the fish markets in some areas were closed or had reduced their opening hours by closing on alternate days. Some markets managed by local bodies closed because they were unable to guarantee social distancing. Overall, most fish markets remained open, but business was very slack: the differences among markets might explain the large differences in the proportion of respondents indicating the reduction of fish market trading as limiting their activity (**Figure 10**). In the more organized ports (especially in the northern Adriatic and in Tuscany), where the sales network rested on sound relationships with wholesale traders (fish markets and wholesalers), the response to the emergency was to switch to on demand fishing. On days that were agreed weekly or daily, the vessel owners would be informed of the catch amounts that the wholesalers and the markets expected to be able to sell, thus generating demand-driven fishing. In addition, they teamed up in cooperatives to meet the demand of traders and fish markets. However, these actions involved especially bottom and pelagic trawlers, whose larger landings confer a greater bargaining power, whereas fisheries based on passive gears such as trammel net or longlines were less able to adapt (NISEA, 2020).

Another potential explanation for the differences in the response to COVID-19 shock could be related to the different dynamics of the pandemic observed in southern vs. northern Italy. In fact, the Northern part of Italy, that is the area corresponding to the GSA09 and the GSA17, was hit first and harder by the pandemic (Bertuzzo et al., 2020; Di Ciaula et al., 2020) and in those areas the authorities first applied severe restrictive measures. Hence, the areas of northern Italy were the most unprepared in the face of the emergency, while the southern areas of the peninsula (and all their productive activities including fisheries) have had more time to organize and face the difficulties generated by the pandemic. In addition, the market of Milan, the biggest one of the North Italy, was closed during the lockdown, determining the loss of the most important commercial outlet for the marine fisheries products of the GSA17 and 9.

The results presented in this paper represent one of the first assessments, at a large spatial scale, of the pandemic-related changes in the fishing activity that occurred in the year 2020. It is worth noting that the changes in the fishing effort detected through the analysis of VMS data are less impressive than those documented using AIS data in the same areas (Coll et al., 2021; March et al., 2021; Russo et al., 2021). More in general, AIS-based researches report large effects of the COVID-19 shock, but probably these wide variations (and in particular the huge reductions in effort reported in some studies) are based on the limits of the AIS system which, as demonstrated in the literature, can lead to underestimate the real activity because it is not uncommon for fishers to switch off to hide the position of some fishing grounds or because the system does not provide adequate coverage in all areas of the Mediterranean Sea (Russo et al., 2016; Shepperson et al., 2018).

From a more directly biological point of view, the heterogeneity of the response of the fleet has determined important changes not only of the total level of fishing effort, but also of that relative regarding the various fishing grounds. What happened in the Adriatic Sea is the most important example. The combined spatial analysis of fishing effort (**Figures 5**, **6**) and the LPUE of the main species indicates that the fleet, especially during the first months of the year but also during spring/summer, has strongly concentrated its activity in the coastal areas straddling the GSA17 and 18, along the zone that surrounds, on the Italian side of the Adriatic Sea, the Pomo pit. In fact, the LPUE for red mullet (MUT), hake (HKE) and Norway lobster (NEP) increased in GSA17 in different months during the first semester. This general trend toward an increase in inshore fishing could be explained by a more cautious strategy of fishermen during a period of crisis such as the pandemic. In this sense prudence refers to the higher costs related to fishing on deeper grounds: such costs can be incurred only having the reasonable certainty to obtain as much revenue from the sale of the landings (Russo et al., 2015).

Since the results of stock assessments are not yet available, it is not possible to establish what the effects were on the stocks. Also, for this reason, the LPUE are not used in this study as a proxy for the abundance of the various species but, rather, are used to analyze the strategy of the fleet, assuming that high values of LPUE of a species reflect a fishing strategy targeted to the exploitation of that specific resource. Notably, GSAs 13 and 15 that had the largest reduction of effort (in hours and days, **Figure 7**) were resulting as having no effects on LPUE (**Figure 8**).

Therefore, from a general point of view, the Italian fleet distributed in the harbors of the seven GSAs surrounding the Italian coastline (but that exploits in important ways at least other two GSA, the 13 and the 15) has reacted to the COVID-19 shock according to two almost opposite modalities. On the one hand (GSA9, 10, 16, and 17) there has been a more or less pronounced contraction of fishing effort, especially in the first half of the year, which can be explained by the incapacity or impossibility of fishermen to identify and implement alternative strategies to overcome the emergency (**Figure 10**). On the contrary, in the second group of GSAs (11, 18, and 19), the fleet managed to adapt, probably by activating direct channels with wholesalers (**Figure 10**) and being able not only to contain the effects of the shock, but even increasing the fishing effort. In both cases, however, the COVID-19 shock has influenced the strategy by pushing fishermen to reduce the exploitation of offshore areas (emblematic of the case of GSAs 13 and 15) and to increase the activity on some coastal areas, in which fishing effort has also increased significantly (**Figure 7**).

These results indicate that the ability to respond to a crisis such as that caused by the COVID-19 also depends on the organization of sales and distribution and on the entrepreneurial spirit of the various seafarers. Moreover, the results of this study suggest the possibility that, under external crises that increase perceived risks, fisheries can change fishing strategy reducing exploitation of offshore and deep-water species while increasing that of more coastal ones. In the near future, if this has to become a more recurrent situation, this behavior might have negative effects on some coastal species, especially in some areas such as the southern Adriatic and the south coast of Sicily.

Another important evidence of this study is that, after the strong impact of the COVID-19 shock during the first semester of the year 2020, the activity of the fleet has returned quickly to the levels of the previous years during the second half of the year. This shows that the fishing system as a whole has been very responsive and that, in addition to the overall reduction, the COVID-19 shock has led to a strong imbalance in the allocation of fishing effort in space and time.

## CONCLUSION

In conclusion, we believe that this study could represent a crucial starting point for the evaluation of the effect of the COVID-19 shock, and the related fishing stop, on natural resources. Indeed, our analyses provide a snapshot on the marine fisheries in the Mediterranean basin throughout the entire 2020, which in all likelihood, will go down in history as a year characterized by very severe restrictions of human activities. Whether such restrictions had, somehow, affected natural resources it will be possible to integrate our outcomes into management strategies and into decisions made by policy-makers In particular, the results of this study indicate that: (1) Without limits to the fishing effort, the benefits for fishery resources induced by the fishing pressure reduction (occurring for shocks like COVID-19 or unreasoned temporary bans) could be shortly nullified when fishing activities restart; (2) in absence of catch regulation, when fishing activities restart the fishers increase their activity on coastal areas characterized by greater abundance of resources including small size specimens, and where the effective fishing time could be longer than in offshore areas, in order to maximize catch.

## DATA AVAILABILITY STATEMENT

The datasets presented in this article are not readily available because raw VMS data, landings and individual responses to the questionnaire are confidential. Metadata and statistics are available by request to the corresponding author. Requests to access the datasets should be directed to corresponding author.

## ETHICS STATEMENT

Ethical review and approval was not required for the study on human participants in accordance with the local legislation institutional requirements. The patients/participants provided their written informed consent to participate in this study.

## AUTHOR CONTRIBUTIONS

TR, LL, SL, RS, EC, and AP performed statistical analysis. TR, EC, SF, SL, RS, and FF wrote the manuscript. TR, LL, RS, ES, and SL contributed to the experimental design. All authors revised the manuscript and approved the submitted version.

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## SUPPLEMENTARY MATERIAL

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fmars.2022.824857/full#supplementary-material

**Supplementary Figure 1 |** Violin plot of the values of LPUE per species, month and GSA. The values of the years 2015–2019 are represented by the violin, while those of the year 2020 (affected by the pandemic) are represented as red asterisks.

**Supplementary Figure 2 | (A)** Absolute changes in the value of total Fishing Days by GSA, Season and Depth stratum; **(B)** absolute changes in the value of total Fishing Hours by GSA, Season and Depth stratum.

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# Preliminary Estimation of Marine Recreational Fisheries (MRF) in the Time of COVID-19 Pandemic: The Marche Region Case Study (Adriatic Sea, Italy)

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Marine Recreational Fishing (MRF) is a highly attended complex activity, extremely evident along the coastlines, and mainly practiced among riparian communities. For that reason, this activity plays an important role to effectively contribute to the collective well-being, both from the social and economic points of view. However, it may negatively affect the fish stocks and the marine environment in general, mainly due to the removal of biological resources. The growing need to evaluate the magnitude of marine recreational fishing is recognized worldwide, especially in the last decade, when inclusive fishing programs began to focus their attention on this fishing activity. Based on its unexpected evidence and its wider repercussion on social behavior, the COVID-19 pandemic is considered by the scientific community as one of the most unique opportunities to better understand the social phenomenon and their repercussion on the environment. In this work will be reported very preliminary results on the consistency of marine recreational fishing in the case study of the Marche region (Italy). Number of recreational fishers and fishing effort were estimated through a telephone survey conducted in the Italian side of the Northern Adriatic Sea (FAO GFCM Geographical Sub Area 17) by interviewing 580 households. The sampling strategy also included a recall survey, which was carried out every month on a list of recruited fishers. In this manner, additional information was collected, such as detailed fishing effort, catches, and expenditures. In addition, biological data of catches were estimated through several on-site surveys. The information collected from January and December 2020 was affected by the COVID-19 pandemic in terms of social restrictions and access to marine places, inevitably impacting on marine recreational fishing features, including the biological resources and the related economic aspects.

**Keywords: marine recreational fisheries, COVID-19, biological resources, economic impact, restrictions**

## INTRODUCTION

Recreational fishing, its component, and relative sectors have several definitions (Pawson et al., 2008). Food and Agriculture Organization of United Nations (FAO) defines this activity as "fishing of aquatic animals (mainly fish) that do not constitute the individual's primary resource to meet basic nutritional needs and are not generally sold or otherwise traded on export, domestic or black markets" (FAO, 2012). In fact, recreational fishing is considered a non-profit sporting activity, governed by specific laws [minimum sizes of catches, fishing restricted areas, equipment, etc; (Hyder et al., 2017)]. However, for management, legal and research purposes, it is necessary to have a shared definition of the recreational fishery (Herfaut et al., 2013).

Marine Recreational Fishing (MRF) is an important and popular activity in most coastal areas of the world (Pranovi et al., 2016), with large numbers of participants and significant economic and social impacts. It is estimated that around 9 million Europeans (or 1.6% of the total population of the European Union) are engaged in marine recreational fishing, for a total of 78 million fishing days, generating six billion euros of new capital per year and millions of related jobs (Hyder et al., 2018), representing an important economic engine in some sectors (e.g. tourism), which create benefits in terms of income and employment.

Compared to United States, Canada, Australia, and New Zealand, in Europe the management of this activity has been largely neglected (Cooke and Cowx, 2006), and even if MRF is considered as an economic and sociological opportunity, generating new sources of income, intense marine recreational activities in general, could even be a source of ecological problems (Bellanger and Levrel, 2017).

Potential issues posed by the lack of data about estimates of catch effort and socio-economic aspects to the recreational fisheries were already highlighted by the Scientific Advisory Committee on Fisheries (SAC) of the General Fisheries Commission for the Mediterranean (GFCM). This gap is particularly important for stocks that are overexploited by commercial fisheries and by which recreational fisheries might be an additional component of fishing mortality.

Currently, at Mediterranean level, all catches attributable to MRF are completely unknown and therefore excluded from the assessments of the status of commercial stocks. As a general rule, commercial and recreational (i.e. total) catches should be merged to better understand the dynamics of the main stocks (Freire and Rocha, 2020), even because for some specific resources in certain areas, MRF catches might surpass commercial ones (Coleman et al., 2004; Ihde et al., 2011). Indeed, sustainable management of fisheries requires the estimation of both its commercial and recreational components because the synergy of both sectors is responsible for the total fishing mortality induced on a stock (Gemert et al., 2021). Considering the overexploitation status of many fish stocks (FAO, 2020), estimated only taking into account commercial catches, it becomes imperative to quantify the magnitude of MRF, in order to estimate the total fishing pressure on the resources.

To this purpose, the development of an efficient monitoring system is a key element for understanding (Green et al., 2005) and quantifying the MRF footprint. The main challenge in collecting data from MRF is its geographically disperse nature (Freire and Rocha, 2020), the "nomadism" of the users (Smallwood et al., 2011), and the heterogeneity of practices and their seasonality (FAO, 2012). In the Mediterranean context, another factor increasing variability is that each country has its own legislation for this activity. In fact, even if in some countries, there are examples of mandatory registration programs (Gaudin and De Young, 2007)\, daily catch limit (e.g. Italy and Spain), catch declaration, licensing or registration, which could facilitate effort limits, that are not always required.

With the growing interest that has been observed in this activity in recent years, the EU has called for more regular and adequate information on this sector, not only to better manage shared fisheries resources, but also to meet the interests of various actors in the world of fishing. However, as harvest rates, even the economic impact of this activity on the society is difficult to estimate.

The global pandemic associated with COVID-19 has affected commercial, artisanal and recreational fisheries worldwide. The impacts resulting from the pandemic varied according to the different level of action applied by the various national governments to reduce the transmission of the virus within the community (Ryan et al., 2021). In general, the measures adopted at the global level were the following: social and physical distancing, travel restrictions, and the obligation to stay at home. Lockdown measures, especially during the early phases of the pandemic, led to such dramatic changes in human-environment interactions that some are now referring to this period of reduced human mobility and activity as the "Anthropause" (Rutz et al., 2020). In Italy, the strongest restrictions coincided with the spring season, when in normal circumstances, MRF would be a common activity (Paradis et al., 2020). In particular, lockdowns, as they consist of strict prohibitions against non-essential activities, may have had some effect on fishing effort, along with other typical components of MRF and related activities (Howarth et al., 2021).

Given that the pandemic will maybe persist for years (Billington et al., 2020), there is an urgent need to learn from current and ongoing experiences. Currently, fisheries scientists are learning about the impacts of the COVID-19 on fisheries using traditional assessment tools [e.g., social surveys; (Cooke et al., 2021)]. However, the current moment provides an opportunity to understand what lessons can be learned from the Anthropause for the management of recreational fisheries in the future.

The most widely used methodology around the world to estimate MRF footprint is the survey. A survey is a specific research approach that, through the adoption of standardized construction procedures (questionnaires) and the extraction of a representative sample of subjects, allows the statistical elaboration of a set of information (Mauceri et al., 2020). Different kind of surveys have been tested all over the world, each one with its advantages and limitations (Hartill et al., 2012;

Skov et al., 2021). In general, they differ for the cost-effectiveness of the methods (Bellanger and Levrel, 2017), considering that there are always trade-offs between survey costs and the precision of the estimates (Pollock et al., 2002).

In this sense, the Handbook for Data Collection on Recreational Fisheries in the Mediterranean and Black Sea was specifically designed to pursue the objective to collect robust and timely information on the impacts of recreational fisheries on marine living resources and their interactions with other human activities in the coastal community. It provides a clear methodological framework to allow Mediterranean and Black Sea communities to implement suitably harmonized sampling and survey monitoring schemes for recreational fisheries (Grati et al., 2021).

Here will be presented a pilot study performed in Marche Region, Italy, aimed at estimating the magnitude of MRF in the area, and the possible effects of pandemic-related restrictions. Following the methodology described in Grati et al. (2021), three kinds of survey (telephone, on-site and recall) were performed in parallel and integrated, taking advantage of the strengths of each one.

## MATERIALS AND METHODS

### Study Area

Marche region has 173 km of coastline, which together with Friuli Venezia Giulia, Veneto, Emilia Romagna, Abruzzo, and Molise, constitutes the Italian side of the Geographical Sub Area (GSA) 17, Northern Adriatic Sea (**Figure 1**). The coast is mainly low, with many beaches (81%) interrupted by high cliffs (19%) in correspondence of the Conero promontory. Moving offshore there are sandy bottoms mixed with mud. From north to south thirteen main rivers flow along this area, including five larger ones (Potenza, Chienti, Tenna, Aso, and Tronto) and minor seasonally dry streams. The high supply of nutrients through river waters determines a high primary production which is reflected in the food chain, leading to high fish productivity and

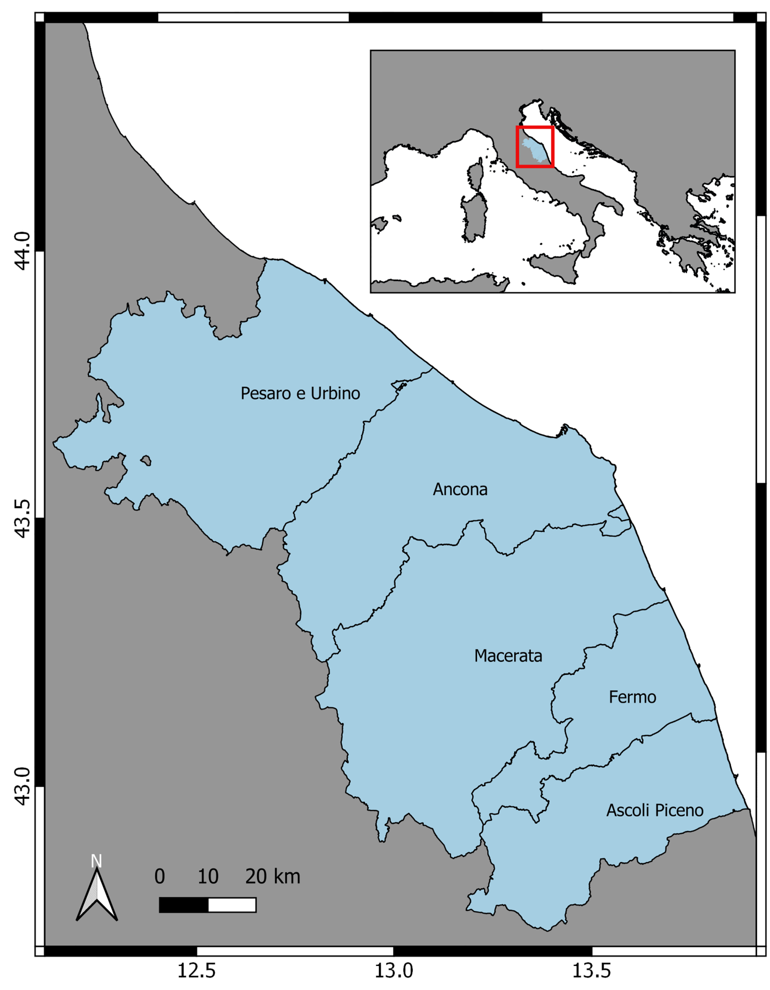


**FIGURE 1** | Marche region and its provinces (Italy).

making the Adriatic one of the most productive areas in the Mediterranean for fishing purposes. Along the coast there are a total of 18 between port structures and tourist marinas, which are hotspots for many shore fishers, and at the same time, they are docking points for boat fishers (Ministero delle Infrastrutture e dei Trasporti, 2020).

