The role of marine stakeholders in the co-production of scientific knowledge: lessons from Galicia (NW Spain)

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Abstract
Small scale fisheries (SSF) are managed worldwide under data-poor situations. In this scenario, the use of fishers' ecological knowledge (FEK) about the local marine environment has been found useful to provide data to management, but also to foster the involvement of the fishers in the management of common pool resources. We show here that the engagement of fishers in co-management processes and the development of initiatives to collect and use the FEK in fisheries management are mutually reinforced processes. We found that the production of scientific knowledge based in the use of FEK can be very reliable. For example, in Galicia (NW Spain) the use of the FEK helped to design new marine protected areas (MPAs), manage relevant commercial and recreational fisheries, and also identify adaptive strategies for fishing fleets. FEK can help managers and policy-makers ensure more coherent and realistic management of complex marine socio-ecological systems and promote the self-regulation of the fisheries sector. The development of general frameworks to systematize the integration of FEK in the management of the fisheries is recommended.

Key Words: co-production of knowledge, traditional ecological knowledge, co-management, fisheries, Galicia (NW Spain).

Introduction

The management of small-scale fisheries (SSF), traditionally poor in scientific data, has been extensively based on the use of fishery-dependent information to perform fisheries assessments (Weeratunge *et al.*, 2014). Moreover, the involvement of scientists, managers and fishers in the collection of fishery-dependent information fosters the development of co-management models, which in turn increase the empowerment of SSF fishers and their sense of responsibility (Jacobsen *et al.*, 2012; Mora *et al.*, 2009). Local ecological knowledge (LEK) is conceived as a knowledge system derived from the continued use of an ecosystem that integrates practices and beliefs related to a sociocultural framework different from normal science. LEK differs from normal science, not so much by the type of observations that are collected, as by the way in which they are interpreted and organized. LEK complements and enriches scientific knowledge, since it increases the spatial and temporal resolution of observation, while increasing the level of detail and other novel information. Thus, fishers' ecological knowledge (FEK) about local marine environments is, in addition to a knowledge contrasted by the accumulation of information over generations, a continuously updated source of knowledge collecting the latest changes and dynamism occurred in the local marine environment. FEK should be considered not only as a history of practices, where fishers learn and transmit working techniques, but also as a history of the representation and understanding of the local environment in which they operate. In this way, FEK, in addition to being linked to practice as know-how, is also related to a conceptual network of spatial and environmental knowledge as essential or more than manual and technical culture. FEK arises from a process that presupposes an active cognitive subject in constant interaction between mental and manual work, and with its environment (field of reference and action). It is the constrictions imposed by the marine environment that trigger the fishers' need for knowledge to solve them. Consequently, FEK can be considered as a source of alternative information, complementary to traditional scientific knowledge (Agrawal, 1995; Davis and Wagner, 2003; Goldman and Schurman, 2000). Thus, FEK has huge applications and can be integrated into fisheries sciences at different levels (e.g., for marine spatial planning, fisheries management, etc.) although its true potential remains unexplored (Huntington, 2000). We hypothesize here that the involvement of fishers in co-management processes and the development of initiatives to collect and use the FEK in fisheries management are mutually reinforced processes. Therefore, we have analyzed the connections between relevant co-management procedures in Galicia (NW Spain) and initiatives that used the FEK in the production of scientific knowledge. In the end, we provide general conclusions about how to improve the use of FEK to take advantage of opportunities and cope with future challenges in fisheries management.

The fisheries management framework in Galicia

Galicia is the main fishing region of Spain, accounting for over 40% of the country's fleet, 50% of catches reported by Spanish vessels fishing in EU waters and more than 60% of total employment in fisheries-related sectors (Scientific Technical and Economic Committee for Fisheries, STECF, 2017). Therefore, many coastal populations are highly dependent on fishing activities (Freire and García-Allut, 2000; Villasante, 2012).

The Autonomous Government of Galicia (Xunta de Galicia) has been managing commercial and recreational coastal fisheries for nearly 40 years, while fisheries in external waters are managed by the Spanish Government (Jefatura del Estado de España, 1981). Management of some benthic, sedentary marine organisms is based on territorial user rights to fisheries (TURFs) (Xunta de Galicia, 2009a), but despite recent demands for more co-management by fishers' associations for some fisheries, e.g., the case of the common octopus (Pita *et al.*, 2016), most coastal fisheries are still managed by a conventional top-down approach (Macho *et al.*, 2013). Moreover, the implementation of new management measures has been limited by the lack of scientific information and statistical databases (Arnáiz, 2001; Molares and Freire, 2003; Pita *et al.*, 2017).

1. The case of marine protected areas of fishing interest of Galicia

1.1 The relevance of collective construction processes in the management of fisheries resources as common goods: the case of the marine reserve of "Os Miñarzos"

In 2002, artisanal fishers from Lira (North-central coast of Galicia) began a process to create a marine protected area (MPA) of fishing interest that conclude its formalization in April 2007, under the name of Marine Reserve of Fishing Interest "Os Miñarzos" (Xunta de Galicia, 2007) (Fig. 1).

