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Assessing the importance of kelp forests for small-scale fisheries under a global change scenario

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Kelp forests are critical habitats for temperate coasts that are experiencing dramatic declines worldwide in recent decades. Yet, even though they often support wildlife populations of high socioeconomic value, the consequences of kelp forest decline for small-scale fisheries (SSFs) have received surprisingly little attention. Here, we take the first step to fill this gap through the local ecological knowledge (LEK) of SSF fishers whose fisheries are associated with this habitat in NW Spain. LEK was used to 1) estimate kelp forest loss, 2) identify the main fisheries associated with kelp forests, 3) gain insight into the changes these fisheries may have undergone in recent times, 4) evaluate the economic importance of kelp in the study area, and 5) describe the commercial chain of exploited kelps and relevant fisheries related to them. Fisher's knowledge of kelp forests was documented through interviews with the help of a semi-structured questionnaire with open–closed questions about the small-scale fishery and its target species. Additionally, participants were asked to map the current and former (20 years ago) distribution of kelp forests in their fishing area. Results show that a range of fish, crustaceans, mollusks, echinoderms, and even the kelp itself are fished/harvested in the study area, suggesting the socioeconomic value of those species. The most intensively targeted species usually belong to fisheries with high commercial value, and first-sale data indicate that they are worth some 10 million euros to the local economy. On the other hand, compared to two decades ago, fishers reported a substantial contraction in the area occupied by kelp forests and decreases in the fisheries typically associated with this habitat. Landing data partly support this perception of a decline in catches. Altogether, this information will be useful to foster kelp forest conservation and to evaluate their socioecological and economic implications for SSFs.

KEYWORDS

management, fisheries, ecological knowledge, kelp forest, small-scale fisheries

Introduction

Kelp forests are highly productive habitats that dominate temperate rocky reefs in most marine environments worldwide, providing multiple ecological, economic, and cultural ecosystem services (Steneck and Johnson, 2014; Vergés and Campbell, 2020). Among other functions, kelps enhance local biodiversity by being foundation species that create biogenic habitats and facilitate complex biological interactions (Dayton, 1985; Steneck and Johnson, 2014, Krumhansl et al., 2016). Their role as habitat providers include many commercial species with high economic value (Blamey and Bolton, 2018; Vergés and Campbell, 2020). In particular, abalones and lobsters are typically regarded as the most important commercial fisheries linked to kelp forests, generating millions every year worldwide (Smale et al., 2013, Bennett et al., 2016, Carr and Reed, 2016; Blamey and Bolton, 2018). The best estimates of the value of the ecosystem services (e.g., fisheries) provided by kelp forests are from South Africa and Australia. In South Africa (Blamey and Bolton, 2018) and the Australian Great Southern Reef (Bennett et al., 2016), it has been estimated that kelp forests generate a revenue of 434 million/year US$ (427 million/year €) and 1,066.4 million/year AU$ (726 million/year €), respectively, of commercial/recreational fisheries. In Europe, only a few investigations have explored in depth the commercial fisheries linked to kelp forests in the NE Atlantic. Those studies have estimated, for example, a revenue of ~£30 million per year (35 million/year €) to the UK economy alone for the lobster fishery (*Homarus gammarus*) (Smale et al., 2013 and references within). Despite the importance of kelp forests for the fishing sector (Bertocci et al., 2015), there are still gaps in the knowledge of commercial fisheries that depend on these habitats in many areas.

Kelp species themselves are a valuable economic resource in many areas (Bajjouk et al., 2015, Blamey and Bolton, 2018, González-Roca et al., 2021). In Europe, the use of kelps dates back to the Neolithic period (Mesnildrey et al., 2012). Currently, kelp harvesting is a traditional activity in many Atlantic European small-scale communities, such as Northwest Brittany (Alban et al., 2004) or Norway (Frangoudes, 2011), and it has had different social purposes including human consumption, animal feed, medicines, fertilizers, and even as building materials (Frangoudes and Garineaud, 2015, Delaney et al., 2016). In this regard, many of the ecosystem services that kelp forests provide for human well-being are also threatened by their losses (Hynes et al., 2021).

In NW Spain, kelp forests host a diversity of faunal groups with commercial value in the region, such as fishes (e.g., *Labrus bergylta*, *Dicentrarchus labrax*, and *Pollachius pollachius*), crustaceans (e.g., *Maja brachydactyla*), mollusks (e.g., *Octopus vulgaris*), and echinoderms (*Paracentrotus lividus*) (Pita et al., 2018, Pita and Freire, 2019, Fernández et al., 2020). Many of these species move millions of euros (€) annually (Pita et al., 2016, Piñeiro-Corbeira et al., 2022) in the region. Fishing in this region is mainly characterized as small-scale fisheries (SSFs), where the fishing activity plays a vital role in providing employment and sustainable livelihoods for people and maintaining cultural heritage (Pascual-Fernández et al., 2020a). Here, SSF fishing activities are conducted nearshore, many of them on rocky reefs dominated by kelp forests (Guyader et al., 2013, Piñeiro-Corbeira et al., 2022). In fact, Galicia concentrates 57.37% of the Spanish small-scale fleet, being one of the regions with the highest socioeconomic dependence on fishing in the European Union (EU) (Villasante et al., 2015). Fishing landings are sold fresh in the fish markets of each zone at daily auctions (Surís-Regueiro and Santiago, 2014). Many of the fish auctions are managed by *cofradías* (fisher organizations) (Bavinck et al., 2015, Pascual-Fernández et al., 2020b). After that, marine products are distributed, thanks to large fish processors, local fish merchants, and retail traders, until they reach the local marketplace and supermarkets and restaurateurs. Seaweeds themselves also have a relevant economic value, being the kelp-harvesting sector that has grown in recent decades (Piñeiro-Corbeira et al., 2022). In fact, in Galicia, four species are harvested, processed, and distributed by national and international retailers.