The study area, as well as the entire world in 2020, was affected by the virus SARS-CoV-2, generating the Covid-19 pandemic. In Italy different typologies of restrictions were put in place (e.g. lockdowns, curfew, prohibition of certain activities, etc.) starting from national restrictions to regional regulations, based on the phases of the contagions. Depending on the type of prohibition imposed, the repercussions on MRF and related activities ranged drastically during 2020 (**Figure S1 Supplementary Materials** and for more details **Tables 1, 2** in **Supplementary Materials**).

## Telephone Survey

The telephone survey was a part of a wider pilot study in the Italian GSA 17, involving 6 regions: Friuli Venezia Giulia, Veneto, Emilia Romagna, Marche, Abruzzo, and Molise, started from the 22$^{nd}$ of May to the 8$^{th}$ of June 2020. This task was committed to a specialized company that used two different strategies: CATI (Computer Assisted Telephone Interview) and CAMI (Computer Assisted Mobile Interview). With the integrated use of CATI and CAMI, the problems related to the fact that fewer and fewer people have a home telephone was considered negligible. The telephone numbers for the interviews were extracted by chance from the Italian directory for fixed telephones and, from a list of randomly generated and georeferenced cellular numbers, for mobile ones. RDD (Random Digit Dialing), which has been the strong-point in the research sector for over 30 years (Link et al., 2008), was the basis of these telephone surveys. In this way, the selection of people to be involved in telephone statistical surveys was carried out in a completely random manner. Prior to the telephone survey, all the interviewers were trained by the company about the purpose of the interview. In parallel, this activity was reviewed by verifying the quality of the data collected using automatic quality indicators (length of interviews, number of rejections per interview, etc.) and manuals (listening to interviews in real-time).

The sampling scheme for this activity was organized into two strata:

- Coastal municipalities (considering a buffer of 10 km from the coastline), which were oversampled, in order to obtain more interviews with recreational fishers (Bellanger and Levrel, 2017);
- Inland territories (less populous regions), conducting several interviews.

The sample size was identified considering to have an acceptable margin of error (<5%).

Respondents who resulted to be engaged in MRF were asked for additional personal details (age, sex), preferred fishing modality (from boat, shore or spearfishing), and the number of fishing days performed in 2019. Moreover, it was asked the willingness to be recontacted to take part to the following phase of the recall survey. Who answered positively was included in the panel: a list of fishers to be periodically interviewed on a monthly basis.

## On-Site Survey

On-site or *in situ* investigations, although onerous (Hartill et al., 2011), consisted in approaching the recreational fishers directly in the field. The main purpose of this sampling was to try to involve other fishers in the panel, georeferencing their fishing activity in the area. From January 2020, on-site survey was performed from North (Pesaro harbor, PU) to South (San Benedetto del Tronto, AP), randomically extracting the sampling day and the location. The approach to interview was informal, in order to establish a relationship of trust with the fishers. With the aim of collecting harmonious data, it was created a standardised questionnaire centred on personal information, effort and catch and release data (see **Supplementary Materials Table 3**), together with the willingness to be recontacted in the following months.

In this study retained or released catch refers to biological resources subtracted or not from the sea, respectively. The reasons driving anglers to choose the destination of their catch are not taken into consideration in this work.

## Recall Survey

This approach is an off-site data collection method which is a valid tool for estimating all recreational fishing activities on a broad geographical scale, compared to the on-site survey. In fact, it allowed collecting data, all-round year, from contacts in the panel. It was carried out by re-contacting, by phone or by e-mail, the recreational fishers who gave their willingness to continue to collaborate, to collect data on catches, fishing effort, and economic information, relative to a specific period.

The standard form for the interviews carried out with this methodology is the same as in **Table 3** of the **Supplementary Material**, with the difference that the data collected refer to a monthly basis period and not to a single fishing trip and also include some aspects aimed at estimating the expenses incurred by those who participate in MRF.

## Avidity Bias Evaluation Between Panels

In order to reduce the bias in the avidity evaluation, it is highly recommended to bear in mind how the data is collected. In fact, it exists the possibility that fishers who gave their willingness to be interviewed and included in the panel were those who had a deeper interest in fishing, and represented the most avid and prone to expenditures subpopulation (Wynne-Jones et al., 2014). To verify that the sample was not *a priori* biased in this direction, it was necessary to compare the panel with a known sample, representative of the population in terms of avidity (i.e. the number of fishing days in a year). The whole dataset obtained from the telephone survey conducted on GSA17 area was available to perform this comparison. The distribution of the outputs in the probabilistic sample was compared with the distribution of the panellists' outputs using the Bootstrap methodology. Bootstrapping is a statistical procedure for estimating the sampling distribution of a variable; in this case the mean fishing days, by sampling with replacement from the original sample. When the statistical distribution is unknow, it can be used to produce good approximate confidence intervals. With respect to other numerical methods, in fact, bootstrapping methods shows a lower bias or variance (DiCiccio and Efron, 1996) with the advantage that is not necessary to make any assumption about the shape of the distribution of the variable. Instead of generating observations from a known theoretical distribution, observations were generated from the distribution of the sample itself. Two bootstrap algorithms were applied: the first, bias-corrected and accelerated (BCa) bootstrap, gave the chance to construct confidence intervals of the mean for both the distribution (Dixon, 2002), while the second allowed to compare the two distributions directly. The second algorithm applied was characterized by a non-parametric hypothesis test that assumed the difference in average between the two distributions as a null hypothesis (for more details see for example (Chernick, 2011).

## Statistical Analysis

The association between a response variable (fishing days, retained catch, travel expenses, etc.) and the covariate "month" was evaluated by a linear mixed model (Zuur et al., 2009) where the factors "month" and "ID of the fisher" represented the fixed and the random effect, respectively. *Post-hoc* tests were performed with the Bonferroni correction which is more appropriate for an unbalanced design (David, 2019). The statistical analysis was carried in R environment (R Core Team, 2021). In particular, for the linear mixed model, we used the function lmer (package lme4 ver. 1.1-27.1) which is better suited for crossed designs (Hector, 2015). For significant testing, a reference p-value of 0.05 was considered for all hypotheses tested.

# RESULTS

## Telephone Survey

For the whole GSA 17 a total of 44,651 telephone calls were done: 5,207 calls were considered as valid (11.7%), 20,197 people refused the interview (45.2%) and 19,247 calls were deemed invalid for other reasons (such as: non-existent phone numbers, no quota, 6 attempts reached, other outcomes; 43.1%).

In Marche Region a total of 581 households were reached by the telephone survey and a total of 1,576 people was surveyed (**Table 1**). Of these, 369 calls were referred to landline phone numbers (277 coastal, 92 non-coastal municipalities), while 212 were referred to mobile phone numbers (129 coastal, 83 non-coastal municipalities). The margin of error based on the sample size was estimated as 4.07%. The overall population of Marche Region consists of 1,512,672 people estimated for 2021 (ISTAT, 2021); so, this screening survey reached 1,081 inhabitants living in coastal municipalities and 495 ones living in non-coastal municipalities of the region, representing 895,685 (65.3%) and 475,959 (34.7%) inhabitants, respectively. Among interviewed people, only 34 resulted engaged in MRF, 27 of which belonged to the coastal, and 7 to the non-coastal stratum. This generated a participation rate of 2.1% when considering the whole region, corresponding to a participation rate of 2.5% and 1.4% for the coastal and non-coastal municipalities, respectively (**Table 1**).

The mean yearly fishing days (reference year 2019) estimated with interviews were 14.7 days/year. The total number of fishing days by fishing modality showed that the most relevant was represented by shore fishing (230 days, 46%), followed by boat fishing (183, 36.6%) and by spearfishing (87, 17.4%; **Figure 2**).

## On-Site Survey

During the on-site survey a total of 107 people were interviewed in 2020 in the Marche Region; they were all male with an average age of 47.58 years old. About the willingness to contribute to the project, 31 people agreed on contributing to the study as panelists for the recall survey.

## Recall Survey

Considering the relatively low number of panellists recruited from the telephone survey, the recall was performed on both the panel recruited with the telephone survey and the one obtained during on-site survey. A total of 39 fishers was regularly recalled on a monthly basis during the whole year 2020 for collecting data on catches, fishing effort and expenditures. Spearfishers were excluded due to the very poor data availability for this fishing modality.

The average fishing days were estimated at 4.18 ± 4.64 days/fisher/month, 86.9% coming from shore fishing and 13.1% by boat fishing (respectively 723 and 109 days; **Figure 3A**). A seasonal oscillation was observed about the monthly average days at sea by modality, especially in late summer/early winter, when boat modality reached the maximum value in July, estimated in 4.83 ± 5.88 days at sea, whereas shore modality highlight highest values in January at 6.75 ± 4.61 (**Figure 3A**).

In terms of hours spent at sea by each angler, the average value was estimated in 16.65 ± 20.28 hours/fisher/month, of

**TABLE 1** | Telephone survey in Marche region.

| | Coastal | Non-coastal |
|---|---|---|
| Home telephone valid calls | 277 | 92 |
| Mobile valid calls | 129 | 83 |
| **Total valid calls** | **406** | **175** |
| Population interviewed | 1081 | 495 |
| Representing inhabitants | 895.685 | 475.959 |
| Marine recreational fishers | 27 | 7 |
| **Participation rate** | **2.5%** | **1.4%** |

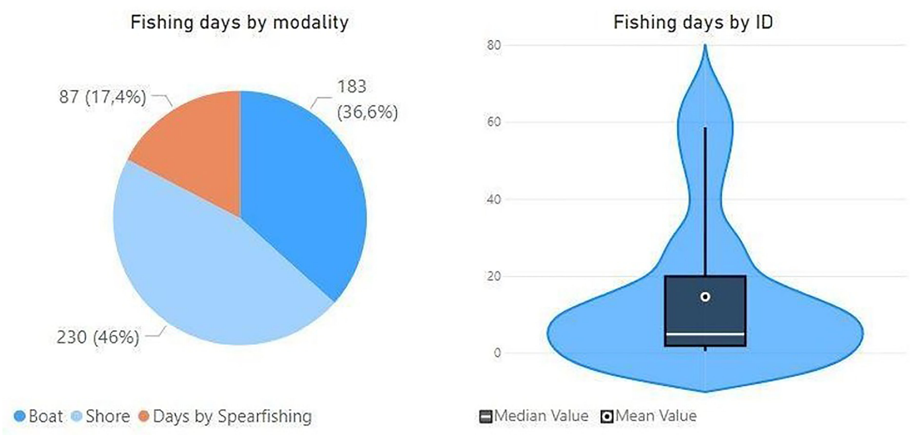


**FIGURE 2** | Number of fishing days by modality (left) and mean yearly fishing days (right) of 2019.

which 81.9% from by shore fishing and 18.1% from boat fishing (**Figure 3B**). The average hours at sea for the boat modality showed high values in June (29.8 ± 13.8), while the shore modality reached 22.8 ± 31.7 hours in May (**Figure 3B**).

The average retained catches, referred to as the quantity of resources subtracted from the sea by interviewed, was estimated in 1.53 ± 3.28 kg fisher/month, of which 55.3% from shore fishing and 44.7% from boat fishing (**Figure 3C**). The monthly average values indicated that the highest catches were obtained in July (3.07 ± 4.97 kg). The value of retained catch by modality highlighted September has the highest monthly value (10.22 ± 12.33 kg) for boat modality, instead, shore modality highlighted maximum values in July (2.92 ± 5.05 kg; **Figure 3C**). In terms of released catch, the mean value was estimated at 0.51 ± 1.42 kg fisher/month, of which 58.7% from shore fishing and 41.3% from boat fishing (**Figure 3D**). The monthly average indicated the maximum in June for boat fishing (2.97 ± 3.58 kg), and in July for shore fishing (0.78 ± 1.11 kg; **Figure 3D**).

The expenditures were considered by grouping all the categories (equipment, natural bait, artificial bait, fuel, and travel). The mean value was estimated in 40.86 ± 88.09 € fisher/month, of which 67.7% spent by the shore anglers and 32.3% spent by boat anglers (**Figure 3E**). Considering the great heterogeneity of these values, there is not a significant trend in the monthly average expenditures, indicating the maximum in October for boat modality (132.91 ± 161.83 € fisher/month) and September for shore modality (94.05 ± 179.32 € fisher/month; **Figure 3E**).

## Avidity Bias Evaluation Between Panels

From the results of the bootstrapping analysis, it was evident that the two distributions were centred around very close values (**Figure 4**), even if the panellists' one showed a greater variance (CI: 14.11-28.42 and 17.18-20.83, respectively; **Table 4 Supplementary Material**). A p-value of 0.92 (**Table 4 Supplementary Materials**) allowed to strongly refuse the hypothesis of a difference in the distribution of the means, meaning that it was possible to consider the fishers of the panel as representative, at least in terms of avidity.

## Statistical Analysis

The statistical analysis performed in order to identify if the factor "month" could affect the other variables revealed no statistically significant effects for most of them. Slight effects of factor "month" were observed only in relation to the variable "Artificial bait" for shore fishers (F value: 2.01, P value: 0.042*) *post-hoc*. All the results obtained from the analysis of variance (ANOVA) were also supported by the linear mixed model analysis (lme) applied to verify correlation among data.

# DISCUSSION

This study contributed to estimate the magnitude of MRF in the time of the COVID-19 pandemic. Here we estimated, for the first time, the participation rate, effort, and expenditures of marine Recreational fishers in the Marche Region, Central Adriatic Sea, Italy (GSA 17). In this work the proposed GFCM protocol (Grati et al., 2021) was applied for the very first time, trying to adopt an harmonized methodology among Mediterranean and Black Sea riparian countries.

Three different surveys, each one with specific issues concerning design, coverage, non-response biases, variability (Hyder et al., 2018), and costs, were integrated in order to take advantage of their pros, and try to overcome the cons. It is widely known that there are trade-offs between survey costs and the precision of the estimates, but it is also true that methods that reduce bias in the estimates may be too expensive. In general, the estimates deriving from on-site surveys are very precise, however, they require a network of experts spread throughout the whole coast, interviewing recreational fishers all year round and at all times of the day. For these reasons, they are much more expensive compared to off-site surveys (Pollock et al., 2002). In this case, the use of several survey methods allowed to obtain a satisfactory estimate on MRF

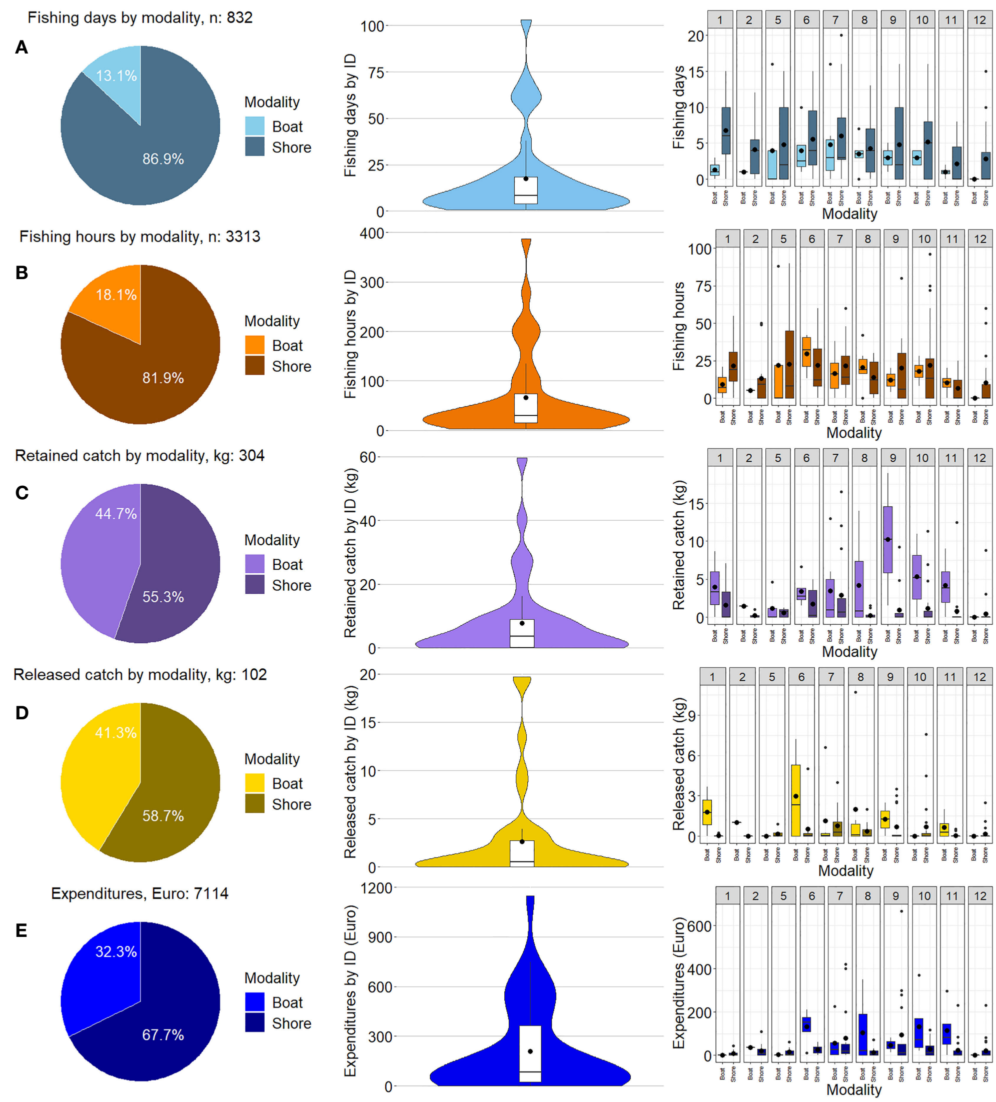


**FIGURE 3** | Data on fishing effort, catches and expenditure from the recall survey in the year 2020. From the left pie chart (n and %), violin plot, and box and whisker plot of variables by modality. From the top: fishing days (days, **A**), fishing hours (hours, **B**), retained catch (kg, **C**), released catch (kg, **D**), expenditures (€, **E**).