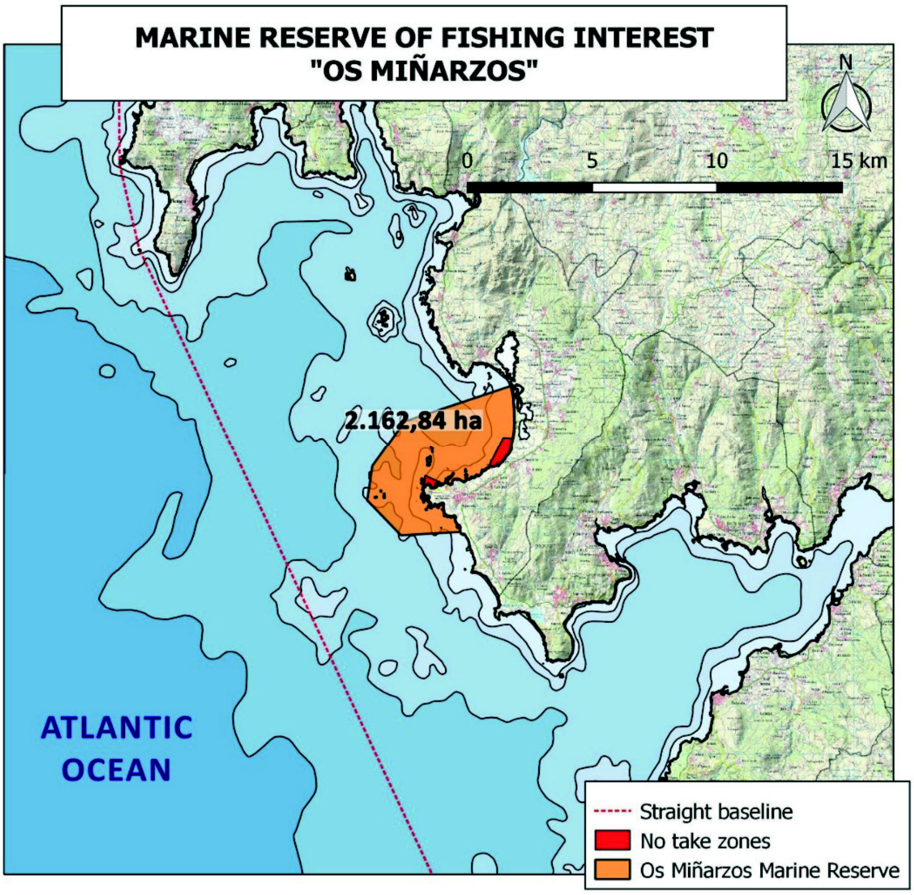

Figure 1. Location of the MPA of fishing interest "Os Miñarzos", on the North-central coast of Galicia.

Under the Fisheries Law of the Xunta de Galicia (Xunta de Galicia, 2009a), the MPAs of fishing interest are tools for the management and conservation of the marine ecosystem. The creation process of this MPA, different from other MPAs, is of interest to the scientific community and managers of the marine environment because: (1) the initiative was developed by the local fishers' community.[In the field of fishing, it is not usual for fishers to propose the creation of a MPA because they usually perceive them as a constraint to develop their fishing activities. The reason for this proposal lies in a previous process of diagnosis about the future of SSF that has led to the belief that the MPA is a solution of continuity for the local fishery sector]; (2) the fishers of this community have maintained an active participation for the five years that the process lasted until its formalization (2002-2007). The best explanation to understand this perseverance, unusual in the fishing sector, is the incentive generated by the MPA in terms of the best expectations for the future; (3) the process of design and creation of the MPA had a high participation of the local fishing sector. This orderly and inclusive participation of the local fishing sector has been facilitated by the earlier building of a strong personal and institutional trust with an external organization through previous collaboration in other projects with this community; (4) the local FEK was integrated with the scientific knowledge for the MPA design, including zoning and spatial management proposals. The local FEK proved highly relevant in this case to define the size, shape, location and management of the no-take zones; and (5) perhaps the most relevant factor in this case was a management proposal that included a governing body made up of fishers, public administration, scientists and NGOs with interests in marine space conservation. The peculiarity of this management model is that the representation of the fishing sector and of the administration was equal, although consensus constitutes the deliberation criterion of the Management Body. Thus, peer co-management is the tool that the artisanal fishing sector of this community has proposed as a formula of co-responsibility in the management of fishery resources.

Ten years after the creation of the marine reserve of "Os Miñarzos", this MPA has shown its effectiveness in several aspects. Thus, trust and collaboration between fishers and scientists has been improved, because the fishers have been providing data and participating in different monitoring programs. Furthermore, there has been a notable reduction in mistrust between the fishing sector and administration, favoring that most decisions of the Management Body have been made by consensus. Moreover, regarding the biological results, although the biological monitoring of fisheries was interrupted in 2011 due to lack of funding, it has been shown that the abundances of sessile and territorial species have been boosted (Fernández-Márquez, 2015).