As in other regions, kelp forests are also declining in Galicia (Barrientos et al., 2022a, Barrientos et al., 2022b), and it has been especially dramatic in the only marine and terrestrial National Park on the Atlantic Spanish coast. To fill this gap in southern Europe, in this study, we have incorporated the SSF knowledge to assess, on the one hand, the loss of kelp forests and its implications using their historical perspective and their local ecological knowledge (LEK) (Neis et al., 1999). Specifically, we carried out this study in collaboration with the small-scale fishers in the study areas of Ría de Vigo and the Islas Atlanticas National Park (IANP). On the other hand, the study was performed to define which are the most important fisheries associated with kelp forests and finally to gain insight into the changes that these fisheries have suffered due to the loss of kelp forests. This collaborative research through participatory mapping (Aswani and Lauer, 2006) and interviews allowed us to advance on research under a data-poor scenario and then assess local stakeholders' perceptions about it (Trimble and Berkes, 2013).

Materials and methods

The study was carried out in NW Spain along the Galician Ría de Vigo fishing zone and its area of influence, which includes the Cíes Archipelago belonging to the IANP (Figure 1). In this fishing area, 16 *cofradías* concentrate approximately 573 small-scale fishing boats, but not all of them fish on kelp areas. For this reason, we focused our study on three of them: Cofradía de Vigo, Cofradía de Cangas, and Cofradía de Baiona, with 227 small-scale fishing boats.

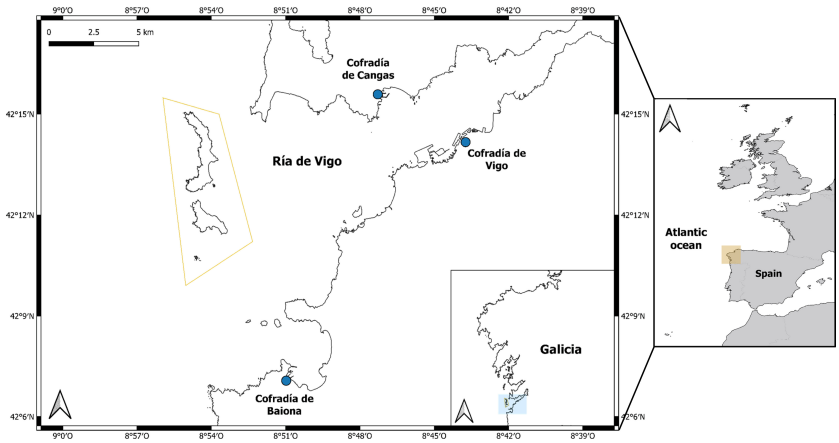

FIGURE 1
Map showing the study area (colored boxes) and the location of the three *cofradías* involved in the study. Polygon is the National Park boundary.

Collaborative research activities were carried out by combining individual small-scale fishers' face-to-face semi-structured interviews (Bernard, 2017) and informal conversations with key stakeholders (e.g., secretaries of *cofradías*, scuba divers, scientists) (n = 20). A questionnaire was used for gathering information from local fishers (Berkström et al., 2019) with open-ended questions. Interviews were conducted between 2020 and 2021 in the three *cofradías* selected, with a questionnaire of 38 questions including binomial (YES/NO), open-ended, and 1 to 5 liker-scale answers. Data collection and storage procedures were followed to ensure proper information, confidentiality, anonymity, and consent. The collected data will remain confidential, will be used only for research purposes, and will not be made available to third parties. The acquisition and processing of personal data were done in conformity with the European legislation (Directive 95/46/EC). Questions covered three main topics: 1) characterization of the main fisheries, including those in kelp forests and kelp harvesting, and 2) main fisheries and 3) harvesting activities in the IANP and Ría de Vigo. In all cases, fishers' perceptions of changes in the described activities and in the marine environment were included.