(Herfaut et al., 2013) and, at the same time, it was a good trade-off for experts' work and total costs. Moreover, the protocol adopted for data collection perfectly fitted the Anthropause induced by COVID-19 restrictions, allowing the study prosecution during 2020. The MRF participation rate estimated in Marche Region (2.1%) was slightly higher than the one calculated by Hyder et al. (2018) for the whole Europe (1.6%), confirming the greater propensity to this activity by people living in coastal areas. Similarly, the average number of fishing days per year was higher in the Marche Region (14.7 days/year in 2019) when compared to what estimated for the European countries (5-10 days/year; Hyder et al., 2018), suggesting that a cultural component and long tradition of the area (Pranovi et al., 2016) could influence the avidity. Given these values of participation rate and avidity, MRF in Marche Region would involve more than 31,000 people exerting a total of 571,000 fishing days/year.

From the results of the telephone survey, shore fishing resulted to be the more popular modality both in terms of people involved and average fishing days/year, confirming the outcomes of many studies conducted in other countries (e. g. Gordoa et al., 2019). Boat fishing was the second most popular modality detected, while spearfishers were fewer. Considering the fragmented information on people participating in this modality and the poor availability of data, spearfishing was excluded from the analysis of this study. It is well known that, due to the nature of this modality, spearfishers are difficult to be involved in on-site surveys (Griffiths et al., 2010), so different strategies to include them in the panel would be needed in future.

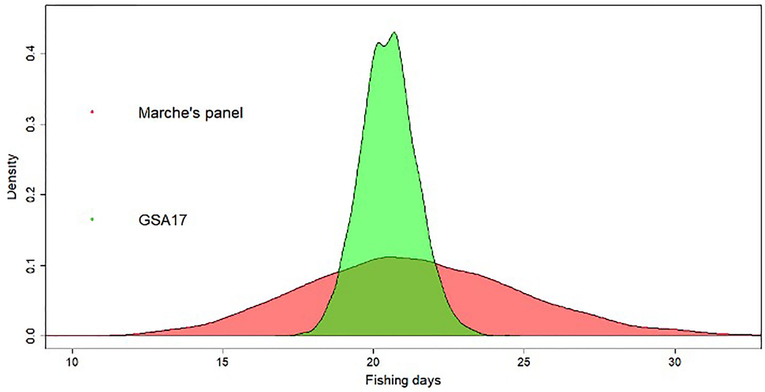


**FIGURE 4** | Distributions obtained from 10000 random draws of the bootstrap algorithm: the green shaded area represents the distribution of the mean of annual fishing days for the probabilistic sample of the GSA17 area, while the red shaded area represents the same statistic for the Marche's panel.

The pressure on the resources evaluated through the retained portion of catches has been estimated as comparable between shore and boat fishing, meaning that under the same fishing time, boat modality has higher Catches Per Unit of Effort (CPUE). This difference in pressure could be due to different factors. First of all, fishing by boat in the Italian side of the North Adriatic Sea allows to reach most appreciated fishing hotspots such as deeper areas or submerged structures, principally represented by mussel culture farms, but also by wrecks and rocky reefs that could increase the chance to catch bigger fishes (Pranovi et al., 2016). It is reasonable to assume the catch estimation as an underestimation due to the daily bag limit that is fixed by national law at 5 kg per day per fisher, which probably could lead interviewers to declare their catch under this limit. In addition, considering the results on the expenditures by modality, from which it is evident that a fishing day from the boat is much more expensive than from the shore, a boat fisher could be inclined to invest these amounts of money only for larger and most satisfactory catches.

Data on expenditures represented a huge challenge in this study, as there is a very wide range of goods and services included in MRF, and it is worth to point out that the direct expenditures here reported were just a part of the total economic value generated by MRF (Andrews et al., 2021). Some aspects, for example, due to the difficulty in obtaining this information by recreational fishers, were not taken into account, such as the transport expenditures from home to the fishing point (e.g., fuel, transit costs, etc.). For that reason, in the updated version of the on-site form the ZIP code of place of residence was included, in order to estimate economic behaviour of anglers such as the "willingness to pay" to obtain Services from MRF.

Some loss in expenses directly related to the pandemic effect on recreational fishing have been already expected, but in other hand, fishers investing in new fishing gear were noted in Italy (Pita et al., 2021). Nevertheless, although the expenditures are a useful rough proxy of the economic impact of recreational fisheries, they neglect some components of the total economic value as for example the one associated to the leisure of fishers. This means that the number proposed in the results is very likely to be a strong underestimate of the total economic value generated by MRF in the Marche region, which confirm the need of investigate the magnitude of the phenomenon.

Activities associated with recreational fishing were seriously affected during the confinement imposed by the different government decrees, as reported for the Canary Islands. The effect of the closure inevitably affected the entire tourism industry and leisure activities (Henry and Lyle, 2003; McManus et al., 2011; Guerra-Marrero et al., 2021), in addition once the social confinement was completed, they are not reactivated in a regular way, but reopening was modulated according to the infection intensity in each region (Guerra-Marrero et al., 2021). Such pandemic condition may have had overwhelming effects worldwide, both on environmental, social, and economic point of view. If we consider the possible effect on how citizens could remodel the value attributed to outdoor activities, it is reasonable to assume an increase of the absolute value of ecosystem services provided by MRF. This phenomenon was already showed, highlighting a significant increase in the number of recreational fishing licences immediately after the confinement (Guerra-Marrero et al., 2021; Thomas, 2021), or an overall increase in fishing effort especially for anglers with lost work or lost jobs (Midway et al., 2021). The motivation on how people participate in recreational fisheries has been changed by the pandemic, moving from a simple outdoor activity for non-consumptive orientations (e.g. "to relax and unwind"), to a consumptive orientations (e.g. "to catch a feed") such as obtain fresh and quality food in a simple way (Henry and Lyle, 2003; McManus et al., 2011; Guerra-Marrero et al., 2021).

At the same time, if in one hand the recreational companies were negatively affected by confinement measures such as cancellation of fishing tournament, prohibition of fishing charters and licences suspension, in the other hand an increased demand for reels, nylon, buoys, hooks, spearguns, masks and fins, and other fishing tools was recorded, reaching 60% in relation to the similar period of the previous year (Paradis et al., 2021). This aspect was influenced not only by the possibility to carry out the outdoor activity of recreational fisheries (Guerra-Marrero et al., 2021), but also because in most cases it was encouraged during the pandemic, also listed as an essential activity, as long as it could be performed while adhering to public health guidelines, so that 92% of the 63 North America jurisdictions did not close or delay the 2020 recreational fishing season (Paradis et al., 2021). During COVID-19, changes in fishing activities were attributed in order of importance to: travel restriction (53%), social distancing (45%), the decision to isolate (37%), personal reasons (26%), fishing quality (11%), access (9%) and cost (4%), as showed in Western Australia (Ryan et al., 2021).

Given the Anthropause induced by COVID-19 related restrictions, all the absolute values resulting from this study about MRF in Marche Region should be analysed taking into account that for 2 months, namely March and April, all the activities were banned; in fact, the lockdown effect is evident in the results for all the considered variables. For 2020, the estimated average fishing days/year, fishing hours, retained and released catches, and expenditures could have been even higher without COVID-19 effects.

Considering an average value of fishing days per month per fishers, estimated as more than 4 days, or retained catch per month per fishers, estimated as more than 1.5 kg, and also the total costs, estimated as more than 40 € per month per fishers, it is quite easy to understand the magnitude of the effects of restrictions induced by COVID-19 in terms of impact on the marine resources and related economy.

Midway et al. (2021) highlighted a change in primary reason for fishing during the pandemic. Fishing to help in mental stress and for social and family bonding was reported by many anglers as increasingly important.

Considering the above mentioned results, and avoid to exceed in speculations, assuming Marche Region as representative of the whole Italian peninsula inhabited by 59 million people (ISTAT, 2021), and expanding these results basing on the participation rate to MRF in the area, it is reasonable to assume that the magnitude of Italian marine recreational fishers could reach 1.24 million people, catching more than 22,760 tons/year of fish resources, and generating more than 607 million € expenditures. If compared to the Italian capture production deriving from commercial fisheries (163,764 tonnes in 2019; GFCM, 2021), and income generated by the national commercial fleet (881 million €; STECF, 2021), MRF could represent even 13.9% of commercial landings and around 68.89% of the commercial income generated.

It is reasonable to assume this estimation could be affected by some uncertainty that could under- or overestimate the results. It is possible essentially because regions could demonstrate different propensity to this activity, on the contrary, the social restrictions caused by the COVID-19 pandemic could affect the behaviour of fishers, causing a re-evaluation attributed to the time spent for this outdoor activities.

Other factors could contribute to the distortion of the above estimation, such as the willingness to answer correctly to the recall survey, without thinking about the repercussion of declarations, or different percentage and distribution of fisher typology, differently impacting resources, and expenditures.

In conclusion, this case study estimating MRF in Marche Region confirmed the relevance of the sector, not only in Adriatic Sea, but also at European level. Much remains to be done to fully understand the features of this fishery, especially from the environmental, social, and economic point of view. However, from the estimation produced so far it is evident the need to characterize in detail MRF both at national and basin level, moving toward a sustainable exploitation of the sea and their resources, also considering the value of this activity both as source of economy, health, and well-being for the whole community.

## DATA AVAILABILITY STATEMENT

The dataset presented in this article is not readily available because the authors are not the data owners. Requests to access the dataset should be directed to luca.bolognini@cnr.it.

## ETHICS STATEMENT

Ethical review, approval, and written informed consent for participation were not required for the study, in accordance with the local legislation and institutional requirements. The study was not directly connected and did not include manipulation of vertebrate animals or cephalopods.

## AUTHOR CONTRIBUTIONS

LB, FC, VF, AP, LS, MS, and FG collected the data, FC and SG performed the statistical analysis, LB and MS wrote the manuscript with contributions from all authors. All authors discussed the results. All authors contributed to the article and approved the submitted version.

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## SUPPLEMENTARY MATERIAL

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fmars.2022.823086/full#supplementary-material

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# SAR Satellite Imagery Reveals the Impact of the Covid-19 Crisis on Ship Frequentation in the French Mediterranean Waters

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The Covid-19 pandemic is the latest example in a growing number of health, social, economic, and environmental crises humanity is facing. The multiple consequences of this pandemic crisis required strong responses from governments, including strict lockdowns. Yet, the impact of lockdowns on coastal ecosystems and maritime activities is still challenging to quantify over large spatial scales in comparison to the pre-Covid period. In this study, we used an object detection algorithm on Synthetic Aperture Radar (SAR) images acquired by the two Sentinel-1 satellites to assess the impact of the Covid-19 crisis on the presence of boats before, during and after lockdown periods in the French Mediterranean Exclusive Economic Zone. During the French most severe lockdown period (March – May 2020), we observed that ship frequentation remained at the same level from March to July 2020, instead of rising towards the summer peak like in previous years. Then, ship frequentation increased rapidly to a normal level in August 2020 when restrictions were lifted. By comparing morning and evening (7:00 am and 7:00 pm) ship frequentation during this period to pre-Covid years, we observed contrasting patterns. On the one hand, morning detections were particularly high, while on the other hand evening detections were significantly lower and less concentrated in coastal touristic waters than in previous years. Overall, we found a 9% decrease in ship frequentation between the year 2020 and the 2017-2019 period, with a maximum of 43% drop in June 2020 due to the lockdown. So, the Covid -19 crisis induced only a very short-term reduction in maritime activities but did not markedly reduce the annual ship frequentation in the French Mediterranean waters. The satellite imagery approach is an alternative method that improves our understanding of the pandemic impacts at an unprecedented spatiotemporal scale and resolution.

**Keywords: Covid-19, lockdown, fisheries, synthetic aperture radar, ship detection, French Mediterranean**

# INTRODUCTION

The humanity's demand on natural resources is increasingly exceeding Earth's biological rate of regeneration, inducing a growing number of social, economic, environmental and health crises (Bordo et al., 2001; Otero et al., 2020). The most recent and striking example is the Covid-19 pandemic (Sohrabi et al., 2020), a global health crisis that in addition to the worldwide loss of human lives, constitutes an unprecedented challenge to our globalized societies (OECD, 2020). To slow down the spread of the virus, governments set-up several preventive measures such as border shutdowns, quarantines, and lockdowns. According to the International Labor Organization (ILO), nearly half of the world's global workforce has been at risk of losing their source of income due to lockdown measures. Informal workers are particularly vulnerable due to the lack of social aids and access to quality health care (ILO et al., 2020). With severe lockdowns limiting manual work and short food circuits, economic inequality is bound to increase in the aftermath of the pandemic. On the other side of the same coin, the drastic changes in our behavior imposed by the Covid 19 crises had major impacts on our environment by significantly decreasing our anthropogenic pressure (Bates et al., 2020; Bates et al., 2021). Thus, our socio-ecological systems have been profoundly modified over the last two years but most of the effects remain poorly quantified particularly in the vast ocean which is still challenging to monitor across space and time.

Human activities in the oceans rely on movements and exchanges whether for people or goods. However, lockdown measures impacted the local and global demand for seafood (Knight et al., 2020; Ortega et al., 2020) and restricted public access to the sea and even to the shore. Such effects should be reflected in spatiotemporal patterns of ship density, including those of the fisheries sector (Bennett et al., 2020; Depellegrin et al., 2020). Indeed, with a switch in consumption habits to long-lived products and the sudden closure of the food services sector, several fisheries halted their production due to a lack of demand (FAO, 2020a; Russo et al., 2021). One early example is the lobster fisheries worldwide that mainly depend on China's imports, which halted before the World Health Organization (WHO) declaration of Covid 19 as a public emergency (Knight et al., 2020). Several other fisheries worldwide saw their fishing efforts decreasing dramatically. Indonesian shark trade dropped by 70% (Mongabay, 2020) while Peru, which holds the world's largest commercial fishery, decreased its fishing activities by 80% (Global Fishing Watch, 2020). Similar consequences were seen in the Mediterranean where fishing efforts fell by 34% and landings declined by 49% during lockdown periods in comparison to precedent years (Coll, 2020; Coll et al., 2021). Furthermore, in several countries, including France, governments have provided financial aids to the fisheries sector to compensate for the operating losses. This allowed fishers to reduce their activity with limited impact on their income (Carvalho et al., 2020). It also meant a short recess from human activities for the exploited ecosystems that may have benefited from several months of hiatus in anthropogenic pressures (Coll, 2020). Yet, this potential hiatus in maritime activities remains unassessed over large scale due to limited standardized data and a lack of comparative baseline.

Satellite detection has often been used to track boats and fisheries behavior. Automatic Identification System (AIS) and Vessel Monitoring System (VMS) are self-reporting systems that provide massive data to monitor vessel activity and human presence in the oceans (Ferrà et al., 2018; James et al., 2018; Kroodsma et al., 2018; Depellegrin et al., 2020; Armelloni et al., 2021). Some studies used these data to assess the impact of Covid-19 on marine traffic (March et al., 2021). Alternatively, the development of Synthetic Aperture Radar (SAR) satellites has unlocked the possibility of detecting the location of marine vessels without requiring voluntary or automatic reporting *via* transmitters on board (Friedman et al., 2001; Pelich et al., 2015; Stasolla et al., 2016). Using an active sensor system, SAR images can be taken by day or night and regardless of weather conditions (Fernandez Arguedas et al., 2016). This opens up the possibility of detecting vessel activity that ranges from undeclared and illegal to recreational (Galdelli et al., 2020; Lanz et al., 2021). In contrast to fishing activities that are monitored, at least partly, through catch reports and AIS data, marine leisure activities are still challenging to assess, even more during the Covid-19 crisis while their impact on marine ecosystems and fish stocks is far from being negligible, targeting a large proportion of vulnerable species (Lewin et al., 2019; Hyder et al., 2020; Lloret et al., 2020).

In this study, we used the Search for Unidentified Marine Objects software (SUMO) developed by the European Union Joint Research Centre (JRC) (Greidanus et al., 2017a) in order to assess the impact of the Covid 19 crisis on the spatiotemporal patterns of boat density across the French Mediterranean coasts. The crisis resulted in a severe lockdown from the 17$^{th}$ of March to the 11$^{th}$ of May where the French population was required to quarantine at home with few exceptions (essential workers, health reasons, compelling family reasons or grocery shopping). Yet, the extent to which this lockdown induced a decrease of maritime activity and a hiatus in human pressure upon coastal ecosystems is unknown. With almost a dozen images per month, we were able to highlight the presence of human activity in the French Mediterranean between 2017 and 2019 as a "control" period compared to 2020 when the most severe lockdowns occurred.