In any case, this MPA has inspired other neighboring communities to propose another MPA of fishing interest on the Northern coast of Galicia (Xunta de Galicia, 2009b). Furthermore, a procedure for the extension of this MPA has been initiated in 2009 and it is currently in the final stage. The purpose is to move from the current 2 162 ha to 50 000 ha (in coastal waters), where eight fishing communities and 750 boats will be potentially benefiting (Fig. 2).

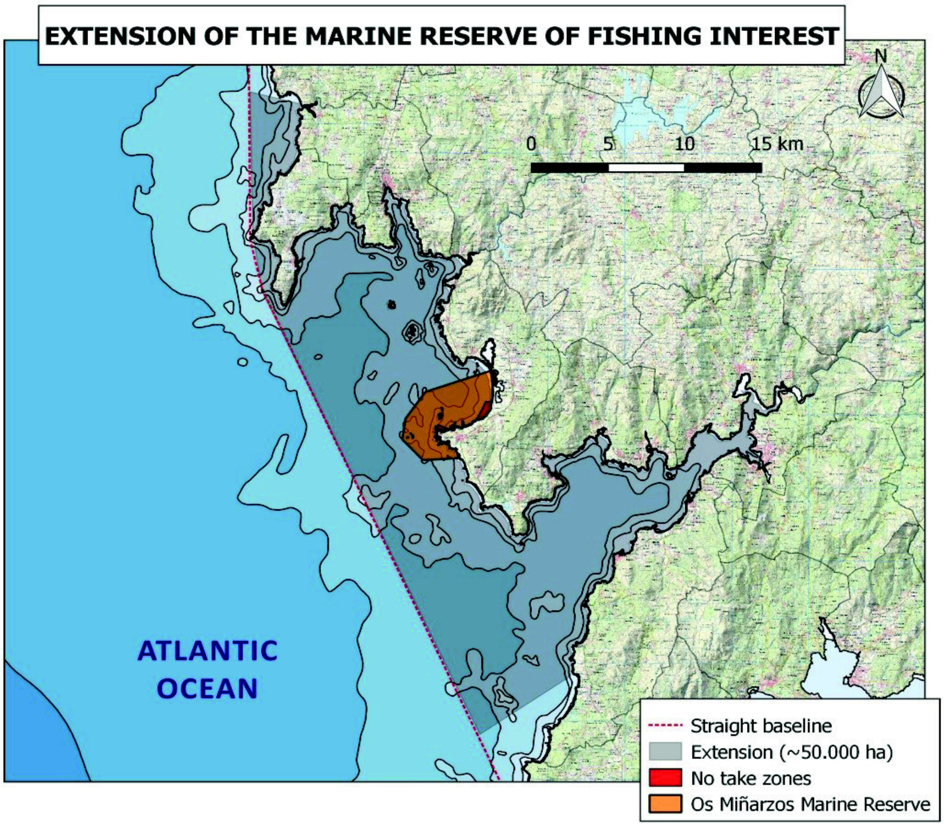

Figure 2. Proposed extension of the MPA of fishing interest "Os Miñarzos".

1.2 The role of local ecological knowledge of fishers in the design and zoning of the extension of the marine reserve of "Os Miñarzos"

In this process, a similar methodology to the original case of "Os Miñarzos" has been followed, where the use and application of FEK for the development of a habitat cartography has been a central point.

From the methodological point of view of the design for this new MPA, the changes made in comparison to other MPAs include a modified attitude of the facilitating entity towards fishers and the methodological focal points adopted. Throughout the process the entity has had a low and neutral profile. A bottom-up approach was adopted, and participative methodologies and community mediation, in an inclusive, open and flexible way were applied, checking the legitimacy of each step. A systemic and holistic approach to the social situation enabled the integration of complexity throughout the process; starting with a fragmented and divided fishing sector, the main challenges were to construct a common expectation for the future, encourage communication, for fishers to build up trust in themselves (awaken collective awareness) and with scientific and management institutions, and generate a spirit of necessary social entrepreneurship and autonomy.

In the process of creating the MPAs of "Os Miñarzos", fishers have taken part in the design and collectively defined the most suitable management plans for the sustainable fishing of common fishing resources. Proposals for regulation were more restrictive than those proposed by general laws. Furthermore, they incorporated criteria of spatial management which includes no-take zones. The process of collective construction and transformation of new management frameworks is slow and complicated, but it is necessary, not just to achieve consensus in the proposal but also to increase the fishing sectors' commitment to sustainability targets. In order to involve it in this process it was necessary to point out the advantages of constructing a model based on the general rather than individual interest. All this is boosting change, from a more competitive mentality to a more cooperative one, to the point that it is almost impossible for the fishing sector to consider going back to the previous scenario. In this specific case, local FEK have been used to identify species' essential habitats, perceptions of scarcity and abundance in the annual cycle of some species, identification of spawning and recruitment of target species, etc. (Fig. 3). Such information and data were essential to identify essential habitats to support the proposal of the extension of the MPA and the proposed zoning.