In addition, different participatory maps (n = 50) (Aswani and Lauer, 2006) were produced with the collaboration of the fishers who were interviewed. Information provided by fishers about the historical reconstruction of kelp forests was compared with data from underwater visual census in the area made by other studies carried out in parallel by the research team of this study (Piñeiro-Corbeira et al., 2021, Barrientos, et al., 2022a, Barrientos et al., 2022b). The *cofradías* had a critical facilitating role in identifying the most experienced fishers who usually work in kelp forest areas. Consequently, four fishing productive units that harvest seaweeds (*Laminaria ochroleuca* and *Laminaria hyperborea*) in Ría de Vigo were extensively interviewed. A small-scale fishing productive unit integrates a group of people involved in the economic activity of fishing (e.g., catching, processing, and distribution) and who may assume different roles (Pascual Fernández, 1991). They can have more than one boat and, considering their members, accumulate knowledge, expertise, and skills over generations, which allows them to position themselves in the marine environment activities (De la Cruz-Modino et al., 2022, Piñeiro-Corbeira et al., 2022). Additionally, 16 small-scale fishers who harvest target species associated with kelp forests in Ría de Vigo and the IANP were likewise interviewed. All were asked to mark on a map their fishing areas, kelp forest locations, and places where kelp has disappeared. A nautical chart (1:42,000) of the study area was provided to each participant together with fine-tipped colored pens to mark the areas where kelp is still present, areas where it has disappeared, and fishing areas for their most valuable fisheries associated with these habitats. Information provided during the questionnaire-led interviews and the kelp forest and fishing areas drawn in maps were digitized and georeferenced into a Geographic Information System (GIS) using a polygon shapefile using QGIS 3.24.3-Tisler. Digitized maps were combined into a single map to visualize similarities and differences in the information provided by the interviewees.

Landings data (weight and economic value in €) from 2001 and 2021 for species associated with kelp forests were obtained from the regional government called *Xunta de Galicia* (https://www.pescadegalicia.gal/). This information derives from sales notes issued by fish auctions or authorized centers for the first sale of fresh fish products. Landings trends between 2001 and 2021 were analyzed using a simple regression procedure with the help of the statistical package Statgraphics Centurion XVI (StatPoint Technologies, Inc.). Data from *Xunta de Galicia*

were also employed to identify the seaweed harvesting landings by *cofradía* and their value. Thanks to the support of the biologists of the *cofradías*, we identified the most experienced fishers related to kelps. On the other hand, thanks to the support of the *cofradías* and some regional fishing responsible, we could reconstruct the distribution chain of the different marine resources that can be exploited in the kelp forests, including the kelp itself. We reconstructed these patterns for several species through a graphical component in this paper.

Results

Given that this project was carried out during the coronavirus disease 2019 (COVID-19) pandemic and that some fishers temporarily ceased activity, we estimate that there were 200 fishers actively working during this period in the study area. Some of them fish by combining different productive units (De la Cruz-Modino et al., 2022, Piñeiro-Corbeira et al., 2022) and different fisheries along the year. Based on the interviews and questionnaires implemented to the three *cofradías* that contributed to this project, we estimate that at least 150 fishers may focus their extractive activity mainly on kelp forest habitats, and all of them work in the IANP regularly.

Historical reconstruction of kelp forests

According to the fishers who were interviewed, kelp forests occur along the entire rocky coast of Ría de Vigo and nearby areas. However, they have perceived a decline in their occurrence (Figure 2). Most of them agree that this loss started about 15 years ago and increased more recently. According to their perceptions, most of the kelp forest loss occurred outside Ría, where only isolated patches of kelp forest habitat remain in some areas (Figure 2). On the other hand, kelp forests persist along most of the rocky coastline inside Ría, although, also in this area, some fishers identified sites where kelp forest areas have shrunk. Overall, according to information obtained from fishers, in recent years, kelp forests would have lost 1,913.59 ha and would still be present on 2,708.905 ha. This represents a loss of 41.4% of the kelp forests estimated to have existed at least 15 years ago. These results coincide with the observations of key informants (e.g., researchers, National Park managers) who observed the loss of kelp forests in the IANP and the presence of healthy forests inside Ría.

Fisheries associated with kelp forests

Fishers in Ría de Vigo dedicate their fishing effort to more than one species. According to information obtained by the interviews, 32 species are fished in kelp forest areas (Supplementary Material Table S1) contributing to the local economy, with 17 million € in 2021, at the first sale point. Most fishers focus on between four and six species throughout the year, although three of the interviewed catch between eight and 14 species (Supplementary Material Figure S1). In most cases, these species were caught in areas currently or formerly occupied by kelp forests. The main groups captured in kelp forest sites were fishes, mollusks, and crustaceans, followed by echinoderms, seaweeds, and cnidarians (Supplementary Material Figure S2).

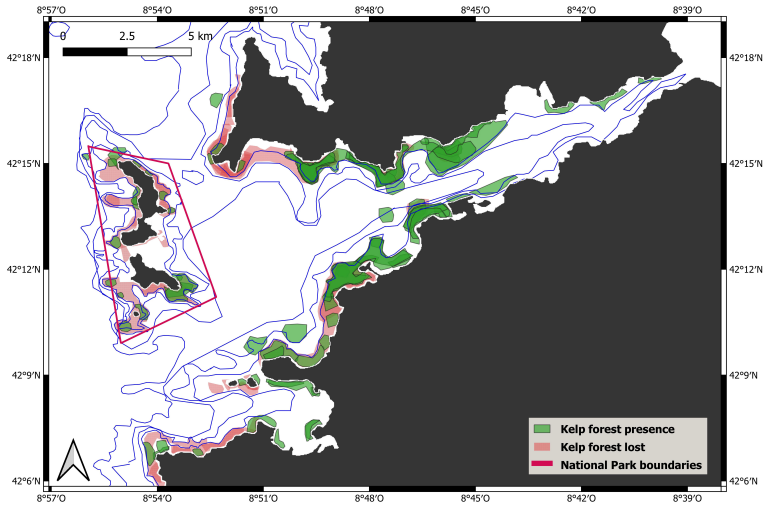

FIGURE 2
Kelp forest distribution in the study area inferred from local ecological knowledge. The map integrates the information provided by local small-scale fishers on the current (kelp forest present) and historical (kelp forest lost) occurrence of kelp forest areas in Ría de Vigo.