# MATERIALS AND METHODS

## Study Area and Data Collection

Our study aimed at quantifying human activity in the French Mediterranean waters. We used the French maritime boundaries and exclusive economic zones (200NM, version 11) (Flanders Marine Institute, 2019) in the Mediterranean Sea, which are composed of the Gulf of Lion and the waters around the island of Corsica (**Figure 1**).

We used satellite images collected by the two radar satellites of the European Space Agency Sentinel-1 Copernicus mission (Copernicus, 2021). Sentinel-1A was launched in April 2014 while Sentinel-1B, an identical satellite, was launched in

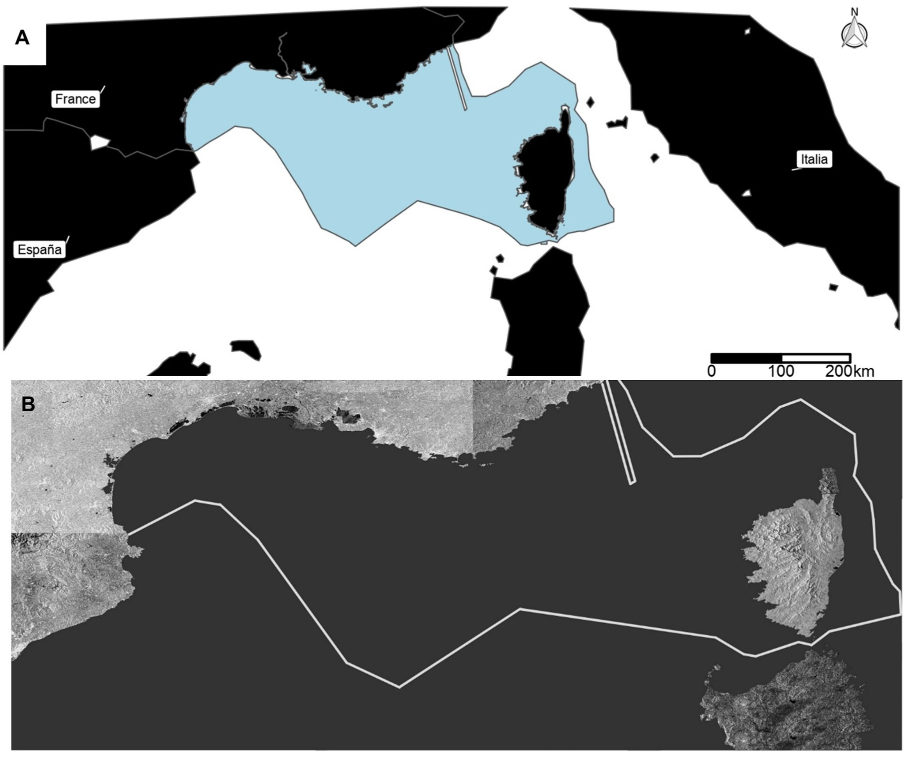


**FIGURE 1** | **(A)** Plot depicting the French Mediterranean Exclusive Economic Zone (EEZ) and study area, represented in blue. **(B)** Study area built with several SAR images captured between 6th and 18th of March 2020. In white lines, the French Mediterranean EEZ. Shapes are different due to the angle from which the images are taken by the satellites. Copernicus Sentinel data 2020.

April 2016 onto the same orbital plane. Together they collect images from the earth surface by day or by night, without being affected by cloud coverage. This allowed us to have a complete dataset of synthetic aperture radar (SAR) images from early 2017 until late 2020. Each SAR image covers part of the study area and each given location of the study area was captured by 12 to 24 images each month, resulting in around 60 images per month covering the entire study area. Both satellites orbiting around the earth in a near-polar orbit have a 12-day revisit period in which acquisitions are made either early in the morning or late in the afternoon. In this part of the Mediterranean Sea, images were captures between 7:00 and 8:00 am for morning acquisitions, and between 7:00 and 7:45 pm for afternoon acquisitions. Preliminary to this study we performed several visual verifications of the SAR satellite's ability to detect a variety of ships. With field work in the coastal towns of Sète, Banyuls and the Island of Corsica, we were able to clearly identify ships of over 15 meters in length of all types of material (smaller than 15 meters for metallic ships).

In order to assess the impact of the Covid-19 pandemic, and particularly the lockdown put in place by the French government between March and May 2020 (Sanchez, 2021), we collected all Sentinel-1A and 1B images each year from March to November starting 02/03/2017 to 28/11/2020. With these dates we were able to compare the lockdown period and the aftermath during the summer of 2020 to the three prior years. A total of 2 183 images weighing approximately 1.7 GB each was downloaded from the Alaska Satellite Facility "SAR Search Vertex" interface (https://asf.alaska.edu/). In addition, the JRC SUMO software (https://github.com/ec-europa/sumo) produced a folder containing all detection information weighing approximately 1 GB, totaling around 6 TB of information. We were able to locally store the data, but the storage aspect rapidly becomes an issue with bigger scale studies.

## Ship Detection With Synthetic-Aperture Radar Imagery

The images we used were acquired using the Interferometric Wide swath acquisition mode (IM), and we performed our assessment on Ground Range Detected images in high-resolution (10 meters per pixel) and dual polarization. Being an active sensor system, Sentinel-1 satellites can transmit and receive a signal in either a horizontal (H) or vertical (V) polarization. As different targets on the ground have different polarization signatures with different intensities, reflecting one polarization into another, integrating both polarizations into the target detection process allows for an improved qualification of targets. When using radar satellites and imagery, the signal returns are usually disrupted by noise or clutter due to unwanted objects or bad weather conditions. This can possibly induce false positives that can overestimate boat density (Gandhi and Kassam, 1988). To overcome the problem of clutters and noise we used the Constant False Alarm Rate processing scheme (CFAR) that sets a threshold for each cell based on the information and noise power of the neighboring cells (Anastassopoulos and Lampropoulos, 1995). After setting thresholds, those algorithms can detect objects separating them from the background and has been widely used in the marine environment for ship detection as well as other applications (Leng et al., 2015; Kang et al., 2017; Lanz et al., 2020).

## SUMO Algorithm

To perform ship detection on the SAR images, we used the Search for Unidentified Maritime Objects (SUMO) algorithm based on the pixel-based CFAR method (Greidanus et al., 2017a). After applying cross-polarization and co-polarization detection threshold adjustments (Galdelli et al., 2021), SUMO applies a land mask and proposes different buffers to avoid coastal interference. In this study we used a 50-meter buffer integrated into the SUMO software based on OpenStreetMap (2017) to detect coastal activities while avoiding continental interference. The next steps of the object detection apply the CFAR approach by deriving a local detection threshold for all polarization channels. Then, nearby detected pixels are clustered together into a detected object and all detection attributes can be extracted (e.g., geographic location, length, significance). The SUMO algorithm can thus discriminate between real ship detections and false alarms based on the attributes of each object. This algorithm was developed with a user interface to run it and manually check every detection to test the performance of different parameters. The software can also be used in "automatic" mode and analyze a series of images that are specified through a configuration file in which all needed parameters for a SUMO analysis are entered as well (Greidanus et al., 2017b). In this case, we used a parametrization which minimizes false positives but allows for the detection of all ships with a length over 15 meters based on literature and field work (Santamaria et al., 2017). To focus on the coastal activities of fisheries and recreational boats, we removed the shipping lanes provided by the dataset of Halpern et al. (2015) at 1km resolution, by filtering out observations that were in cells where the density of transport ships was equal or higher to 10. This was carried out considering the amount of information lost when filtering out the ships. Under the threshold of 10 transport ships per square km the amount of information lost becomes significant (**Supplementary Material Figure 1**). We therefore filtered out commercial shipping lanes following the procedure detailed in Santamaria et al. (2017): we removed detections where SUMO assigned a low-level of reliability, assumed to correspond to false positives. Finally, we manually excluded images affected by radio frequency interference (RFI) (**Figure 2**). These interferences mostly occur due to ground sources, and to a lesser extent to the Radarsat-2 SAR satellite which operates in the same frequency band as Sentinel-1 (Santamaria et al., 2017).

## Data Analysis

We compared the total number of detections yearly from 2017 to 2020, but also extracted monthly and daily marine activity to highlight the effect of the lockdown. We were able to statistically compare mean daily observations between 2020 and different periods during 2017-2019 using the mean comparison t-test implemented with the "t.test()" R function after a log transformation of our data in order to obtain a normal distribution. Since discriminating recreational and fishing activities is impossible directly through SAR imagery, it was assumed that the recreational activities are much lower during the morning hours (i.e., before 8AM) and outside of the summer season. By looking at the difference between seasonal but also morning and evening detections, we assessed the extent to which leisure activities were affected by the Covid-19 restrictions. In order to compare the 2020 activity to a control period, we used the mean yearly and monthly detections of the 2017-2019 considered as a baseline. In addition, ship concentration around coastal and touristic areas is an indicator of ship activity and presence of leisure boats. To compare the differences in ship clusters between 2020 and prior years, we used the "kde2d()" R function from the "MASS" package to calculate spatial kernel density of the detections (from 0 to 1).

In order to limit false positives, we removed 32,231 detections identified by SUMO as being ships with a length under 15 meters. Twenty-seven images were removed when filtering out outliers (for which the number of detections was higher than 95% of observed values per image). We manually removed

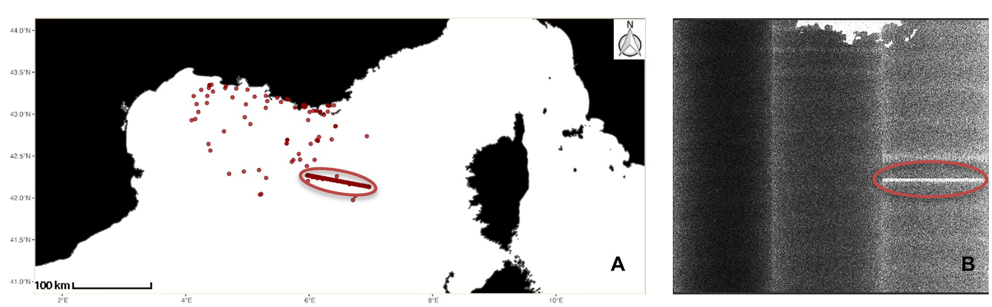


**FIGURE 2** | Example of Radio Frequency Interference (RFI) in detections on a SAR image. **(A)** Detection plot of an image with RFI. **(B)** The SAR image used for the detection process (12/11/2020). Circled in red is the RFI that translates into a row of false positives in the detection plot. Copernicus Sentinel data 2020.

34 images submitted to high radio frequency interference (RFI) by examining all high detection images by a human observer.

## RESULTS

After excluding detections located in commercial shipping lanes and false positives identified by SUMO, which together resulted in the removal of 75,788 detections, a total of 2,114 images were analyzed, comprising 107,462 potential ship observations. In total, 527, 486, 533 and 568 images were collected respectively from 2017 to 2020, with a yearly mean number of acquisitions of 545 (sd = 29). Monthly number of acquisitions varied from 49 to 73 images, with a mean of 59 images per month (sd = 5) (**Figure 3**).

The total number of detections increased from 2017 to 2019, with 26,353 ships in 2017, 26,592 in 2018 and 29,216 in 2019 (**Figure 3**). In 2020, the number of detected ships dropped to 25,004, which represents a 9% decrease compared to the mean of the three previous years. We observed a similar trend for the mean number of monthly detections (see **Figure 4**), with values increasing from 3,357 detections in 2017 (sd = 1,011, min = 1,408 and max = 4,710), to 3,484 detections in 2018 (sd = 1,219, min = 1,385 and max = 5,038) and 3,894 detections in 2019 (sd = 1,468, min = 1,632 and max = 5,586). As for the yearly number of detections, a drop was observed for the year 2020, with a mean number of monthly observations of 3,431 detections (sd = 1,490, min = 1,789 and max = 5,599). However, monthly detections were highly variable across the studied months. Finally, the mean daily number of observations exhibited the same trend from 271 in 2017 (sd = 146, min = 1 and max = 651), 282 in 2018 (sd = 154, min = 5 and max = 677) to 311 in 2019 (sd = 169, min = 1 and max = 714) then dropping to 277 in 2020 (sd = 171, min = 2 and max = 690).

The data highlight three distinct periods in ship detections: the lockdown period, from March to May 2020, the post-lockdown in June 2020, and the return to a normal period for maritime activities during summer, from July and onwards. From March to May, a total number of 5,944, 5,966 and 6,723 ships were detected in 2017, 2018 and 2019 respectively, while only 5,626 were detected from March to May 2020 during the lockdown period, representing a 8% drop compared to the mean of previous years. Likewise, a decrease in the mean number of daily observations was observed due to the lockdown from 195 in 2017 (sd = 110, min = 5 and max = 442), to 242 in 2018 (sd = 166, min = 5 and max = 708) to 201 in 2019 (sd = 99, min = 6 and max = 394) and then 145 in 2020 (sd = 69, min = 9 and max = 362). Mean daily detections were significantly different between 2020 during the lockdown period and the same time of year for the 2017-2019 period ($p$-value < 0.001).

A similar drop of ship detections took place during the post-lockdown period, in June 2020, compared to previous years. Total ship observations were of 3,737, 3,475 and 4,121 in 2017, 2018 and 2019 respectively. Ship observations were only 2,142 in 2020, representing a drop of 43% in detections compared to the average number of observations over 2017-2019. This was translated in the mean number of daily observations: 316 (sd = 146, min = 29 and max = 559), 294 (sd = 124, min = 16 and max = 672) and 336 (sd = 122, min = 17 and max = 457 and) in 2017, 2018 and 2019 to 213 in 2020 (sd = 135, min = 11 and max = 527). A difference that was again statistically significant between the 2017-2019 period and 2020 ($p$-value < 0.001).

A different trend was observed for the summer period, from July to September. We observed 12,531, 13,341 and 14,668 ships in 2017, 2018 and 2019, and 13,688 ships in 2020, which corresponds to a drop of only 7% compared to 2019, and to a level very close to that in 2018. Mean daily observations were 321

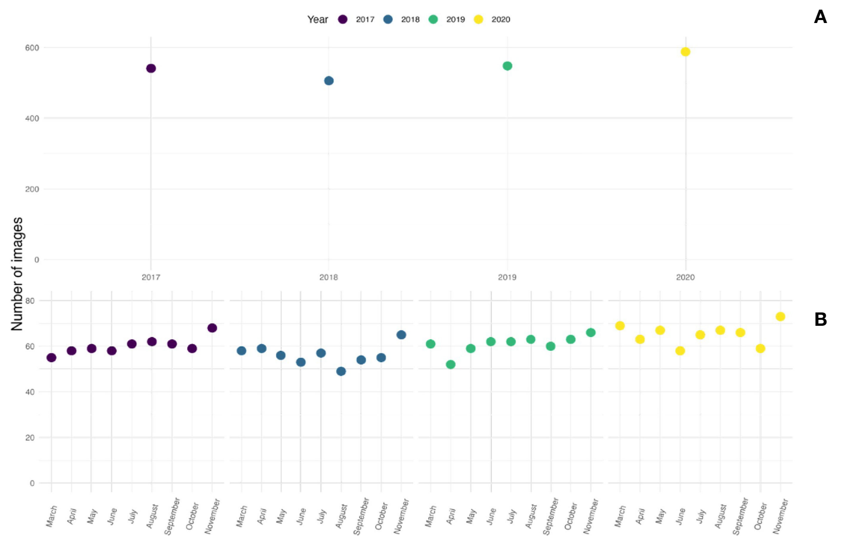


**FIGURE 3** | Number of images available from the Sentinel-1 mission database **(A)** yearly and **(B)** monthly on the French Mediterranean EEZ.

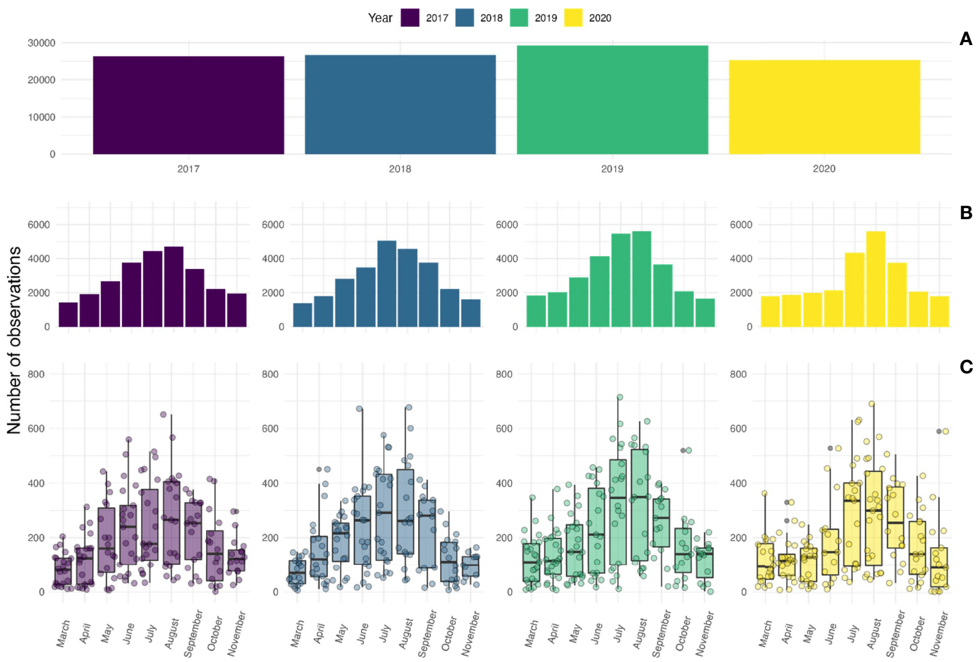


**FIGURE 4** | Number of ship detections with the SUMO algorithm **(A)** yearly, **(B)** monthly, **(C)** daily in 2017, 2018, 2019 and 2020 on the French Mediterranean EEZ.

in 2017 (sd = 147, min = 16 and max = 651), 352 in 2018 (sd = 157, min = 15 and max = 677) and 389 in 2019 (sd = 171, min = 10 and max = 714), then 362 in 2020 (sd = 169, min = 25 and max = 690 and), this latter value being not significantly different from that of 2018 (*p*-value = 0.26), indicating a recovery of maritime activities during summer 2020 despite the pandemic and lockdown (**Figure 5**).