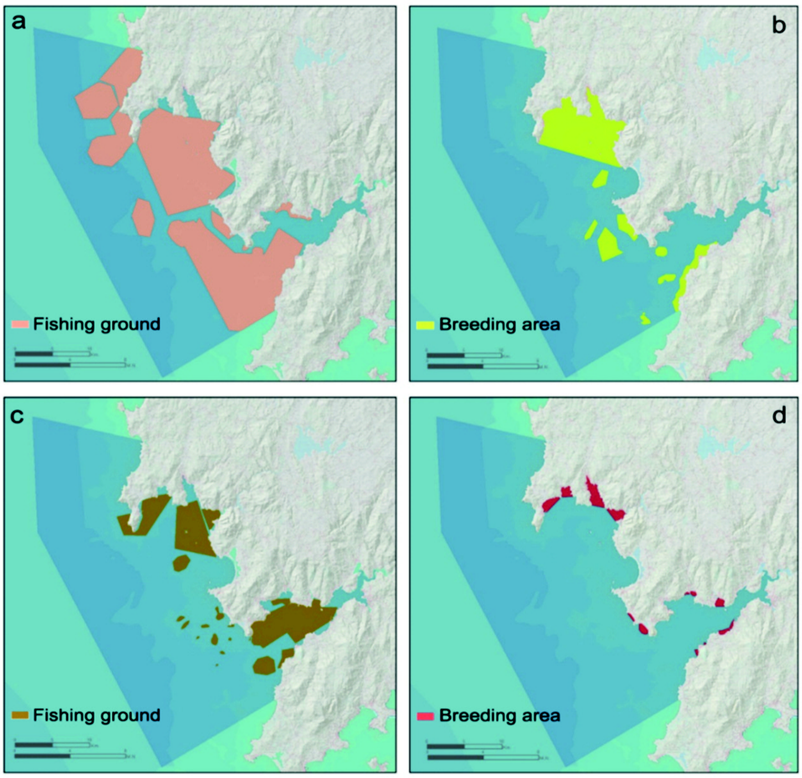

Figure 3. Map of the proposed extension of the MPA of fishing interest "Os Miñarzos" (shaded area) showing: (a) distribution of the fishing grounds of common octopus, based on local FEK; (b) distribution of the breeding areas of common octopus, based on local FEK; (c) distribution of the fishing grounds of European spider crab, based on local FEK; and (d) distribution of the breeding areas of European spider crab, based on the local FEK.

2. The case of the industrial purse seine fleet of Galicia

2.1 The role of social transformations in global fisheries

Research on marine social-ecological systems (SES) and sustainability goes with calls for deep social change (Steffen *et al*., 2015). Most of the research done on marine SES was focused on the transformations of the marine ecosystems and their ecological functions (Folke *et al*., 2011). However, it is highly difficult to address today's great challenges in global marine change and sustainability without a better understanding of how real and enduring social transformation comes about and how it can be initiated, promoted or (re)directed (Villasante *et al*., 2017).

To date there has been no systematic review of the social transformation of marine SES globally. Under the financial support of the ICES Science Fund Project "*Social transformations of marine social-ecological systems*", scientists, NGOs and the fisheries sector co-developed a new theoretical and a global database (Social Transformations Database, STD) with detailed information about the different human dimensions of the oceans and their drivers that have been documented.

Villasante *et al*. (2017) defined a social transformation in marine SES as a fundamental and critical change of values, institutions and practices of a social structure at the same time. To analyze the phenomena of social transformations in the marine arena, they examined the following core elements: (1) *values*, which refers to shared ways of living and thinking that include symbols and language (verbal and non-verbal); knowledge and beliefs (what is "good" and "bad"); (2) *institutions*, which contains the diversity of laws, regulations and costumes with competence to adopt decision on marine activities; and (3) *practices*, which includes the changes experienced by different marine activities (e.g., industrial and small-scale fisheries).

The STD provides a high-quality, descriptive, open-source information resource for students, lecturers, policy makers and researchers. The database was created based on a systematic literature review (Villasante *et al*., 2017). The authors searched for scientific papers published between 1950-2015 period in the Web of Scopus, by using the following criteria: "resilience", OR "shift", OR "change", OR "transform", OR "adapt", OR "transition", AND "marine", OR fisheries", AND "social". No geographical boundaries were stated in the selection criteria as preliminary test. Searches included all articles published until our cut-off date of 31 December 2015. These articles were then filtered at three different stages of detail, each filter excluding studies which are not related to the key words used in the search. A total of 456 articles were sourced from peer-reviewed literature and because of the filters and selection criteria employed and described above, 122 articles were reviewed fully in detail (Villasante *et al*., 2017).