Necora puber, *M. brachydactyla*, and *O. vulgaris* were the main fisheries, considering their commercial value, followed by the fishes *D. labrax* and *L. bergylta* and the sea urchin *P. lividus* (Figure 3).

Our results indicate that kelp forest areas are under high fishing pressure throughout the year. All of the small-scale fishers who were interviewed carry out their activity in Ría de Vigo and the IANP, although the particular places where they do most of their fishing depend on which *cofradía* they belong to (Supplementary Material Figure S3). Most fishers always fish in the same areas, regardless of the target species, and only change the fishing gear they use at any given time. They employ a range of nets (purse seines, gillnets, and trammel nets) and pots and hook-and-line gear (longlines, drifting longlines). Nets are mainly used for some fishes (e.g., *Mullus surmuletus*, *Diplodus sargus*, *L. bergylta*) and spider crab *M. brachydactyla*, while hook-and-line gear is used for fishes such as *D. labrax* and *P. pollachius*. On the other hand, pots are used to fish all crustaceans (e.g., *N. puber*, *H. gammarus*, *Palaemon serratus*), some fishes (*Trisopterus luscus*, *Conger conger*), and some mollusks (*O. vulgaris*, *Sepia officinalis*). Seaweeds, the sea urchin *P. lividus*, and the mollusk *Haliotis tuberculata* are fished by hookah diving.

Although all species are eventually caught everywhere along the rocky coastline in the study area, our results show that invertebrates (Figure 3) are fished over larger areas than fish (Figure 4). *N. puber* is the species that is captured at most sites, followed by *M. brachydactyla* and *O. vulgaris*. This information is consistent with landings data, where these species were among those landed in largest quantities between 2001 and 2021 (Figure 5). In fact, together with *P. serratus*,

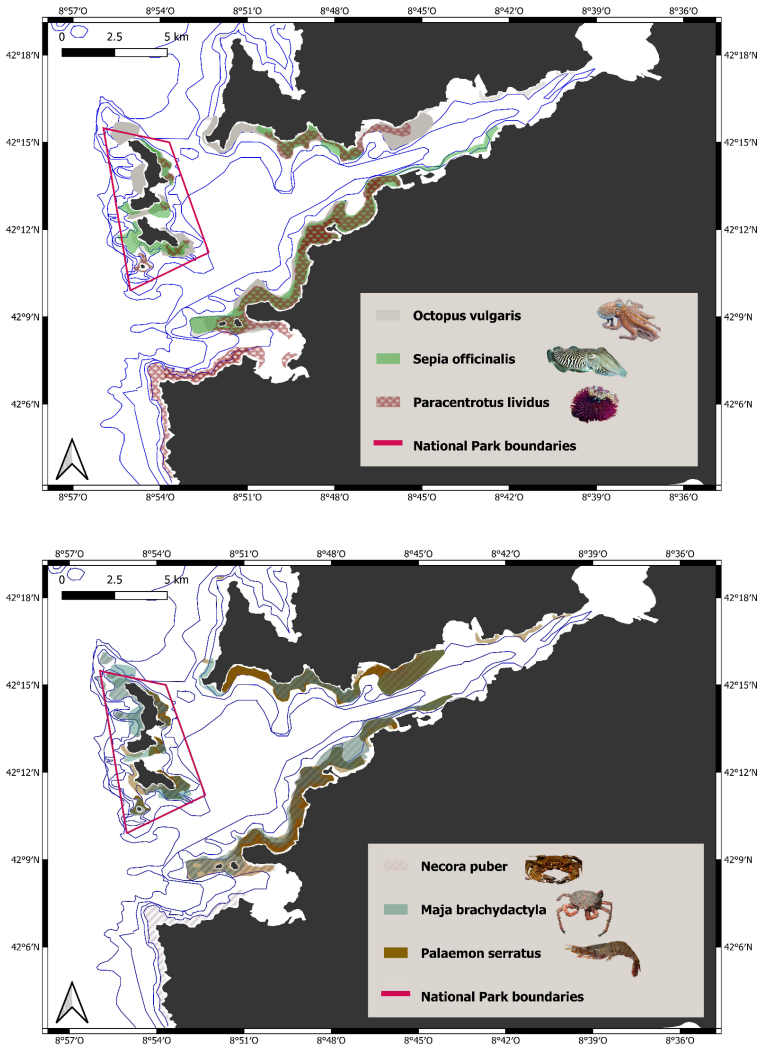

FIGURE 3
Fishing areas of invertebrate commercial species with higher economic value in Ría de Vigo inferred from fishers who were interviewed.

S.officinalis, and *P. lividus*, these species are among the highest priced in the region, contributing to the local economy an average of ~5.5 million €/year (first sale estimate, value-added is not included) (Figure 5). Of the fish that inhabit kelp forest areas, the interviewed fishers caught some of the most economically valuable fish according to 2001–2021 landings data (*D. labrax*, *D. sargus*, *C. conger*, and *Pagellus bogaraveo*). *D. labrax* and *D. sargus* are the species caught in most sites in Ría, especially within the National Park, followed by *C. conger*. *P. bogaraveo*, on the other hand, is fished in small well-defined areas. All of them together contributed an average of ~3 million €/year to the local economy (first sale estimate, value-added is not included) (Figure 5).