When discriminating between fishing and leisure activities, the same decline of boat density was observed during the lockdown period from April to June 2020 (**Figure 5**). However, during the busiest period of the summer season (August), monthly detections were notably lower along the coastline in the evening than in the morning. In August and September, morning detections were 2,558 and 2,996 respectively, whereas evening detections were 2,152 and 1,941 respectively (**Figure 5**). When looking at the spatial density of ship detections, plotting the difference in kernel densities between 2020 and the 2017-2019 period highlights a significant decrease in ship concentrations in the eastern part of the French Mediterranean coast and the western side of Corsica's coastline. This phenomenon is particularly visible during the evenings of the post-lockdown summer season, whereas morning concentrations are less contrasted when compared to previous years (**Figure 6**).

## DISCUSSION

Studies on the Covid 19 pandemic and its impact on marine activity and fisheries have been limited by data availability in order to build reliable comparisons (Pita et al., 2021; Villasante et al., 2021; White et al., 2021). SAR imagery used for ship detection can overcome this limitation by quantifying human activity in the oceans within hours of the event, as well as to compare ship density patterns in a standardized way for time series of archived data. The first key finding of our study is the visible increase in ship detections over the 2017 - 2019 period in French Mediterranean waters, especially during the summer season. This is consistent with the yearly 10% increase in the number of recreational vessels in the Mediterranean sea which represent 90% of the Mediterranean fleets (Cappato, 2011; ICOMIA, 2018). Furthermore, 70% of the world's superyacht charter contracts are in the Mediterranean (Piante and Ody, 2015). These observations reinforce the context where the Mediterranean Sea has already been assessed as a hotspot in anthropogenic stressors and fishing overcapacity (Micheli et al., 2013; Lucrezi et al., 2017; Ramírez et al., 2018; FAO, 2020a; Duarte et al., 2021).

As expected, ship density patterns during the lockdown period in 2020 contrast sharply with those in the three previous years. With a 9% reduction in annual ship detection, considering recreational boats are far less numerous at sea than commercial fishing boats between March and May, lockdown measures likely had an impact on fisheries activity. Similar results were found by Guyader et al. (2021) from official 2020 reports, with a 10% decrease in French ship activity (days out at sea) compared to 2018-2019. This global phenomenon has been reported from catch records elsewhere in the Mediterranean Sea and around the world (Coll, 2020; FAO, 2020b; Ortega et al., 2020; Coll et al., 2021; Russo et al., 2021). In a study conducted by

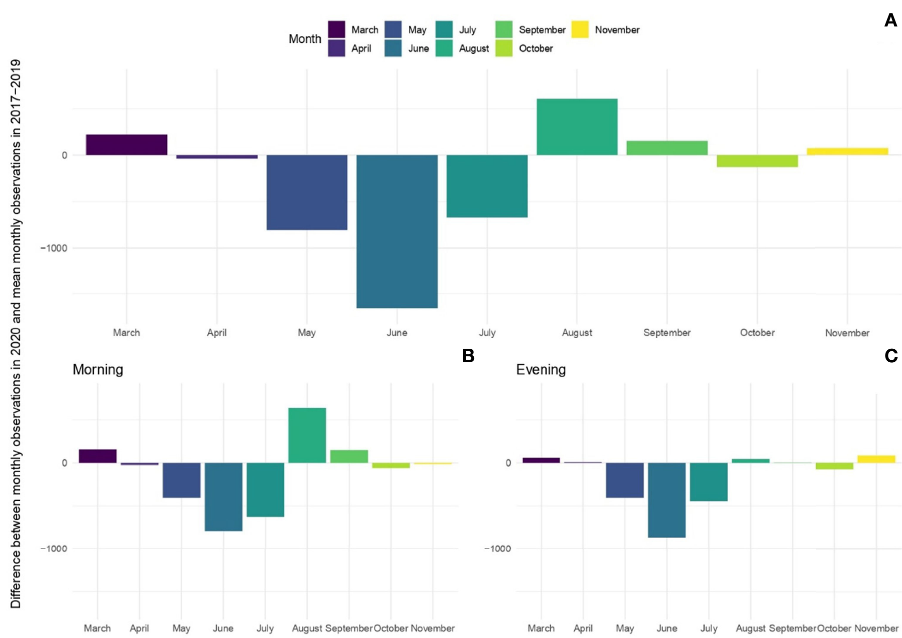


**FIGURE 5** | Difference in monthly detections between 2020 and the 2017-2019 period. Negative values represent a decrease in number of detections in all images **(A)**, only for morning images 7:00 am to 8:00 am **(B)**, only for evening images taken from 7:00 pm to 7:45 pm **(C)**.

Spagnol et al. (2021), based on interviews of the owners of 392 Mediterranean fishing ships of different length categories, the number of fishing trips appeared as the most impacted variable by the Covid 19 crisis. Fishing activity abruptly decreased with the lockdown due to the uncertainty on what was authorized or not. Subsequently, closed markets and a change in consumer habits produced a drop in demand which forced the sector to adjust in order to avoid unsold fish and a collapse in prices (Fontana, 2020; Goubert, 2020; Tillet, 2021). This was particularly true for larger ships and trawlers that could not sell the entirety of their landings due to the large tonnage they represent. Therefore, most ship owners decided to stop their activity entirely during the lockdown period, maintaining their enterprise with the help of governmental aid (Spagnol et al., 2021). This is reflected in our data with a marked decrease in boat density during the lockdown period (March-May) including June, even though French lockdown restrictions were lifted by the middle of May (Sanchez, 2021), with a 43% decrease in ship detections compared to the 2017 - 2019 period. Ship detection did not increase until August, when most summer vacations start in France with an important part of the population heading to coastal cities for recreational purposes (Cappato, 2011; Lucrezi et al., 2017; ICOMIA, 2018). Our results on ship detection show an overall small decrease in boat presence during the peak of the summer season in 2020 compared to previous years. Indeed, boat activity dramatically increased in July 2020 to reach levels comparable to pre-Covid years. This suggests that fishing and recreational activities were almost back to normal one month after the end of lockdown measures ended as suggested by Spagnol et al. (2021). Their study showed that the number of fishers who perceived the impact of the Covid-19 crisis on their activity went down from 70% during the lockdown period, to 25% in the following months. We can notice that the Mediterranean is the only French marine region that saw a decrease of the perceived crisis impact during the summer season, while 59% to 65% of fishers are still being affected by the health crisis along the Atlantic coastline. Our study corroborates Spagnol et al. (2021) and Guyader et al. (2021) results with a complementary method which improves our understanding of boat activity at a smaller spatial and temporal scale.

Indeed, the analyses of the morning and the evening detection data revealed large differences between 2020 and the prior years. Morning detections during July, August and September increased in 2020 compared to the mean detections between 2017 and 2019. On the contrary, evening detections were remarkably lower for the same period. In addition, the spatial distribution of morning and evening detections is different during summertime, with evening detections being largely concentrated close to coastal touristic areas (**Figure 5**). This supports the idea that detections observed around 7:00 am are most likely due to fishing activity that takes place further away from the coastline, and those observed around 7:00 pm mostly represent recreational boats staying close to the land. In addition, evening detections in 2020 were significantly less concentrated around coastal areas than in previous years, especially along the eastern part of the French coastline which is the most touristic area. This noticeable decrease in ship detections reflects an important drop in coastal activities in the aftermath of the Covid-19 lockdown. Interestingly, morning activity at sea,

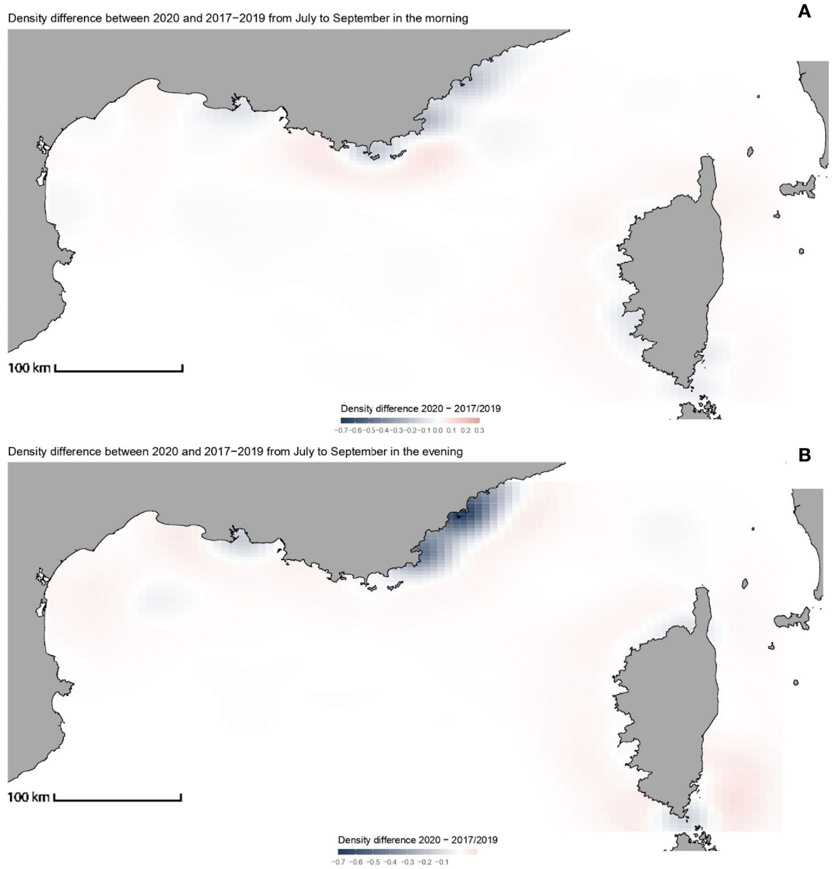


**FIGURE 6** | Difference in Ship detection density between 2020 and the 2017-2019 period for the peak summer season for **(A)** morning 7:00 am to 8:00 am detections and **(B)** 7:00 pm to 7:45 pm detections.

which can be mostly attributed to fisheries, seems to have increased after the lockdown. Consistent with the results of Spagnol et al. (2021), although fisheries had a 3 to 4-month hiatus in activity, as soon as the lockdown measures were lifted, morning Mediterranean fishing trips seem to have resumed at levels comparable or higher to previous years. This observed increase in morning sea trips is counterbalanced by a considerable decrease in evening trips, raising the question of the Covid-19 impact on leisure boat activity in these highly touristic coastal areas.

In the context of research in marine surveillance and in comparison with AIS, the SUMO algorithm has been used as a detection tool and a reference for developing effective alternative methods for SAR imagery object detection (Mazzarella et al., 2015; Santamaria et al., 2017; Grover et al., 2018; Aiello et al., 2019). This method allowed us to obtain an extensive dataset, thanks to the Sentinel-1 project that is fully operational since late 2016. SAR imagery can provide data archives and accessibility while not being affected by cloud cover nor sunlight and not needing voluntary actions on board to detect ship locations. These advantages make SAR a good alternative to other methods. Nevertheless, high wind conditions can cause small waves on the water surface that can result in false positive detections. It is important to take this into account and be careful with unusual numbers of detections in certain images. Another limitation comes from the use of Sentinel-1 SAR images which have a 10m resolution per pixel. With this resolution, our detection method cannot consider ships smaller than 15 meters, which represent a large part of recreational boats and many artisanal fisheries vessels. Consequently, the impact of the pandemic on the smaller fishing ships and recreational boats cannot be robustly quantified using this method. In addition, by the nature of a SAR image, we cannot obtain more information on a ship than its length (activities and equipment are unknown). However, when coupled with AIS and Optical imagery, we could potentially identify boat types and activities opening the door towards a better and more precise understanding of our use of marine resources (Galdelli et al., 2020; Galdelli et al., 2021; Kroodsma, 2022). Integrating different detection methods will eventually allow us to build a more complete picture of our presence and activities in the oceans over an unprecedented spatiotemporal scale and resolution.

## DATA AVAILABILITY STATEMENT

The original contributions presented in the study are included in the article/**Supplementary Materials**. Further inquiries can be directed to the corresponding author. All scripts and data can be accessed through the github repository: https://github.com/RaphSeguin/SAR_fishing_covid.

## AUTHOR CONTRIBUTIONS

IP, RS, TC, RD, YS and DM contributed to the conception and design of the study. IP and RS researched possible satellite detection methods. IP downloaded and organized the image database, ran detection algorithms, and redacted the manuscript. RS performed the statistical analysis, data processing and graphical outputs. PV helped with image processing and methodology research. YS and DM guided and contributed to the results analysis, manuscript read and corrections. TC and RD contributed to manuscript reviews. All authors approved the submitted version.

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## SUPPLEMENTARY MATERIAL

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fmars.2022.845419/full#supplementary-material

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# The Impact of COVID-19 on Participation, Effort, Physical Activity, and Well-Being of Sea Anglers in the UK

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Recreational sea angling is an important recreational activity in the United Kingdom with around 1.6% of adults participating and a total economic impact of around £1.5 billion each year. There are positive impacts of angling on physical health and mental well-being. The COVID-19 pandemic resulted in several national lockdowns in the UK, which along with additional local restrictions and personal circumstances due to the pandemic, have impacted people's ability to fish. Angling was not allowed in the UK for some of the first lockdown (March to May 2020), and further restrictions were implemented subsequently that varied between the countries and regions. The impact of COVID-19 on the participation, effort, physical activity, and well-being of UK sea anglers remains unknown. A panel of UK sea anglers, which record their activity and catches as part of the Sea Angling Diary Project, were surveyed to assess changes in sea angling participation, physical activity, mental well-being, and expenditure between 2019 and 2020. We compared the sea angling effort and catches of the diary panel between 2019 and 2020. We found reduced sea angling effort in the panel, including sessions and catches, between 2019 and 2020, with the largest impact being in April 2020. We found that there was a significant reduction in expenditure during April 2020 with 64% of respondents spending less on sea angling than in a typical April. In total, 67% of respondents reported reduced happiness and 45% were less active due to sea angling restrictions. Using a general linear model, we found that even though anglers said that being able to go fishing has resulted in high World Health Organization Five Well-being Index scores, other factors also had significant effects. These included: age; physical and mental health status; angling activity; travel to fish during COVID-19; and whether they fished in July 2020. Of those who responded, 66% classified themselves as at either high or moderate risk to COVID-19. This work has shown that COVID-19 has negatively affected marine recreational fisheries in the UK, and not being able to go sea angling has negatively impacted participation, effort, physical activity and well-being.

**Keywords: marine recreational fisheries (MRFs), recreational sea angling, COVID-19, well-being, physical Activity, participation, effort, United Kingdom**

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## INTRODUCTION

Marine recreational fisheries are important activities creating economic impacts (Cisneros-Montemayor and Sumaila, 2010; Hyder et al., 2017, 2018) and social benefits through physical health and well-being (Mcmanus et al., 2011; Armstrong et al., 2013; Griffiths et al., 2017), but can also impact on fish stocks (Hyder et al., 2017; Hyder et al., 2018; Radford et al., 2018; Lewin et al., 2019). Marine recreational fisheries (MRF) are generally not embedded in governance structures in many countries (Arlinghaus et al., 2019; Potts et al., 2020) and is often unlicensed meaning that the participants are not well characterized (Hyder et al., 2017; Hyder et al., 2020b). Motivation for participating in MRF is diverse (Fedler and Ditton, 1994; Arlinghaus, 2006; Beardmore et al., 2011), making responses of fishers difficult to predict [e.g. for the management of marine recreational fisheries and to understand and monitor climate change (Arlinghaus et al., 2016)]. Sea angling using rod and line is the most common form of MRF in the UK (Armstrong et al., 2013; Hyder et al., 2020a; Hyder et al., 2021), with over 700,000 participants fishing for over 6 million days and catching over 40 million fish a year (Hyder et al., 2020a; Hyder et al., 2021). Sea anglers in the UK generate a total economic impact of over £1.5 billion, supporting over 13,000 jobs (Hyder et al., 2020a). In addition, sea angling in the UK has benefits to the individual (e.g. physical health and well-being) and societal benefits (e.g. environmental improvement work and volunteering) (Armstrong et al., 2013).

In 2019, the outbreak of COVID-19, led to a global pandemic from early 2020 through to at least the date of this publication (World Health Organization, 2020). Governments across the globe began to react with designed measures to control the spread of the virus (Hiscott et al., 2020). In particular, multiple governments created national lockdowns and other restrictions to reduce social interaction (Hiscott et al., 2020), such as limiting travel (Iacobucci, 2020; Wilder-Smith and Freedman, 2020) and access to non-essential activities (Ding et al., 2020; Storr et al., 2021).

The COVID-19 pandemic has been shown to have an impact on MRF across the world (Skov & Gundelund, 2021; Pita et al., 2021). The potential for impacts on MRF varied between countries as the restrictions on activities differed (Pita et al., 2021). In the UK, the number and duration of lockdowns and associated restrictions varied between the different countries and regions and were complex (Pita et al., 2021) resulting in varying impacts on sea angling spatially and temporally. At the beginning of the COVID-19 pandemic, UK lockdowns restricted people's ability to participate in recreational angling in both fresh and saltwater. From the 23rd March to the 13th May 2020, any form of angling was completely banned in the UK (Institute for Government, 2021). After this, there were a series of varying restrictions at UK, national (devolved administration), regional and city levels. Other factors relating to the pandemic, including infection, requirements to 'shield', restrictions on travel and personal decisions about safety will also have impacted people's ability to participate in sea angling. However, the impact of COVID-19 on the participation and effort, physical activity, and well-being of UK sea anglers remains largely unknown.