Villasante *et al*. (2017) extracted from the literature review key information on twenty very common variables that helped evaluate whether social transformations could be applied to marine SES. The results of the literature review showed that the topic of social adaptation, change and transformation in marine SES attracted little attention for the scientific community in the 1950-2014 period (Villasante *et al*., 2017).

Further these topics started to receive important attention only since 2010, when a total of 10 papers were published, while the highest number of papers (15) was published in 2015.

2.2 Navigating transformations of the Spanish purse seine fishery

Based on the variables extracted from the literature review, Villasante *et al*. (2017) co-constructed with the FEK of key actors of the main industrial fisheries sector association of Galicia (ARVI) the social transformations of the Spanish purse seine fishery under the European Union (UE) Common Fisheries Policy (CFP). The fishing fleet is composed by vessels <25 m longitude and most vessels are based in Galicia. The fishing fleet mainly harvests key commercial pelagic species such as sardines, anchovies, mackerel and horse mackerel.

The social transformations of the Spanish purse seine fishery consisted in restructuring the fisheries sector, changing in the harvested species and diversifying the seafood markets over the last 25 years (Table 1). These changes are considered "*undesirable*" due to the lack of quotas and the application of the CFP, which at the national level is adopted by the Spanish Government. The implementation of the CFP to the fleet generated losses of fishing vessels, catches and employment in Galician coastal communities, but also lack to achieve key United Nations Sustainable Development Goals (SDG). This represents a valuable contribution to achieving key sustainable development goals, specifically by contributing to economic growth (SDG 2.3), employment growth (SDG 8.1), primary producer productivity (SDG 8.5), and gender equality (SDG 5.1).

Table 1. Source: Social Transformations Database of the ICES Science Fund Project. Main characteristics of the social transformations of the Spanish purse seine fishery.

Drivers	Impacts on fisheries sector	Impacts on human well-being	Adaptive strategies
-Change in the fisheries management system (from national quota to the TAC system)	-Reduction of fishing vessels	-Loss of seafood products for human consumption	-New species to compensate (mackerel)
-Lack of TAC/quota	-Reduction of catches -Loss of employments in coastal zones -Knock-on effects on the rest of the economy	-Loss of cultural ecosystem services	-Development of annual production and commercialization plans

Due to the lack of opportunities to modify the CFP, the adaptive strategies developed by the Galician fisheries sector have been focused on harvesting other commercial species and the development of annual production and commercialization plans to promote the self-regulation of the fisheries sector. The revitalization of the purse seine fleet would help avoid the socio-economic consequences of past mismanagement and generate new growth opportunities not only for the fisheries sector but also for the canned industry in key Galician coastal communities.

3. The use of the fishers' ecological knowledge, cost-effective tools and participatory models in fisheries management

3.1 The case of the common octopus trap fishery in the Ría of Arousa

Spain is among the largest consumers and importers of octopus (FAO, 2014), and Galicia is the Spanish region in which this species has greater economic and social relevance (Cornide, 1788; Cunqueiro, 1973). However, the management of coastal common octopus in Galicia generates many disagreements between fishers and policy makers (Pita *et al*., 2016). To improve this management we successfully used the FEK and cost-effective monitoring techniques based on participatory models developed with the participation of the main association of small-scale fishers of Galicia (*Federación Galega de Confrarías de Pescadores*, FGCP). In our study, we used FEK to obtain maps with the distribution of the fishing grounds of common octopus in the Ría of Arousa (central coast of Galicia), while GPS data-loggers and log-books were used to monitor the activity of vessels fishing octopus with traps to estimate the distribution of the intensity of the fishing effort and of catches per unit of effort (CPUE). Following Pita and Muiño (2014), key octopus fishers sketched the location of the octopus fishing areas on maps; this information was included into independent layers in a GIS, and finally added to achieve a single layer in which the zones where two or more fishers agreed on the distribution of octopus fishing grounds were added. In our study, 174 km^2 of octopus fishing grounds, mainly distributed in the mid and outer parts of the Ría of Arousa (Fig. 4a), were identified.