Fishers' perceptions about kelp forest loss and its impact on small-scale fisheries

Most fishers noticed changes in their fishing areas at rocky reefs dominated by kelp forests (n = 14). In most cases, they highlighted a decrease in fishing catches in the areas where kelps were no longer present. Some said that since there was no kelp forest, fish breed less or even move to deeper areas where kelp is still found. Three of the interviewees said that they did not know the reasons why there is less fishing in areas where kelps disappeared and that these changes vary from one year to another. Some believe that overfishing could also be another reason for the decline in fisheries. One of the interviewees stated that he had had to change the way he fished because of these changes. Most of the interviewees agreed that these fishing changes have been taking place for the last 10 years. Overall, landings data partly support these perceptions, as two of the main fisheries showed a clear decline over the last 10 years: octopus (slope = -0.030 ± 0.017 kg/year; P-value = 0.0921) and the conger eel (slope = -0.066 ± 0.012 kg/year; P-value = 0.0000). On the other hand, landings for spider crab (slope = 0.081 ± 0.016 kg/year; P-value = 0.0001) and velvet swimming crab *N. puber* (slope = 2.067 ± 0.658 kg/year; P-value = 0.0054) showed an increase in recent years (Supplementary Material Figure S4). Other fisheries showed no obvious trend over time, with small fluctuations among years.

Seaweed harvesters (n = 4) also admitted to having noticed changes in their seaweed harvesting areas. In their case, they have had to devote their fishing effort to other kelps and even to other seaweeds. Two harvesters said that they have been noticing these changes for more than 10 years. Contrary to this, two of them believe that the changes have a seasonal component and vary greatly from year to year. In any case, all kelp harvesters affirm that the increase in herbivory pressure by an herbivorous fish (*Sarpa salpa*) was the reason for the loss of kelp forest areas. Many of the interviewed highlighted that this fish increased its abundance in recent years. In fact, fishers reported that they capture *S. salpa* in the waters of the IANP frequently, precisely where the greatest losses of kelp forest area have been reported (Supplementary Material Figure S5). Data landings support this fishers' perception (slope = 0.192 ± 0.058 kg/year; P-value = 0.0037) (Supplementary Material Figure S4).

Kelp harvesting and associated species commercialization

Our results showed that different kelp species are harvested by *cofradías* with different intensities and manufactured by different

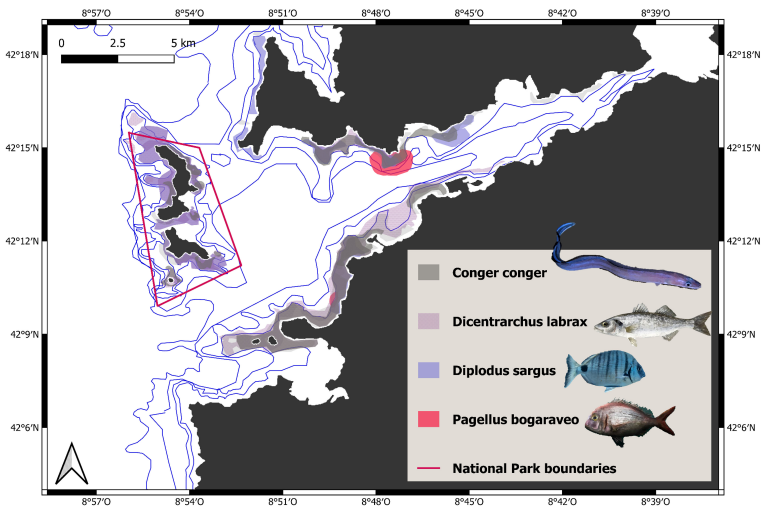

FIGURE 4
Fishing areas of finfish commercial species with higher economic value in Ría de Vigo inferred from fishers who were interviewed.

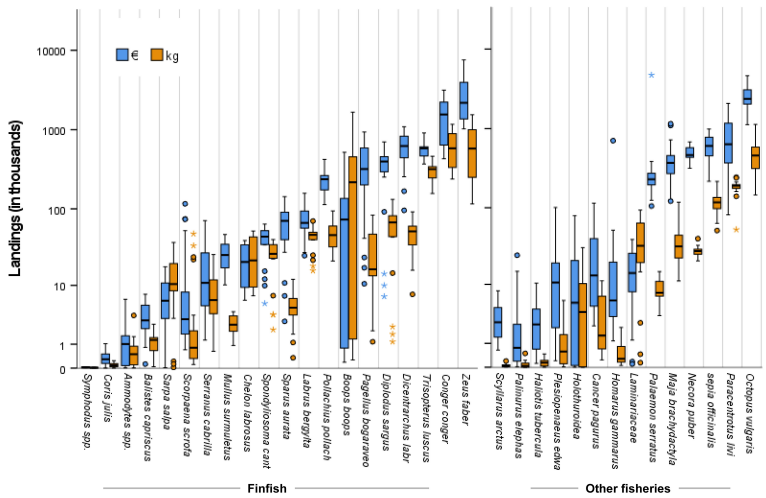

FIGURE 5
Landings data (2001–2021) in euros and kilograms for fisheries typically linked to kelp forest areas in NW Spain. From bottom to top, boxplots show minimum, first quartile, median, third quartile, and maximum. Outside (>1.5 times the interquartile range above or below the box) and far outside (>3 times the interquartile range) values are displayed as dots and asterisks, respectively.