There is a wealth of evidence that shows that participating in sport and active recreation can improve physical health and well-being (McNally et al., 2015). Whilst some research has sought to identify the benefits that outdoor recreation can have for participants (Benefits of Outdoor Sport for Society; Eigenschenk et al., 2019), research on the health benefits of angling in general, and sea angling in particular, is limited (Mcmanus et al., 2011; Armstrong et al., 2013; Griffiths et al., 2017). In the UK, 72% of anglers in the National Angling Survey said that angling helped to keep them healthy, 27% said it was their main way of being physically active and 70% said it helped them deal with stress (Brown, 2019). It is estimated that around 1.6% of UK adults participate in recreational sea angling each year, contributing a total economic impact of over £1.5 billion each year (Hyder et al., 2020a).

The impact on the health and well-being of individuals who undergo a reduction or possible loss in outdoor recreational sports due to COVID-19 are not fully understood. It has been shown that restrictive access to blue spaces to pursue outdoor recreational activities such as angling, contributed to the negative effects of the pandemic on health and well-being (Guzman et al., 2020; Astell-Burt and Feng, 2021; Pouso et al., 2021), highlighting further that health is not equally distributed across society as access varies across the population (Geary et al., 2021). Outdoor recreational sports are vital for physical and mental health and well-being, and there is further evidence-based research into the benefits of combining outdoor recreational sports with nature and the natural environment (St Martin, 2007).

Here, we investigate the impacts of COVID-19 on existing UK sea anglers' physical activity and well-being. We use a survey targeted at a diary panel of UK sea anglers and hypothesize that not being able to fish during lockdown months has negatively affected the physical activity and well-being of UK sea anglers. In addition, we use data collected on angling activity from the diary panel in 2019 and 2020, to determine the impacts of COVID-19 on sea angling sessions and catches. We hypothesize that there was a reduction in sea angling effort as a result of lockdowns, other restrictions, and personal circumstances that limited angling activity.

## MATERIALS AND METHODS

To assess catch per angler, volunteers completed a catch diary throughout the year where all angling trips were recorded known as the Sea Angling Diary Panel (SADP; Hyder et al., 2020a; Hyder et al., 2021) (**Table 1**). The SADP varied in size between years since it began in 2016, reaching a maximum size of 2,126 diarists in 2020 (Hyder et al., 2020a; Hyder et al., 2021). For our investigation, we extracted the data from 2019 and 2020. The panel covered the whole UK and was recruited through several different channels including email lists of known sea anglers, print and electronic publicity delivered through tackle shops, charter boats and sea angling organisations and clubs, face-to-face recruitment at events, and social media. New participants are recruited annually to maintain and increase the numbers on

**TABLE 1** | A glossary table of the different sources of data used to assess the impacts of COVID-19 on UK sea anglers.

| Data source | Description | Number of respondents | Year |
|---|---|---|---|
| Watersports Participation Survey (WPS) | An independent face-to-face survey conducted to estimate a population level number of sea anglers, demographic profile, and activity. Sampling was stratified by region and social grade, and with 15-19 households selected at random within each stratum. When households were not available or chose not to participate, a new household was chosen at random until the desired sample size was reached. Interviews took place in September and were done in waves. Population level estimates were calculated accounting for socio-demographic differences between the sample and population based on the UK census. | 12,000 | Conducted annually since 2016, with 2019 data used in this study to assess potential bias in SADP. |
| Sea Angling Diary Panel (SADP) | A diary panel of volunteer UK sea anglers who recorded all their fishing sessions and catches. Due to lack of registry of sea anglers and low response rates to postal and phone surveys, this consisted of self-selected sample of volunteers from a list of sea anglers who had participated in a range of previous surveys and from respondents to various media campaigns. Participants were more avid, older and fished for more years than the UK population of sea anglers, but was similar in composition to a probability-based diary panel recruited from a postal survey. The total number of participants providing data on fishing activity and catch varied each year. | 2019: 1,706 2020: 2,129 | Conducted annually since 2016, with 2019 and 2020 used in this study. |
| SADP data 2019 and 2020 | Comparison of participation, effort, and catches by anglers recording catches in SADP in 2019 (pre-COVID-19) and 2020 (during COVID-19). The number of diarists represented were those who had fished and entered sufficient data to be included in the analysis. | 2019: 988 (58% )2020: 849 (40%) | 2019 (situation pre-COVID-19) and 2020 (during COVID-19). |
| COVID-19 survey | An additional bespoke survey conducted on the 2020 SADP to assess the impact of COVID-19 on their sea angling activity and physical health and well-being. Multiple reminders were sent to maximise response rates. | 2020: 559 (26%) | Bespoke survey done in October 2020 to assess impact of COVID-19. |

*The survey name is used throughout the study to ensure consistent nomenclature. Number of respondents and response rates are given in brackets.*

the sea angling diary panel whilst many diarists participate over multiple years. Previous analysis of this panel has shown some bias, with diarists generally older, more avid, and had been fishing for more years compared to the general population of sea anglers (Hyder et al., 2020a; Hyder et al., 2021). Annual estimates of the general population of UK sea anglers, how often they fish, and what they caught have been generated since 2016 (Hyder et al., 2020a; Hyder et al., 2021; www.seaangling.org). As no register of sea anglers exists for the UK, this involved separate surveys of effort and catch per unit effort (Pollock et al., 1994). To estimate effort, an independent face-to-face survey was done each year of 12,000 households across the UK that provided a population-level estimate of the numbers, demographic profile, and activity of sea anglers in the UK called the Watersports Participation Survey (**Table 1**) (Hyder et al., 2020a; Hyder et al., 2021).

To understand the impact of COVID-19 on UK recreational sea anglers, two approaches were used. Firstly, data on participation, effort, and catches from the existing UK SADP (Hyder et al., 2020a; Hyder et al., 2021) were compared between 2019 and 2020 to assess the impact on numbers, travel to angling locations, and catches on individual angling trips (hereafter termed SADP data 2019 and 2020; **Table 1**). Secondly, an additional bespoke survey was conducted of anglers participating in the UK SADP (Hyder et al., 2020a, 202) about the impact of COVID-19 on their sea angling and physical health and well-being (COVID-19 survey; **Table 1**).

## Comparing Sea Angling Effort, Locations, and Catches in 2019 and 2020

To assess the impact of COVID-19 on fishing activity, outputs from the sea angling the SADP effort and catch survey in 2019 and 2020 were compared (SADP data 2019 and 2020; **Table 1**) (Hyder et al., 2020b; Hyder et al., 2021). SADP participants were encouraged to use an online tool and mobile app after every fishing session, to record their activity, such as fishing location, number of catches (kept and returned) and type of equipment used. They were asked to complete information for each month of the year about whether they have fished or not in that month, their sessions in that month (location, duration, method, platform), and all their catches for each session including species, length and numbers caught, kept and returned. The number of sessions reported, the number of diarists reporting fishing, fishing locations, and catches (kept and returned) was extracted from the database for each month in 2019 and 2020. Seasonal patterns were plotted for the two years for the number of sessions reported, numbers of sessions per diarist on each platform, numbers of diarists fishing, catch rates per trip, locations of trips and distances travelled. These SADP data 2019 and 2020 were interpreted in the context of periods of lockdowns and restrictions that impacted access to sea angling in the UK.

## Assessing the Impacts of COVID-19 on Sea Angling

To understand the impact of COVID-19 on UK recreational sea anglers, an online COVID-19 survey was conducted on the SADP. At the time of the research, the panel consisted of 2,129 adults (16 years of age and over) who were recreational sea anglers. Sea anglers on the panel were sent a link to the online survey through Survey Monkey (https://www.surveymonkey.co.uk/). They provided consent to participate before completing the survey and no identifying personal data (email or name) were collected. The survey was sent on the 1$^{st}$ October 2020 and a reminder was sent to the same audience on the 27th October 2020 before responses were closed on the 1st November 2020.

### Survey Design

The survey was designed to collect a range of data about respondents, including their normal or perceived (pre-COVID-19) sea angling activity (**Supplementary Materials Q1–Q10**); the impact of COVID-19 on their sea angling activity (**Supplementary Materials Q11–Q28**); and sections to assess impacts on physical activity, well-being and sea angling-related expenditure. The survey also asked about their anticipated sea angling activity in the near future and demographic questions to provide a profile of respondents. The survey questions are included in **Supplementary Materials**.

#### *Sea Angler Profile*

The first section of the survey was designed to provide information so that the sea angling profile of respondents could be compared to other data (such as that held on the SADP). This asked about the avidity of the respondent in the preceding 12 months; the platforms they usually fished from; other forms of angling they have done; their normal mode and distance of travel to sea angling; and some questions to assess the centrality of sea angling to their lifestyles, their skills, their retention of fish and the months in which they had been sea angling in 2020. Demographic questions asked about age, sex, physical and mental health disability and ethnicity (Sport England, 2021) as well as employment status and postcode.

#### *Sea Angling Activity During COVID-19*

The second section was designed to gather data about in which months (March – September 2020) the COVID-19 pandemic had prevented them from going sea angling; the most important reason that had prevented them from going sea angling (government restrictions, isolation, minimizing risk, or other reasons); which of those months they would normally have fished; whether they had fished since restrictions were lifted or partially lifted; and whether that had been at a higher or lower rate than normal for that time of year. These questions were designed to assess not only the direct effect of COVID-19 on their sea angling in 2020, but also to provide counterfactual data on what they might have done if the COVID-19 pandemic had not happened.

#### *Physical Activity Levels*

The third section asked respondents about the effect that not being able to go sea angling had on their physical activity levels. They were provided with a series of statements about the effect of not sea angling on their physical activity and asked to rank these on the Likert five-point scale from whether they 'strongly agreed' to 'strongly disagreed'. The statements provided were designed to identify causal relationships between not sea angling and lower levels of physical activity. Respondents were also given the opportunity to provide a qualitative statement about the impact of COVID-19 on their activity.

#### *Impact of COVID-19 on Well-being*

The World Health Organization Five Well-being Index (WHO-5) was used as a self-reported measure to determine the impact of not going sea angling on respondents' well-being (WHO, 1998; Topp et al., 2015). Following the same format for the physical activity questions, respondents were asked to what extent they agreed or disagreed with a series of statements about their well-being, adapted from the WHO-5 well-being indicators. Following this, respondents were provided with the WHO-5 self-reported measures and asked about their well-being in the preceding two weeks, followed by a question asking them to relate their responses to their ability to go sea angling to provide some data on causal relationships between sea angling and well-being.

#### *Impact of COVID-19 on Angler Participation, Effort and Expenditure*

The final set of 'impact' questions asked respondents to say what their expenditure on sea angling had been in April 2020 (when no sea angling was allowed in the UK) and what they would spend in a 'normal' April. This allowed some analysis of the impact of not being able to go sea angling on sea angling-related economic expenditure. Following this, respondents who had been able to go sea angling since the initial lockdown in April were asked about how COVID-19 had affected their sea angling behaviour – such as whether they had travelled further or less distance than usual, avoided crowded places or not participated on charter boats. Finally, some data suggested that the pandemic had led to more people taking up fishing: in England, the Environment Agency, which manages freshwater fishing, said that sales of licence to fish in freshwater had increased by 17% in 2020 (Environment Agency, 2020). To help assess whether the pandemic had led to more people fishing in the sea as well, respondents were asked whether they had taken people fishing who had not fished before or if they knew of people who had either fished for the first time or returned to fishing after a break-in 2020.

### Statistical Analysis

A generalised linear model was used in R statistical computing environment (R Core Team, 2015) to determine predictor variables that could impact the WHO-5 score (WHO, 1998; Topp et al., 2015). To determine the impact of COVID-19 on the participation rates, effort and expenditure of sea angling a Wilcoxon t-test was used to compare the number of days fished and expenditure in 2019 vs 2020 in PAST- Paleontological Statistics v4.0 (Hammer et al., 2001). Multinomial logistic regression was used to examine which predictors affect whether respondents spent more or less on angling (compared to no change) in April 2020 compared to a typical April. The 'no change' category was defined as the reference level.

## RESULTS

### Respondent Profile

In total, we received 635 (30%) responses to the survey, of which 559 (26%) respondents completed the survey. There was a bias in age and gender, as there is in the SADP generally, where respondents were generally more likely to be male and older in comparison to the UK sea angler population (**Table 2**). As expected, the location of the respondents matched the SADP location profile, which is also somewhat different to the UK sea angler population (**Table 2**). The bias in the SADP which was older, more avid male sea anglers, and therefore our responses to the COVID-19 survey, has been defined and analysed in Hyder et al. (2020a).

## Comparing Sea Angling Effort, Locations, and Catches in 2019 and 2020

The number of sessions reported by anglers in 2020 decreased significantly from February with almost no sessions reported in April 2020. The average number of sessions per angler exceeded 2019 figures in July-September 2020 and matched 2019 later in the year (**Figure 1A**). The proportion of anglers fishing per month in 2020 followed a similar pattern to the average number of sessions reported, with a significant decrease in comparison to 2019 levels with some recovery from July onwards (**Figure 1B**). The average catch per angler reported in 2020 remained lower than those reported in 2020, with April reporting the largest difference and numbers recovering in the summer months (**Figure 1C**). The total distance travelled by anglers from their home to their session site was significantly lower in April 2020 compared with the same month in 2019 (**Figure 1D**). Total distances did not recover to pre-COVID-19 levels until August and then followed a similar pattern in the autumn and winter months compared with 2019.

## Assessing the Impacts of COVID-19 on Sea Angling

### Respondent Effort and Participation

Anglers were significantly less likely to fish in each month from March to September in 2020 than in a typical year (Wilcoxon: $p < 0.001$). April represented the largest change between a typical year and 2020, where 57% of individuals who would have typically have gone sea angling did not do so (**Figures 2A**, **3**). For individuals who were not able to go sea angling in particular months, the single most important reason was that there were government lockdowns or restrictions on travel/activities (54%), followed by their own decision to minimise risk (21%). The main reason for not fishing in March and April was due to government lockdown or restrictions on travel/activities (67%) (**Figure 2B**). In August and September, 18% of individuals reported they made their own decision not to fish to reduce risk, whilst 57% of individuals reported that they were not restricted and therefore this did not prevent them from fishing (**Figure 2B**).

The survey found that 45% of anglers had chosen to fish in places where they could avoid other people, and this was more than they would normally have done (**Figure 4**). Cited reasons in the qualitative responses included crowding at their regular fishing spots (either public use of the beach or increased numbers of other anglers): "When lockdown ceased the coast was swamped with people, so I couldn't/didn't want to fish in amongst the crowds"; and "Far more anglers on the beach than pre-pandemic. Many people, non-anglers, on the beach and in the sea, therefore, could not guarantee fishing safety for all nor able to ensure social distancing." Most anglers (58%) reported that they did not know other people who had not fished before who have done so since the COVID-19 crisis began (**Figure 5**).

### Expenditure

There was a significant difference in people's sea angling expenditure when comparing spending in a 'typical April' to spending in April 2020 (Wilcoxon test: $p < 0.001$). In total, 363 (63%) people had spent less, 161 (28%) reported no change in their spending and 51 (9%) people has spent more in April 2020 than they typically would on sea angling.

**TABLE 2** | Characteristics of the respondents to survey in comparison with the whole Sea Angling Diary panel and the UK population of sea anglers in 2019.

| Measure | Respondents* | Sea Angling Diary Panel (SADP) | UK sea anglers** |
|---|---|---|---|
| Total Number | 531-559 | 2,129 | 551,000 |
| **Age* (%)** | | | |
| 16-34 | 1.6 | 12.8 | 27.5 |
| 35-54 | 22.9 | 34.9 | 44.3 |
| 55+ | 74.1 | 52.2 | 28.9 |
| Prefer not to say | 1.4 | 0.1 | — |
| **Location*** (%)** | | | |
| East | 10.4 | 10.8 | 3.7 |
| East Midlands | 2.7 | 3.5 | 5.8 |
| London | 2.8 | 2.7 | 2.6 |
| North East | 6.5 | 5.5 | 4.7 |
| North West | 10.8 | 10.9 | 4.3 |
| Northern Ireland | 1.9 | 2.2 | 13.4 |
| Scotland | 5.7 | 6.9 | 7.1 |
| South East | 20.5 | 19.5 | 24.4 |
| South West | 18.0 | 18.9 | 11.5 |
| Wales | 10.6 | 9.5 | 11.7 |
| West Midlands | 4.0 | 3.9 | 5.4 |
| Yorkshire and Humber | 6.1 | 5.7 | 5.5 |

**The number of respondents that completed demographic questions ranged from 531-559. **Percentages have been calculated for common categories to allow comparisons with the WPS 2019. The confidence intervals for the total number of UK sea anglers is 370k – 726k.*

****Survey respondents (n = 4, 0.8%) and panel members (n = 16, 0.8%) living in the region 'Other' have been excluded from this table to allow for comparison with the WPS 2019. The Total Number is the number in each group, while all Age and Location are represented as a percentage (%).*

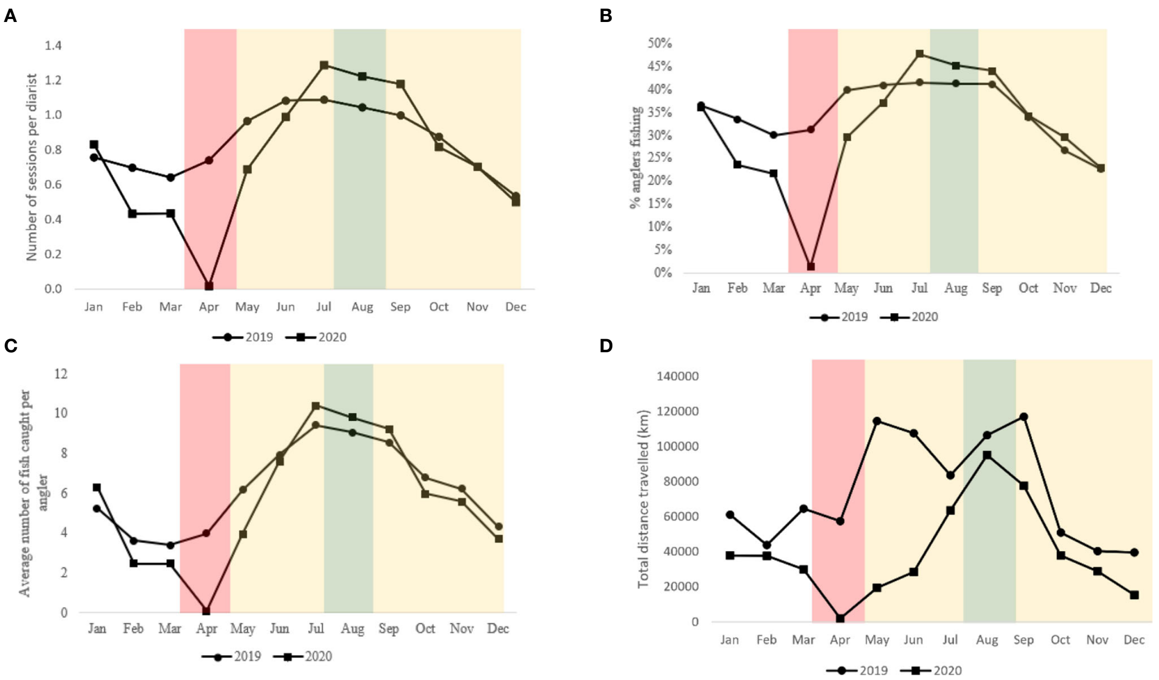


**FIGURE 1** | Seasonal patterns of angling activity and catches in 2019 and 2020, generated from the UK sea angling surveys. **(A)** the average number of sessions per diarist per month; **(B)** the proportion of anglers that fished each month; **(C)** the average catch per angler; **(D)** the total distance travelled by anglers from their home location to their fishing site per month (totals for distance travelled were used instead of averages due to a wide variation in session numbers). Red represents the full lockdown, yellow is a partial lockdown, green is when the lightest restrictions were in place, no colour is prior to COVID-19 pandemic lockdowns.