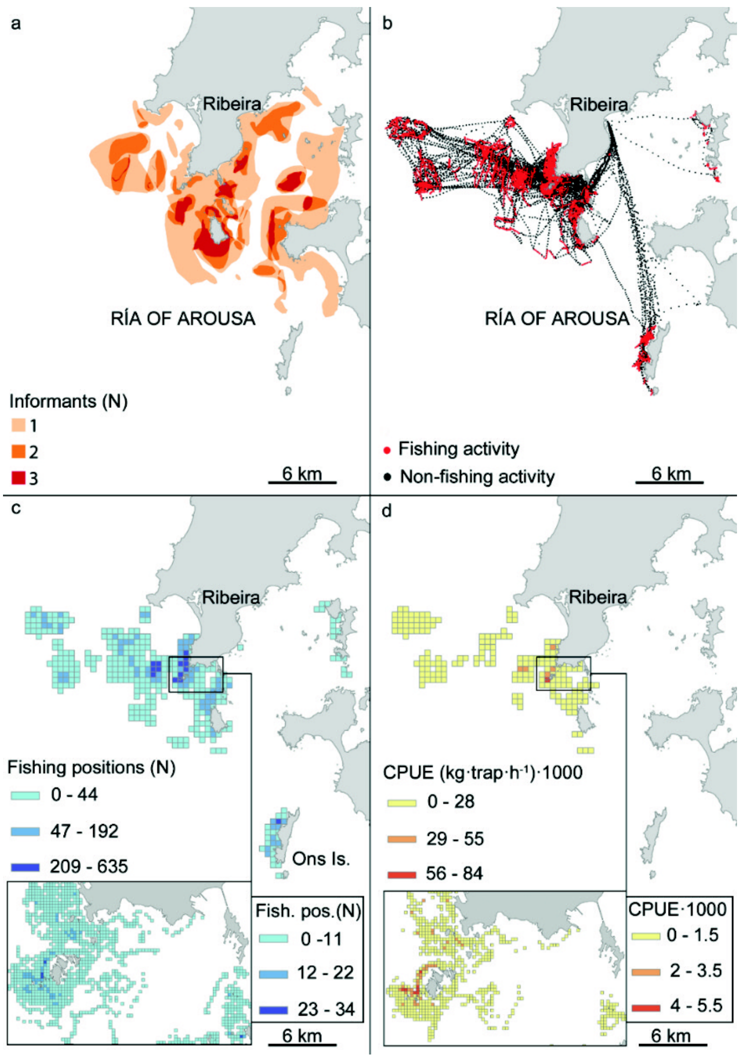

Figure 4. Source: Pita *et al*. (2016). Map of the study area in the Ría de Arousa showing: (a) distribution of the fishing grounds of common octopus, based on the FEK. The number of informants for each of the identified areas is indicated; (b) distribution of the records stored in GPS data-loggers carried on the vessels. Based on analyses of vessels' speed, the fishing activities and non-fishing activities have been distinguished; (c) estimated number of fishing positions for common octopus obtained in on-board GPS data-loggers by 500×500 m cells. In detail, fishing positions by 50×50 m cells; and (d) estimated CPUE (kg·trap^{-1}·h^{-1}·1000) of common octopus obtained in on-board GPS data-loggers by 500×500 m cells. In detail, CPUE by 50×50 m cells.

On the other hand, fishing vessels participated in a monitoring program, carrying low-cost GPS data-loggers that recorded the position of the vessels and provided information about catches in fishing log-books (Pita *et al*., 2016). Fishing and non-fishing activities were differentiated by Pita *et al*. (2016) through the analysis of the speed of the vessels, and the CPUE of each of the fishing hauls was distributed equally among their GPS positions (Fig. 4b). Most of the fishing effort was exerted in the outer part of the Ría of Arousa (Fig. 4c), also the most valuable fishing grounds in terms of CPUE (Fig. 5d) (Pita *et al*., 2016).

Pita *et al*. (2016) showed that the results of the fisheries monitoring were coincident with the FEK-based cartography because most of the fishing positions (70%) were located within the fishing grounds indicated by the fishers (Fig. 4a-c).

3.2 The case of the squid and cuttlefish fishery of the Ría of Vigo

Despite their ecological, social and economic relevance (Hyder *et al*., 2018), marine recreational fisheries (MRF) have been little studied in Southern Europe (Pita *et al*., 2017). Thus, MRF share with artisanal fisheries a strong lack of valid data for fisheries management Europe (Lloret *et al*., 2016; Pita *et al*., 2017).

To test new methods and tools to provide information about MRF, Palas *et al*. (2017) demonstrated that a combination of the use of FEK and low-cost GPS data-loggers provide data that can be also successfully used in the management of coastal ecosystems. In their study, Palas *et al*. (2017) performed interviews with key local informants selected among recreational fishers operating in the Ría of Vigo (South of Galicia), targeting squid and cuttlefish. In the interviews, ecological, social and economic information was collected, and following Pita and Muiño (2014) fishers sketched their fishing grounds for each species (Palas *et al*., 2017). Moreover, following Pita *et al*. (2016) fishing logbooks and GPS data-loggers were used to monitor this recreational fleet (Palas *et al*., 2017).

Palas *et al*. (2017) showed that the access points for shore anglers are in the port facilities, and that boat anglers target squid and cuttlefish over a fishing area of 30 km^2.

Moreover, the results of the fisheries monitoring (Fig. 5) were coincident with the cartography of the fishing grounds (Palas *et al*., 2017) who showed that the intensity of the fishing effort was greater around the mussel farms in the North of the study area. Also, the authors showed that the productivity of the fishing grounds of squid and cuttlefish varied with their location in the study area: catches of squid were higher in the outer part of the Ría, while catches of cuttlefish were higher in the innermost fishing grounds (Fig. 5).