companies. These species are the invasive wakame—named locally as *golfo* (*Undaria pinnatifida*)—and the kelps *L. ochroleuca* and *L. hyperborea* (named locally as *argazo*). *Saccorhiza polyschides* (named locally as *argazo bravo*), which is similar in appearance to the Laminariales, is also harvested in the study area. In addition to kelp harvesting, seaweed harvesters mentioned that there are other species of seaweed that they harvest, such as the red algae *Palmaria palmata*, which grows associated with kelp forest, and also green algae such as *Codium* spp.

According to the auction sales data provided by the *Xunta de Galicia*, there were six *cofradías* (Table S2 Supplementary Material) with authorization for seaweed harvesting in the study area during 2020 and 2021. The *Cofradía de Cangas* is the one that recorded the highest sales of seaweed compared to the other *cofradías*, and it has two seaweed harvesters working actively in the area. Kelps species were the most harvested species during 2021—after the 2020 COVID restrictions—and provided higher revenues. For example, in 2021, 99,935 kg of *U. pinnatifida* were harvested with a revenue of 89,131.50 € at the first sale. Despite those differences in the total amount harvested each year, generally, kelps are semi-processed and commercialized fresh, dehydrated, and preserved. This represents an average of 22 jobs related to this process. Kelp products are distributed nationally and internationally to more than 1,000 retailers.

Among the species associated with kelps, octopus and spider crab should be highlighted due to their popularity and the various ways in which they reach the final customer. Crabs, mollusks, and fishes (e.g., spider crab, octopus, European seabass, or ballan wrasse) are very popular in local gastronomy, and they are consumed both at home and at restaurants. Figure 6 shows the different marketing channels for these species, reflecting the diversity that they can reach the final consumer, who can be both local and visitors. The heterogeneity of the marketing agents involved is also a sign of the important socioeconomic network around the fisheries developed by these three *cofradías* in kelp areas.

Discussion

Global change is causing shifts in marine ecosystems that have consequences for human well-being by disrupting the ecosystem services they provide (Singh et al., 2020). Changes in marine ecosystems are affecting different fisheries along regions with varying intensities and characteristics (Barange et al., 2014). The effects of these changes may affect the accessibility to fish resources, projected to decrease under climatic change, especially for artisanal SSFs (Barange et al., 2018). This decrease may be driven by the direct effects of climatic change, considered the major challenge for global fisheries (Lam et al., 2016), but also by local impacts such as habitat loss (Barange et al., 2018). In fact, in the last decade, the small-scale fleet has declined by 20% in the EU (Lloret et al., 2018) and is expected to continue decreasing according to future projections of fishery catches, which showed a substantial decrease in this region in contrast to colder regions (Barange et al., 2014; Barange et al., 2018). There are still knowledge gaps and insufficient information on changes in marine ecosystems

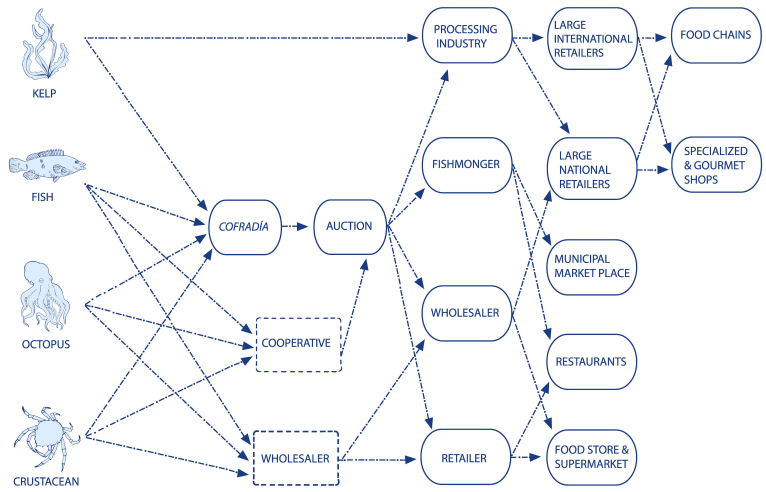

FIGURE 6
Distribution of kelp harvested and marine resources associated along the commercial chain in the study area.

and on the impact that these changes may have on the ecosystem services they provide. In these cases, obtaining LEK through collaborative work with fishers or other stakeholders can be very useful to advance research, including global change or natural hazard scenarios where scientific data are still scarce (Pita et al., 2020, De la Cruz-Modino, et al., 2022). The information obtained from stakeholders can be very useful when designing future scientific work to advance knowledge. In our study, direct work with fishers and key informants who work in the kelp forests of Ría de Vigo has served to reveal the magnitude of the loss of these key habitats. This loss was confirmed by monitoring studies in the same region (Barrientos, et al., 2022a; Barrientos et al., 2022b), showing the extent of these changes as they directly affect a part of the society that lives from the resources obtained from these habitats.