The difference between the nominal values of individual usual spending during a 'typical April' and spending in April 2020 was calculated, and respondents were placed into one of three categories; no change, spent less, or spent more. A multinomial regression model was conducted to determine which variables affected whether an individual was more likely to spend more or less in April 2020 compared to a typical April. This was examined in relation to 'no change', which was used here as the reference category. The centrality of angling to angler's lifestyle was a predictor (coef – 0.11, p <0.05) for spending less in April 2020 compared to a typical April (**Table 3**), in addition to their mental health and well-being score (WHO-5). Fishing in 2020 (at least once) was a significant predictor for a change in spending, both for spending more (coef = 1.4, p <0.001) and spending less (coef = 0.2, p <0.001). Avidity influenced the probability of spending more in April 2020 with more regular anglers more likely to spend more (coef=0.193, p<0.001). Those who have fished only once or not at all in the last 12 months less likely to spend more in April 2020 (coef = 58.88, p <0.001 and coef = -42.35, p <0.001, respectively). Anglers that fished more in April 2020 compared to a typical April were significantly more likely to have spent more (coef = 3.08, p = 0.051). Anglers that fished the same amount in April 2020 compared to a typical April, in addition to those who did not fish at all in April 2020, were significantly likely to have had a change in spend, both spending more and spending less relative to the no change in expenditures (**Table 3**).

## Physical Activity

During COVID-19, 45% of respondents felt that they were less active because they could not go sea angling, while 21% agreed that they were less active for other reasons (**Figure 6A**). Individuals who had either or both a mental and physical health concern (66%) were more likely to be less active because they could not go sea angling when compared to individuals who had neither health concern (38%). Unemployed individuals were more likely to agree or strongly agree that they had been less active because they could not go sea angling (77%) compared to individuals employed (41%), furloughed (40%), or retired (44%). Comparisons based on gender was not possible due to the very low number of female respondents (n=6).

## Well-being

In a subjective measure, respondents were asked to recall the impact of not being able to go sea angling in 2020 had on their well-being. 43% of respondents reported that not being able to go sea angling because of COVID-19 had some form of negative impact on their well-being. For example, 67% said that they 'strongly agreed' or 'agreed' that they were less happy because they could not go sea angling (**Figure 6B**).

The well-being of individuals in the preceding two weeks was scored using the WHO-5 methodology (**Figure 7A**). Anglers were also questioned as to what extent their responses to the WHO-5 measures about their well-being in the preceding two weeks were due to being able to go sea angling (**Figure 7B**). 67% of anglers said

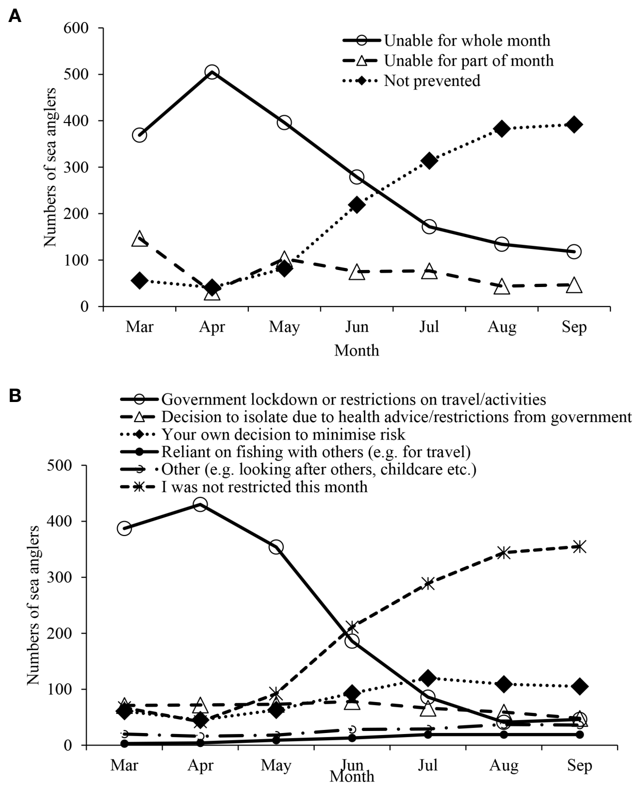


**FIGURE 2** | Impact **(A)** Impact of COVID-19 on the ability of the respondents to access sea angling. **(B)** Reasons for not fishing during COVID-19 across respondents to the survey. As lockdown rules varied across the UK and people were shielding, this is not simply related to the periods of nationwide lockdown.

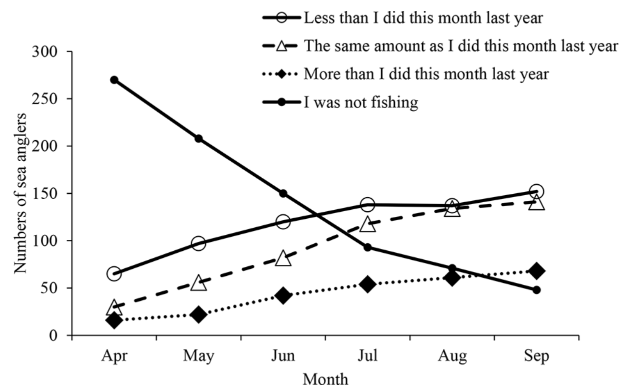


**FIGURE 3** | Effect of COVID-19 on the frequency of fish trips.

their responses were due to being able to go sea angling. Of these 67% had a high well-being score (67%-100%), 26% had a medium well-being score (33%-66%) and only 7% had a low well-being score (0-33%) (Q19, **Supplementary Materials**).

Using a general linear model, we reviewed the other responses as possible variables that could affect individual well-being scores (**Table 4**). We tested all predictor groups within the survey and included those that were significant in the model. We found that even though anglers said that being able to go fishing has resulted in high WHO-5 scores, age, physical and mental health status, angling activity, travel to fish during COVID-19, and July fishing activity in 2020 had significant effects ($p < 0.05$, SE = 15.04, **Table 4**). For example, individuals with a WHO-5 score that was positively impacted by their ability to go sea angling were more likely to have a mental or physical health issue, or both ($p = <0.001$ to 0.29, SE = 2.54 to 4.88, **Table 4**).

## DISCUSSION

Using the evidence collected, we can conclude that COVID-19 had an overall negative impact on recreational sea angling in the UK in 2020, especially during the first lockdown in April 2020. This included participation and effort, physical activity, well-being, and expenditure of sea anglers. This confirms our hypothesis that there was a reduction in sea angling effort as a result of lockdowns, other restrictions, and personal circumstances that limited angling activity. There remains an unknown long-term effect of this negative impact on recreational sea angling especially as the pandemic continues, which could affect restrictions, personal health, or willingness to fish. Participation and effort were negatively affected for many sea anglers by lockdown, health concerns and other personal circumstances related to COVID-19, which impacted mental well-being and physical activity. When reviewing diarist participation in sea angling during COVID-19 in 2020, we found an overall reduction in the number of diarists fishing, number of sessions and number of catches. The data shows that the number of sessions per diarist increased during July, August and September of 2020 suggesting compensation of activity for when it was restricted. In total, 67% of respondents reported reduced happiness and 45% were less active due to sea angling restrictions.

Although surveying anglers has been a common practice in the management and understanding of angler behaviour (Pollock et al., 1994) this survey was limited in nature by some factors. The population surveyed was a research panel of sea anglers in the UK created to provide data for the SADP on participation, catches and expenditure. The SADP is itself self-selected and previous analysis has shown some bias as they are generally older, more avid, and had been fishing for more years when we compare them to the general population of sea anglers (Hyder et al., 2020a). It is suggested that the participants are more engaged in angling and therefore more likely to sign up to the diary project (Hyder et al., 2020a), and were more likely for the restrictions to have affected their well-being because they were unable to fish. The respondents to this survey were a self-selected sample of that panel and as such cannot be taken to be representative of the sea angling population of the UK. However, this study is unique in that it has years of evidence that define and account for bias in the sample size. The reasons that this

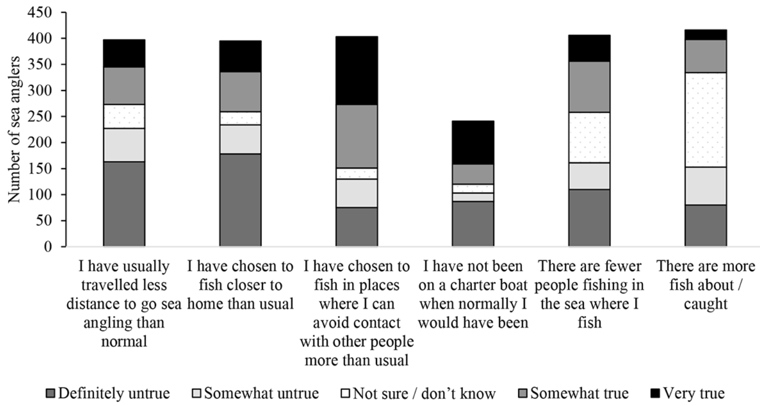


**FIGURE 4** | Impact of COVID-19 on angling experience.

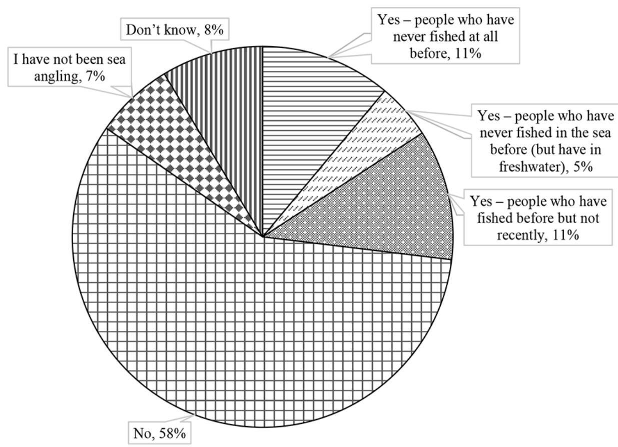


**FIGURE 5** | Changes in participation in sea angling during COVID-19. Responses to the question: Do you know of other people who have not fished before who have done so since the COVID-19 crisis began? Please tick all that apply.

approach was taken are that there is no database of sea anglers in the UK from which a representative sample of sea anglers could be drawn; alternative methods such as a randomized face-to-face survey (Pollock et al., 1994; Mosindy and Duffy, 2007) were not possible during the pandemic and this, and other methods, such as postal surveys would have been prohibitively expensive. Unlike other countries, the UK does not have a licence nor a registry for sea anglers, there is no legal requirement for catch reporting, and response rates to mail and telephone surveys in the UK are low, making probability-based samples very difficult to obtain. Despite the use of a convenience sample, a small UK sea angling diary panel recruited from a randomised postal survey had similar demographic characteristics (Hyder et al., 2020b). Research into mandatory catch reporting in freshwater has resulted in provision of up to a 99% of data where there was commitment and investment from anglers, angler enforcement, and robust fisheries management (Lyach, 2021). However, there are fewer species to record and manage in freshwater compared to the marine environment in the UK (Winfield, 2016), and sea angler preferences for voluntary catch and release for some species (Andrews et al., 2021). The timescale for capturing some data on the impact of the pandemic to avoid recall bias was short, so the most efficient approach was to use the SADP. However, other biases in the sample could include participants not wishing to report angling during legally enforced lockdowns, or generally not including limited or unsuccessful sea angling trips when there is no catch to report (Essig and Holliday, 1991; Hartill and Edwards, 2015). This could have an impact on the true numbers of sessions and economic impact of UK recreational sea angling. A larger, more representative diary panel, with a randomized representative sample, might help address these issues in future surveys. Reweighting the sample

**TABLE 3** | A multinomial logistic regression of the predictors impacted whether respondents spent more, less or no change on angling in April 2020, compared to a typical April.

| Predictor Group | Predictor | April 2020 Expenditure Response Categories | | | | | |
|---|---|---|---|---|---|---|---|
| | | Spent more | | | Spent less | | |
| | | coefficient | Standard error | p-value | coefficient | Standard error | p-value |
| **Mental Health and Well-being Score (WHO5)** | | -0.016 | 0.008 | **0.053** | -0.011 | 0.005 | **0.037** |
| **Centrality to life** | | -0.001 | 0.089 | 0.995 | 0.114 | 0.051 | **0.026** |
| Avidity | **Regular** | 0.193 | 0.570 | **<0.001** | -0.627 | 0.376 | **<0.001** |
| | **Occasional** | -0.247 | <0.001 | 0.676 | -1.039 | <0.001 | **0.007** |
| | **Rare** | -0.913 | <0.001 | 0.172 | -1.756 | <0.001 | **<0.001** |
| | **Once** | -58.877 | <0.001 | **<0.001** | -1.290 | <0.001 | **0.048** |
| | **Not in the last 12 months** | -42.347 | <0.001 | **<0.001** | -2.659 | <0.001 | **<0.001** |
| Fished in 2020 | **Yes** | 1.400 | 0.864 | **<0.001** | 0.198 | 0.359 | **<0.001** |
| June Fishing Activity 2020 | I fished less than I did this month last year | -1.742 | 1.415 | 0.218 | 0.188 | 0.732 | 0.798 |
| | I fished more than I did this month last year | -0.683 | <0.001 | 0.630 | -1.186 | <0.001 | 0.132 |
| | **I was not fishing** | -1.891 | 1.445 | **<0.001** | -0.013 | 0.744 | **<0.001** |
| | I fished the same amount as I did this month last year | -1.972 | 1.418 | 0.164 | -0.918 | 0.711 | 0.197 |
| April Fishing Activity 2020 | I fished less than I did this month last year | 1.123 | <0.001 | 0.412 | -1.200 | <0.001 | 0.085 |
| | **I fished more than I did this month last year** | 3.082 | <0.001 | **0.051** | 0.451 | <0.001 | 0.668 |
| | **I was not fishing** | -1.700 | 1.370 | **<0.001** | -0.120 | 0.662 | **<0.001** |
| | **I fished the same amount as I did this month last year** | 0.689 | 1.555 | **<0.001** | -0.990 | 0.756 | **<0.001** |

*Bold text shows the significant predictors (p < 0.05).*

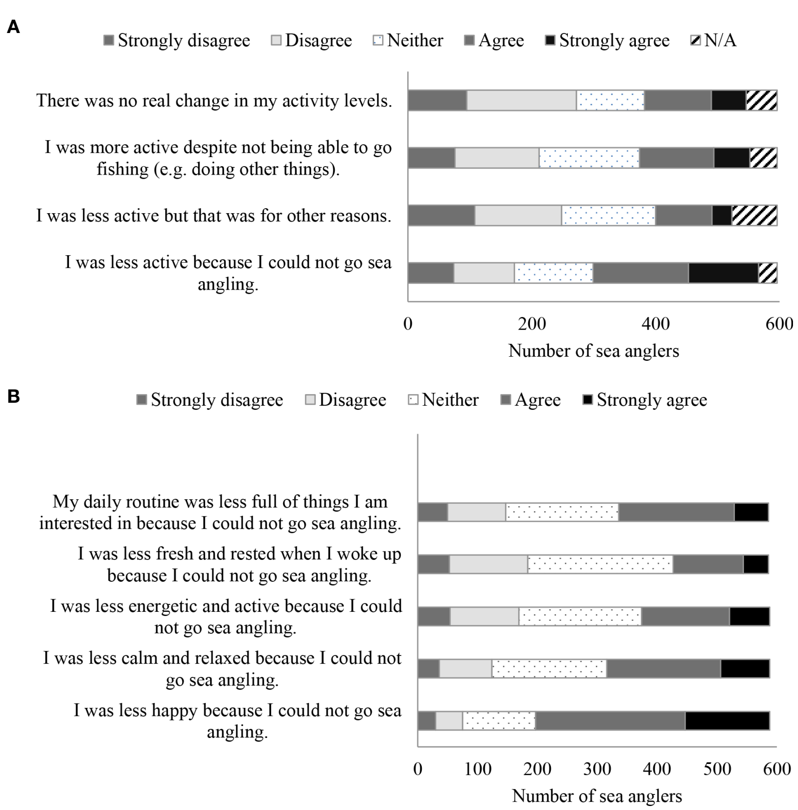


**FIGURE 6** | The role of COVID-19 on impacting levels of physical health **(A)** and well-being **(B)** and the relative importance of sea angling as a driver.