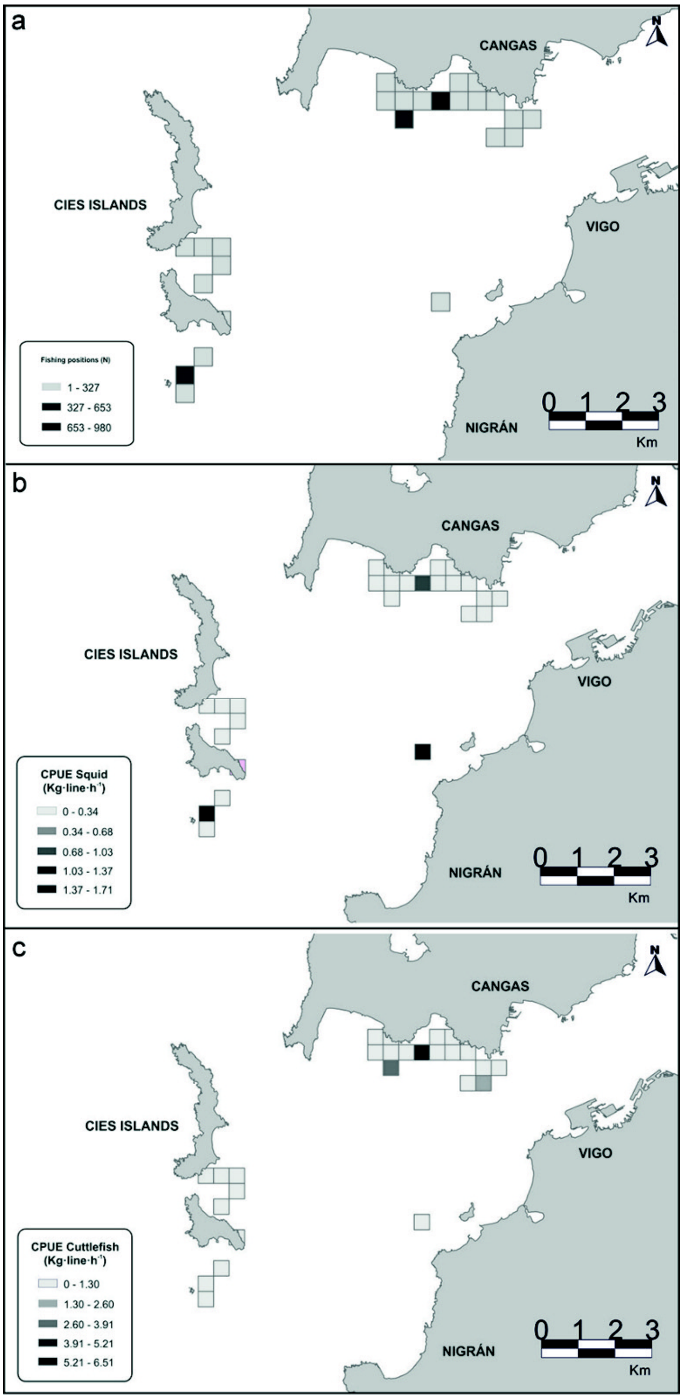

Figure 5. Source: Palas *et al*. (2017). (a) Distribution of fishing effort as the number of fishing positions for squid and cuttlefish obtained in on-board GPS data-loggers by 500×500 m cells , and estimated CPUE (kg· $line^{-1}$· h^{-1}) of squid (b) and cuttlefish (c) obtained in on- board GPS data-loggers by 500×500 m cells.

3.3 Evaluating the use of the Fishers Ecological Knowledge: the case of the Galician purse seine fleet in the Ría of Arousa

There are few studies that analyze the reliability of information based in the use of FEK. However, the results of FEK-based cartographies of fishing grounds have been found highly coincident with fisheries monitoring in the same areas (Palas *et al*., 2017; Pita *et al*., 2016). In this sense, Pita *et al*. (2014) compared the results of a FEK-based fishing ground cartography and the results of a fishery monitoring performed by the same vessels in the Ría of Arousa, showing that fishers tended to fish in the same areas of the FEK cartography, especially when GPS positions were associated with catches (Table 2).

Table 2. Source: Pita *et al*. (2014). Coincidences of the GPS positions with the FEK-based cartography (for the nine-coincident species; 0 = out of the cartography, 5 = 5 fishers coincided).

Species	Coincidences within layers of a FEK-based cartography											
	Total						Reported catches					
	0	1	2	3	4	5	0	1	2	3	4	5
Ammodytidae	2063	41	6	0	0	0	39	0	0	0	0	0
Diplodus sargus	1149	292	261	337	69	2	24	0	2	24	9	0
Engraulis encrasicolus	0	0	0	0	0	0	0	0	0	0	0	0
Pagellus bogaraveo	2035	75	0	0	0	0	15	0	0	0	0	0
Sardina pilchardus	671	1439	0	0	0	0	20	46	0	0	0	0
Scomber scombrus	364	1303	443	0	0	0	124	200	49	0	0	0
Spondyliosoma cantharus	1956	154	0	0	0	0	214	10	0	0	0	0
Trachurus trachurus	398	164	833	182	533	0	251	125	685	168	373	0

In their study Pita *et al*. (2014) used logistic additive multiple regression models (GAM) (Hastie and Tibshirani, 1990) to analyze the relationships between the different layers of a FEK-based fishing ground cartography and the positions of the fishing hauls obtained in a fishery monitoring program on a purse seine multispecies fishery. Pita *et al*. (2014) found a clear relationship ($P<2e^{-16}$) in the case of Atlantic horse mackerel *Trachurus trachurus*, the most captured species, with a very detailed FEK-based cartography with many overlaps between informants (Fig. 6).