Kelp forests are one of the main ecosystem engineers on temperate rocky coasts around the world. Despite their importance as biodiversity-enhancing facilitators, including many economically important organisms, the relationship between SSFs and the occurrence of kelp forests has received little attention (Bertocci et al., 2015). Our results show that at least three fisheries linked to kelps are very important in economic terms. The 32 species caught in areas with kelp forests in Ría de Vigo were sold for 17 million € in 2021 at the first sale point. Unlike in other regions of the world where abalone and lobsters are the most valuable commercial species linked to kelp forests (Bennett et al., 2016; Carr and Reed, 2016; Blamey and Bolton, 2018), the main fisheries in Galicia are octopus (*O. vulgaris*), John Dory (*Zeus faber*), Conger eel (*C. conger*), and sea urchins (*P. lividus*). These species, together with the velvet swimming crabs (*N. puber*), the common cuttlefish (*S. officinalis*), the shrimp *P. serratus*, the spider crab (*M. brachydactyla*), the European sea bass (*D. labrax*), the white seabream *D. sargus*, the blackspot seabream (*P. bogaraveo*), and the pouting (*T. luscus*), each contributes more than 200,000 €/year to the local economy. In South Africa, a current value of 434 million/year US$ of kelp forest is estimated, of which fishing activities both recreational and commercial represent 28% and 15%, respectively (Blamey and Bolton, 2018). There are 39 species with economic value associated with kelp forests (including the kelps *Ecklonia maxima* and *Laminaria pallida*); the West Coast rock lobster (*Jasus lalandii*), abalone (*Haliotis midae*), and kelps being the most important industries (Blamey et al., 2014, Blamey and Bolton, 2018). Kelp forests from the Australian Great Southern Reef have also been estimated to provide high economic attributes that include a revenue of 512.6 million AU$/year of commercial fisheries (both rock lobster and abalone) and 553.8 million AU$/year of recreational fisheries (Bennett et al., 2016). California kelp forests also support important commercial fisheries, including kelp harvesting, several abalone species (genus *Haliotus*), spiny lobster (*Panulirus interruptus*), and about 15 rockfish species (Carr and Reed, 2016). Commercial fisheries linked to kelp forests in the NE Atlantic are also economically important, such as the lobster fishery (*H. gammarus*), which brings in about ~£30 million per year to the UK economy alone (Smale et al., 2013). In addition, fisheries like the velvet swimming crabs (*N. puber*), the spider crab (*M. brachydactyla*), the European sea bass (*D. labrax*), or the Conger eels (*C. conger*) together with the kelp harvesting

are also important commercial fisheries of the European coastline (Smale et al., 2013). It is important to note that this study has only calculated the economic value of these species for catches in Ría de Vigo, which could explain why the economic value of species associated with kelp forests is much higher in other regions of the world.

Kelp forests have been undergoing changes in their distribution and abundance for several years due to global change (Wernberg et al., 2019, Wernberg et al., 2020). The reasons for this regression vary from one region to another, so local knowledge seems necessary to develop management tools fitted to each particular case (Krumhansl et al., 2016). In our study area, although fishers have perceived a decline in kelp forests in recent decades, the extent of this decline remains largely undetermined in part because of the challenge of conducting subtidal surveys over large areas. In this context, using the ecological knowledge of fishers seems a good working approach (Neis et al., 1999; Pita et al., 2020). In this regard, the information provided by fishers reveals that, in recent years, large portions of kelp forest area have been lost in Ría de Vigo, especially at the entrance of the ria where the IANP is located, while kelp forests are still common further inside the ria. This perception is consistent with seasonal monitoring studies of the ria where the collapse of kelp forests within the IANP and the persistence of healthy forests further inland were extensively described (Barrientos et al., 2022a; Barrientos et al., 2022b). Sea urchins are widely regarded as the major consumers of kelp in temperate latitudes, and their ability to overgraze kelp forest stands down to a canopy-free state has been frequently observed elsewhere (Christie et al., 2019). In this regard, fishers' reports indicate that sea urchins in Ría de Vigo are mostly harvested in areas currently or formerly covered by kelp forest stands (Figure 3). However, the seasonal dynamics of kelp forest collapse, the very low local abundances of sea urchins in the surveyed sites, and a detailed analysis of bite marks in more than 1,000 kelp individuals provide little support to the hypothesis that sea urchins may explain the demise of kelp forests at the entrance of Ría de Vigo. Instead, intensive seasonal overgrazing by *S. salpa*, the only herbivorous fish in the region, seems a more likely driver for the contraction of kelp forest areas, being the first time that a fish is shown to cause kelp forest collapse on a reef scale in the temperate Atlantic (Barrientos et al., 2022b). Furthermore, the information obtained from fishers in this study provides further support for this conclusion. Thus, while *S. salpa* catches are restricted to the entrance of the ria and largely overlap with the zones where kelp forests collapsed in recent years, sea urchin harvesting occurs over a wider range and includes zones further inland of the ria where kelp forests are still in good condition (Supplementary Material Figure S5).