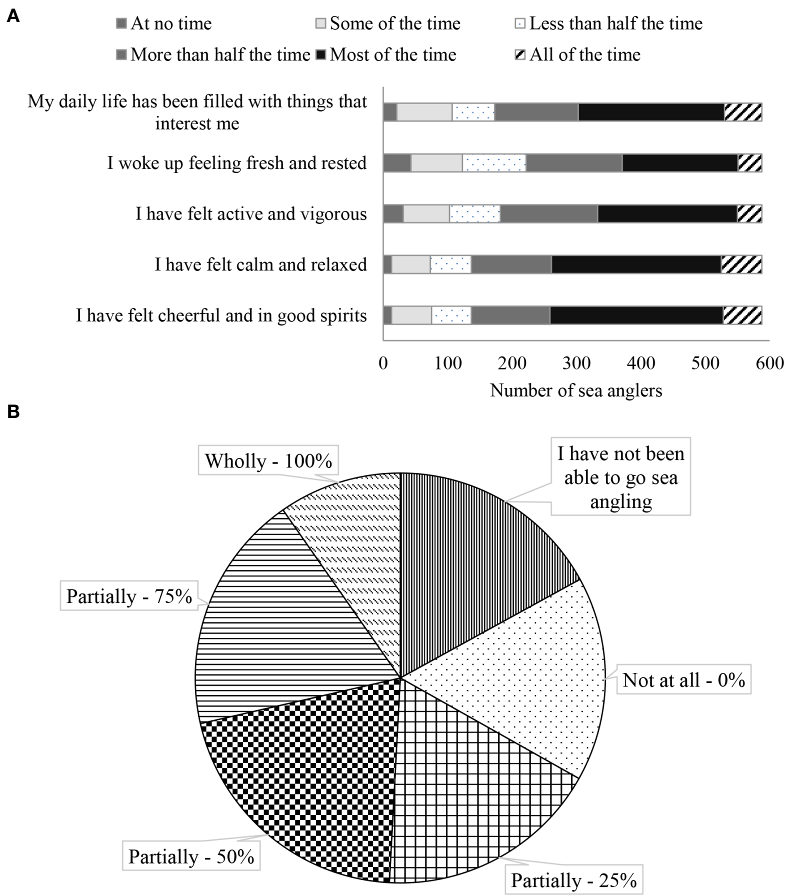


**FIGURE 7** | **(A)** Response from participations on well-being in the last two weeks (**Supplementary Material Q20**) and **(B)** how important restrictions on sea angling are for these outcomes (**Q21** To what extent are your responses due to now being able to go sea angling? Please say from 0% (not at all) to 100% (completely due to sea angling), or tick N/A.; **Supplementary Material**).

to account for bias was not possible, as COVID-19 resulted in the change of WPS methods from face-to-face to online panel in 2020, so different could be due to survey method rather than COVID-19. Finally, the comparison made in the longitudinal survey was used to assess relative changes rather than absolute numbers, which should be robust as long as the bias is consistent. Although the impact of this bias is unknown and we can assume from other research that overall COVID-19 had a negative effect on sea anglers, especially during the first lockdown. However, it is likely that other circumstances of COVID-19 caused greater impact and that not being able to go sea angling was not the only cause.

This survey was taken at a specific point in time to assess the immediate impacts of the COVID-19 pandemic mid-way through 2020. It was designed with an expectation that the pandemic restrictions would likely be short-lived and the survey took place before the second wave and subsequent second lockdown in the UK from 2020 to 2021. To investigate the further effects of the pandemic and the second lockdown on angler participation, physical activity, well-being and expenditure, a subsequent survey on the longer-term impacts of COVID-19 on sea angling could be conducted. Currently, the SADP does not collect information at each session on sea anglers' physical activity, well-being and expenditure, although these factors are surveyed periodically. More regular surveying of these factors could help future comparisons and assessment of impact. It can be seen from the participation levels in the SADP results, those diarists who continued to fish as the second lockdown came into force in December 2020, although this was overall lower than in 2019. Overall, we cannot say whether or not sea angling participation or effort increased in the UK population. Our survey was conducted on existing participants in sea angling, and their responses on whether they knew someone who had taken up angling were not informative enough to contribute any significant information about participation or effort increases.

A change in people's exercise routines, prolonged (two weeks or more) self-quarantine and government-imposed social distancing and isolation negatively impacted well-being, such as an increase in stress and depression (Hawryluck et al., 2004; Dwyer et al., 2020). There is a base of knowledge that explains the

**TABLE 4** | A generalised linear model of the impact of multiple predictors on the mental health and well-being of sea anglers

| Predictor Group | Predictor | Estimate | Standard error | t-stat | p-value |
|---|---|---|---|---|---|
| **Mental Health and Well-being Score (WHO5) Intercept** | | -46.80 | 31.32 | -1.49 | 0.136 |
| Demographics | **Age** | **0.47** | **0.11** | **4.48** | **<0.001** |
| COVID-19 Risk Category | High Risk | 0.56 | 4.17 | 0.13 | 0.894 |
| | Low Risk | 7.12 | 3.73 | 1.91 | 0.057 |
| | Moderate Risk | 1.02 | 3.64 | 0.28 | 0.780 |
| | Prefer not to say | 9.63 | 8.64 | 1.11 | 0.266 |
| Physical and Mental health status | Prefer not to say | -0.92 | 4.29 | -0.21 | 0.831 |
| | **Yes I have a mental health issue** | **-10.71** | **4.88** | **-2.19** | **0.029** |
| | **Yes I have a physical health issue** | **-13.88** | **4.46** | **-3.11** | **0.002** |
| | **Yes I have a physical and mental health issue** | **-8.95** | **2.54** | **-3.52** | **<0.001** |
| | **Percentage score of mental health and well-being during lockdown** | **-0.33** | **0.05** | **-6.37** | **<0.001** |
| Expenditure | April Expenditure (£) | 0.01 | 0.01 | 1.04 | 0.300 |
| | Typical April Expenditure (£) | 0.01 | 0.01 | 0.82 | 0.415 |
| Angling Activity | Angling activity since lockdown | -10.83 | 6.07 | -1.79 | 0.075 |
| | **Future centrality of sea angling in the next 12 months** | **2.19** | **0.97** | **2.25** | **0.025** |
| Travel less during COVID to go sea angling (those applicable) | **Definitely untrue** | **51.45** | **22.02** | **2.34** | **0.020** |
| | N/A* | 41.92 | 22.01 | 1.91 | 0.057 |
| | **I am not sure** | **48.92** | **22.08** | **2.22** | **0.027** |
| | **Somewhat true** | **44.07** | **21.86** | **2.02** | **0.044** |
| | **Somewhat untrue** | **53.09** | **22.05** | **2.41** | **0.016** |
| | **Very True** | **44.27** | **21.60** | **2.05** | **0.041** |
| Fishing close to home | **I definitely did not fish close to home** | **40.87** | **20.71** | **1.97** | **0.049** |
| | **N/A*** | **43.64** | **21.21** | **2.06** | **0.040** |
| | **I am not sure** | **50.29** | **21.26** | **2.37** | **0.018** |
| | **I somewhat fished closer to home** | **50.79** | **21.08** | **2.41** | **0.016** |
| | **I somewhat did not fish close to home** | **43.86** | **20.99** | **2.09** | **0.037** |
| | **I definitely did fish closer to home** | **47.15** | **21.18** | **2.23** | **0.026** |
| June Fishing Activity 2020 | I fished less than I did this month last year | 1.17 | 6.30 | 0.19 | 0.853 |
| | I fished more than I did this month last year | 7.45 | 7.34 | 1.02 | 0.311 |
| | I was not fishing | 1.09 | 6.37 | 0.17 | 0.864 |
| | I fished the same amount as I did this month last year | 4.57 | 6.72 | 0.68 | 0.497 |
| July Fishing Activity 2020 | I fished less than I did this month last year | 7.09 | 7.42 | 0.96 | 0.340 |
| | I fished more than I did this month last year | 10.22 | 8.08 | 1.26 | 0.207 |
| | I was not fishing | 6.12 | 7.76 | 0.79 | 0.431 |
| | **I fished the same amount as I did this month last year** | **18.14** | **7.65** | **2.37** | **0.018** |

**Not applicable was a response option for questions in COVID-19 survey (**Supplementary Material**).*
*N/A has been analysed as a (Predictor Variable) in the model.*
*Bold predictor values are significant (p ≤ 0.05).*

benefits of being in nature for health and well-being (Chaudhury and Banerjee, 2020; O'Brien and Forster, 2020). In the UK generally, there was an increased desire to spend more time amongst nature following lockdown (Lemmey, 2020), which is an integral part of recreational sea angling and is an important motivation for going sea angling (Brown, 2019). However, for some individuals, access to nature was restricted during the pandemic, specifically during lockdowns, and there was likely a negative impact as the added value of exercising in nature was not realized. To understand the more general impact of sea angling on physical activity, well-being, and expenditure in 2021, we will be conducting two new surveys. These surveys utilize an expanded set of questions about impact in these areas based (in part, where possible) on additional validated measures. These data will provide a set of findings some of which will allow comparative analysis to the results presented here and help us understand further information about the impact of the pandemic on anglers during 2021. Analysis of SADP data and national participation data from 2019 will further explore how patterns of participation have changed between 2019, 2020 and 2021.

Prior to the pandemic, participation in recreational angling has been on an overall steady decline. Although participation in sea angling has fluctuated between 2016 to 2019 (Hyder et al., 2020a), freshwater licence sales declined dramatically in the decade before the pandemic (Environment Agency, 2020). Other countries have reported an increase in recreational angling in a similar period, however different methods of survey and modelling to manage angling were used (Hartill and Edwards, 2015; Arostegui et al., 2021). In 2020 countries, including England, Germany, Belgium, and Greece, reported that participation in freshwater recreational angling had increased. For example, in Belgium, there was a 30% increase in licence sales compared to 2019 (Gundelund and Skov, 2021; Pita et al., 2021). In Germany, it was argued that there had been a shift in recreational angling from marine to freshwater, and globally this shift has been beneficial to species under recreational fishing pressure (Pita et al., 2021). In England, the increase in licence sales suggested that more individuals were angling, and it may have been the case that more individuals are likely to be sea angling (gov.uk, 2020; Pita et al., 2021). However, although participation may have increased, our data suggest that effort decreased and those surveyed were sea angling less often in 2020 than in 2019. However, this sample may be more experienced, avid and older than the general population. In other countries, the COVID-19 outbreak lockdowns resulted in a higher participation rate and a change in angler characteristics, such as in Denmark, where individuals were more likely to be younger and less experienced when compared to previous years (Gundelund and Skov, 2021). There is currently no data that allows assessment of whether there were changes in participation and effort between fishing in freshwater and fishing in the sea, although this could be collected in future surveys. In some countries, the lockdowns did not prohibit sea angling, such as in North America, where 92% of jurisdictions did not close or delay recreational fishing and in some, it was even encouraged as a safe activity (Paradis et al., 2021). It was and remains recognized that lockdowns had direct and indirect effects on individual health and well-being, however, these have yet to be fully explored. An important factor in this research, which included anglers from across the UK, was that the restrictions and personal circumstances faced by citizens during 2020 varied enormously, from country to country, region to region and month to month. The only time in which there was a uniform approach to restrictions across the whole of the UK was in April 2020 and it is the results relating to this period that are perhaps the strongest.

The impact of the first lockdown in the UK saw a reduction in participation, effort and spending in sea angling. Most individuals (63%) spent less than a typical April during the lockdown, indicating an economic impact in the recreational sea angling sector. An expected significant predictor of this change was whether or not an individual fished at all in 2020, their fishing activity in April 2020 (the month of angling restrictions), their stated avidity and how central recreational sea angling was to their lives. Centrality to lifestyle was a significant predictor of a decrease in spending on angling. This is likely due to the impact of the pandemic on participation rates, as individuals were unable to go angling at the same rate as in previous years. Interestingly, whether or not an individual fished in June and their mental health and well-being score, WHO-5, were also predictors. The summer months often provide more opportunities to fish, and in 2020 we can see from **Figure 1**, there was a steady increase in recreational angling through to August. Despite the WHO-5 being a predictor for their expenditure, expenditure was not a predictor for WHO-5. Although those who have been able to go back to sea angling have a high or medium WHO-5 score, we found that other factors had significant effects, such as age, physical and mental health status, angling activity, travel to fish during COVID-19, and July fishing activity in 2020 had significant effects ($p < 0.01$, **Table 4**). In other studies of the general population in the UK, females reported higher levels of anxiety than males (White and Boor, 2020). In our study, there was a lower number of females (N = 6), which is also found in the general UK sea angling population but not to the same degree. However, it was estimated that up to 20% of all UK sea anglers are female (Hyder et al., 2020a), while only 1.1% of the responses in the COVID-19 survey were female. This could have been due to the survey being conducted on a known panel of sea anglers, rather than being conducted on the general population through random sampling. White and Boor (2020) also found that respondents who reported either self-isolating before the lockdown, increased feelings of isolation after the lockdown and having livelihood concerns due to COVID-19 had a higher association with poorer mental health and well-being (WHO-5) (White and Boor, 2020). It would have been interesting to gather further information regarding the general impact of COVID-19 on participants, to measure the quality of life (WHO-QOL BREF) (Skevington et al., 2004; WHO, 2012), perceived stress (PSS-10) (Cohen et al., 1983), depressive symptoms (PHQ-9) (Spitzer et al., 1999) or anxiety (GAD-7) (Spitzer et al., 2006). This may have also improved the analysis and understanding of the impacts of COVID-19 and sea angling, especially if comparing individuals who had been angling in the previous two weeks from the time of taking the survey.

As the first study to understand the impacts of COVID-19 on sea anglers in the UK, we have demonstrated some well-being benefits that sea angling can have on participants. Overall, this work has shown that COVID-19 has negatively affected marine recreational fisheries in the UK. We have observed in our sample that not being able to go sea angling had a negative impact on participation, effort, physical activity and well-being. Government and local restrictions, personal health circumstances, aversion of risk and other factors related to the pandemic are reasons participation and effort in sea angling reduced within our sample and therefore subsequently impacted the well-being and physical activity of participants. Similar to other studies in different countries it seemed being able to go sea angling again had a positive impact on our sample, implying that sea angling can make a positive contribution to physical activity and well-being (Lemmey, 2020; Gundelund and Skov, 2021; Howarth et al., 2021; Pita et al., 2021), although other factors can contribute to this. Further research is being conducted in 2021 and 2022 will contribute further data and knowledge to this. This research can contribute to a wider body of knowledge to better inform policymakers about the management of recreational marine fisheries, especially in the event of future pandemics. Lastly, we believe that the longitudinal information regarding the panel surveyed, and the continuing efforts of the SADP to understand marine recreational angling within the UK into 2022, opens scope for further investigation to understand the long-term impacts of COVID-19 on well-being, expenditure, physical activity, and participation.

## DATA AVAILABILITY STATEMENT

The datasets presented in this study can be found online through the Cefas data hub (https://data.cefas.co.uk/). Due to the nature of this data and the protection of the respondent's data, requests to access the data should be made directly to the authors.

## ETHICS STATEMENT

Ethical review and approval was not required for the study on human participants in accordance with the local legislation and institutional requirements. The patients/participants provided their written informed consent to participate in this study.

## AUTHOR CONTRIBUTIONS

All authors set the conceptual framework of this study. SAH, AB and BB carried out the survey and SAH and BB analysed the data with support from KH, ZR, JK and AB. SAH wrote the manuscript with contributions from all authors. All authors contributed to the article and approved the submitted version.

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## SUPPLEMENTARY MATERIAL

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fmars.2022.815617/full#supplementary-material

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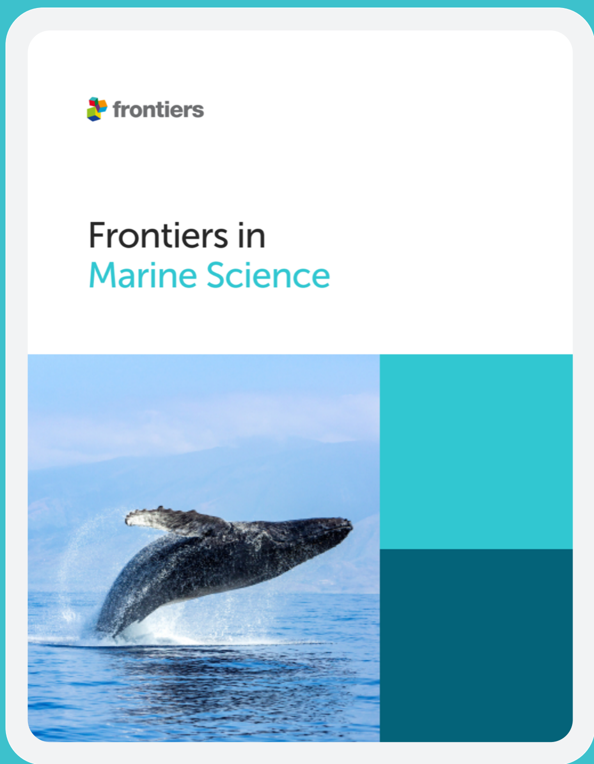


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