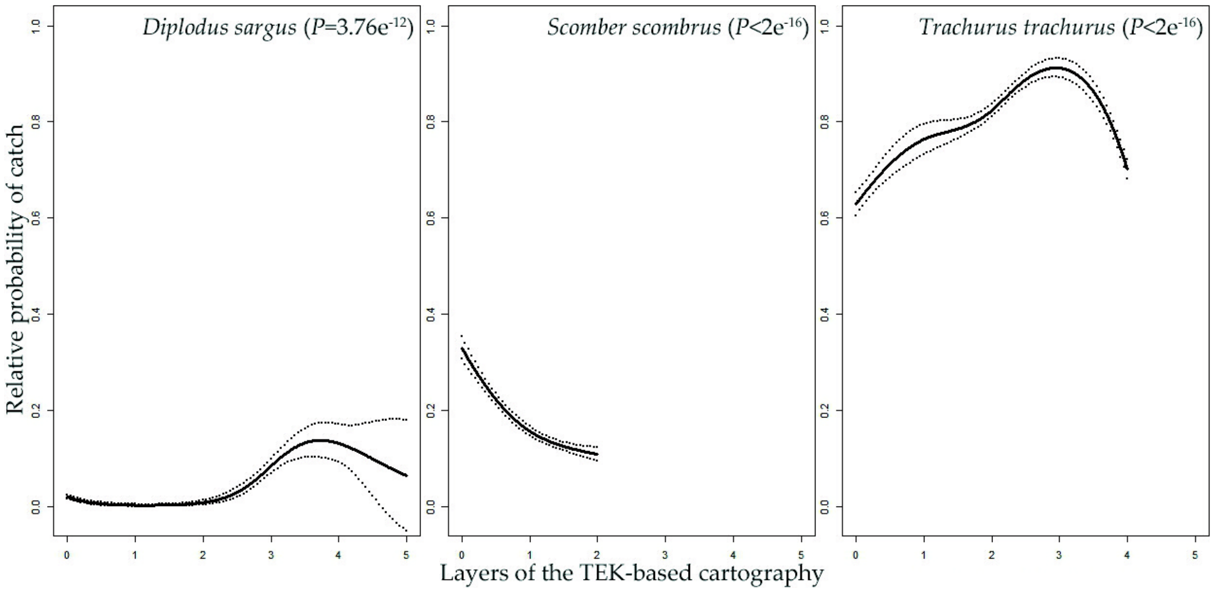

Figure 6. Source: Pita *et al*. (2014). Relationships between the relative probability of catch of the purse seiners and the layers of the FEK cartography by species (0=out of the cartography, 5=5 fishers coincided), obtained by GAM. Models with non-significant effects were not represented.

4. Conclusions

4.1 Lessons learned about the involvement of marine stakeholders in the co-production of scientific knowledge and in the fisheries management

The process of collective construction and transformation of pre-existing management schemes is slow, complex and complicated. Moving from traditional top-down management to frameworks that includes fishers in the management of common resources must overcome powerful inertias. However, the integration of local FEK with the existing scientific knowledge has fostered relevant bottom-up management proposals in Galicia. These initiatives included the use of FEK to define the size, shape, location and management of new MPAs, the use of FEK in combination with cost-effective monitoring techniques based on participatory models developed with the fishers to provide relevant information for the management of commercial and recreational fisheries, and the use of FEK to identify social adaptive strategies developed by the fishers to cope with emergent threats to their activity. The processes of coproduction of scientific knowledge and co-management are facilitated by the progressive strengthening of pre-existing relations of trust based on mutual knowledge among fishers, scientists, managers and policy-makers, and generated through previous experiences.

4.2 Opportunities and future challenges

The information based in the use of FEK was found highly reliable. Thus, by integrating local FEK into scientific knowledge in the management proposals, the fishers' vision of sustainability is also incorporated and more coherent and realistic management measures are legitimated and guaranteed. FEK provides not only information about the local marine environment, but also about the activity of the fishers, which can be used to manage complex SES. Therefore, the use of FEK to identify adaptive strategies developed by the fishers to cope with emergent threats to their activity can be used to evaluate different future alternative scenarios and to promote the self-regulation of the fisheries sector. The development of general schemes that help systematize the orderly integration of this knowledge should be developed in the future.

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