Despite the loss of kelp forests, kelp harvesting is one of the commercial fisheries in this region involving SSFs and companies, although small-scale fishers combine kelp harvesting and other wild fisheries. The amount of kelp harvested is comparable in weight (kg) to the catches of other species with economic value such as the white seabream and the blackspot seabream. However, the economic value of the resource is far below its catch volume (<1 €/kg). Taking into account that the commercialization chain of kelps and other seaweeds, in general, is much shorter than other resources and their high market value when they reach the consumer (e.g., medicines, cosmetics, food), their first sale price should be higher. In this regard, the increase of seaweed producers and traders in the last years may be affecting the first sale price. In this regard, kelps, like other natural resources, require careful management to be sustainable and efficiently harvested, and all actors involved in their exploitation should make the effort to manage the resource and the ecosystem richness associated with it in sustainable ways (Frangoudes and Garineaud, 2015; Delaney et al., 2016; Chuenpagdee and Jentoft, 2018). Our observations suggest that the management of kelp and other seaweed harvesting should be reviewed in Galicia, since, in terms of ecological value and the ecosystem services they provide to humans, they should have a comparatively higher economic value. As well as its market value, considering the growth of the harvesting activities and stakeholders involved in seaweed commercialization

In this context, the support provided by the regional government seems relevant to maintaining the activity, as traditionally, the *Xunta de Galicia* has supported the fishing and aquaculture sectors in general in Galicia, which contribute to the entire regional economy, thanks to the job creation and its effect in other productive sectors (Garza-Gil et al., 2017). In the case of kelps, also their contribution to maintaining local food resources, present in the local gastronomy and restoration, is relevant. NW Spain gastronomy is known for its variety of fish and seafood (Carral et al., 2020), and many of those are caught in the kelp forests, such as the octopus, spider crab, or velvet swimming crab, as this study shows.

Fishers' perceptions and landings data also pointed out relevant fishing changes. According to fishers, in some cases, these changes resulted in less fishing or changes in fishing areas due to the movement of the species to other zones where kelp forests persist. The fishery that had shown a significant decline in landings was the octopus, one of the most important fisheries in this region (Pita et al., 2016). Interestingly, the decrease of octopus coincides with the increase of the spider crab and velvet swimming crab, which could be related to the food chain (Smith, 2003). Although the loss of kelps and the decline in fishing seem to coincide in time, this correlation is not enough to confirm that these changes are due to the loss of kelp forests. Therefore, studies aimed to address these issues are needed to determine whether the loss of kelp could be behind the decline of some commercial species (Araujo et al., 2013).

Many commercial species are still caught in areas where kelp forests were lost, although in lesser abundance. This could be attributed to the presence of other habitat-forming species that could be playing the role of the *Laminaria* spp. in this region (Piñeiro-Corbeira et al., 2022), such as the seasonal species *S.*

polyschides and/or *Cystoseira* sensu lato. According to recent studies, these species have increased their frequency of occurrence in this region in parallel to the loss of *Laminaria* spp. in the last decade (Piñeiro-Corbeira et al., 2016; Barrientos et al., 2020). In this regard, these observations invite us to consider the possibility that some commercial species may not be highly dependent on kelp forest-forming species *per se* but on habitat-forming macroalgae in general. In our study, we have considered kelp forest-forming species to be those in the order Laminariales. However, other studies use the term "kelp" more broadly, including as "kelps" other habitat-forming species such as large brown algae of the order Fucales (e.g., *Cystoseira* sensu lato) and Tilopteridales (e.g., *S. polyschides*), since they provide similar functions (Fraser, 2012; Bolton, 2016; Wernberg et al., 2019).

Conclusions

Despite the importance of kelp forests for coastal ecosystems and the communities that live from their resources, only a few studies have been carried out on the ecology of kelp forests in NW Spain as well as on their social, economic, and cultural importance (Barrientos et al., 2022a; Barrientos et al., 2022b; Piñeiro-Corbeira, et al., 2022). However, information on SSFs and their catches is not easily available (Pita et al., 2019), which makes collaborative activities essential for fisheries research and management. There are some criticisms about introducing local or traditional fishers' knowledge into regular/traditional scientific knowledge and fisheries research (Davis and Wagner, 2003) attending to different methodological and empirical questions. However, under data-poor scenarios or in data-limited locations (Roux et al., 2019), some collaborative activities, as we carried out, can be useful in building knowledge. Simple cost-effective methods can provide important baseline information on several aspects of small-scale fishing activities (Pita et al., 2019) and the status of different habitats, expanding our understanding of the environment (Berkström et al., 2019). Our study highlights the importance of these habitats for the SSFs in the area. In this regard, it would be interesting to know the level of dependence of commercial species on kelp forests as a first step to understanding how their loss will affect the SSFs. This could be a starting point for the design of management tools for the conservation of these ecosystems and their associated fisheries.

Data availability statement

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

Ethics statement

Ethical review and approval was not required for the study on human participants in accordance with the local legislation and institutional requirements. Written informed consent for participation was not required for this study in accordance with the national legislation and the institutional requirements.

Author contributions

CP-C: conceptualization, methodology, field sampling, formal analysis, visualization, project administration, and writing-original draft preparation. SB: field sampling, formal analysis, assistance in manuscript writing. RB: funding acquisition, project administration, formal analysis, assistance in manuscript writing, and supervision. RC-M: funding acquisition, conceptualization, methodology, formal analysis, visualization, assistance in manuscript writing, and supervision. All authors revised and approved the manuscript.

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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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Supplementary material

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fmars.2022.973251/full#supplementary-material

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