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Elevated participation in co-management increases the willingness of stalked barnacle harvesters to adopt highly restrictive and spatially explicit management strategies

Katja J. Geiger [a,b,1,*], Antonella Rivera [c], Alba Aguión [d,e], Marine Barbier [f], Teresa Cruz [g], Susana Fandiño [h], Lucía García-Flórez [i], Gonzalo Macho [d,2], Francisco Neves [g], Nélia Penteado [g], Paloma Peón Torre [i], Eric Thiébaut [j], Elsa Vázquez [d], José Luis Acuña [a,1,**]

[a] Departamento de Biología de Organismos y Sistemas, Universidad de Oviedo, Oviedo 33071, Spain
[b] Tragsatec, Calle Nava 18, Oviedo 33006, Spain
[c] The Coral Reef Alliance, 1330 Broadway, Suite 600, Oakland, CA 94612, United States
[d] Centro de Investigación Mariña and Departamento de Ecoloxía e Bioloxía Animal, Facultade de Ciencias do Mar, Universidade de Vigo, Vigo 36310, Spain
[e] Coasts and Commons Co-Lab, Nicholas School of the Environment, Duke University, United States
[f] Comité Régional des Pèches Maritimes et des Elevages Marins de Bretagne, France
[g] MARE — Marine and Environmental Sciences Centre/ ARNET - Aquatic Research Network, Laboratório de Ciências do Mar, Departamento de Biologia, Escola de Ciências e Tecnologia, Universidade de Évora, Évora 7002–554, Portugal
[h] Xunta de Galicia, Consellería do Mar, Xefatura Territorial da Coruña, Calle Ramón y Cajal nº 1, 5ª planta, A Coruña, Spain
[i] CEP - Centro de Experimentación Pesquera, Avenida Príncipe de Asturias, Gijón 33212, Spain
[j] Sorbonne Université, CNRS, Station Biologique de Roscoff, UMR7144, Adaptation et Diversité en Milieu Marin, Place Georges Teissier, CS90074, Roscoff Cedex 29688, France

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ABSTRACT

Ensuring the sustainability of European stalked barnacle fisheries requires effective management strategies. Insights into the experience of resource users with different management strategies can help to assess their success. To explore the opinion of the harvesters on the management of local fisheries, we conducted a multi-regional survey in Spain, Portugal and France with varying degrees of co-management. We analysed their responses using a multinomial logistic regression to understand what drove the observed differences. No single optimal strategy to achieve sustainability emerged, and the analysis revealed that geographic region was the most significant variable explaining the preferences of harvester. In less developed co-management systems they favored general input and output restrictions and expressed a desire for greater involvement in co-management processes. Conversely, in highly developed co-management systems with Territorial User Rights for Fishers (TURFs) they preferred the most restrictive and spatially explicit management strategies, such as implementing harvest bans and establishing marine reserves. These preferences indicate that harvesters in TURF-based systems exhibit a high level of stewardship and commitment to sustainable resource management. Moreover, our results indicate that the majority of harvesters in the regions in Portugal and France, areas with less developed co-management, are willing to make changes to current management strategies, reflecting their awareness of the need for improvement. To enhance the development of sustainable management practices across the distributional range of fishery resources, management strategies do not only need to be tailored to each region's particular practices, needs, and characteristics, but also consider the readiness of resource users for specific strategies.

* Corresponding author at: Departamento de Biología de Organismos y Sistemas, Universidad de Oviedo, Oviedo 33071, Spain.
** Corresponding author.
E-mail addresses: kgeiger@tragsa.es (K.J. Geiger), acuna@uniovi.es (J.L. Acuña).
[1] Current address: Tragsatec, Calle Nava 18, 33006 Oviedo, Asturias, Spain.
[2] Current address: Fisheries Consultant, Fishermańs Cove, Mahé, Seychelles.

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1. Introduction

Small-scale fisheries (SSFs) in Europe have traditionally received less research effort than large-scale fisheries, despite their social importance as an integral part of the European coastal zone (Guyader et al., 2013). SSFs are not only significant in terms of employment and local economy (García-de-la-Fuente et al., 2016) but also represent the cultural identity and heritage of many coastal communities (Chuenpagdee, 2020). Regardless, however, the social and economic contribution of SSFs to societal well-being has generally been underestimated. SSFs enable people to maintain traditional livelihoods and promote social stability through their attachment to their territory (Guyader et al., 2013). Since 2016, the European Common Fisheries Policy (CFP,2013) has made efforts to improve SSFs management across Europe by prioritising the promotion of efficient management of SSFs in Europe. One approach to improve SSFs management is to identify successful practices and to carefully adapt them to the local context of other SSFs (Geiger et al., 2022).

It was estimated that around 65 % of the total marine SSFs catch lacks formal devolution of rights, which means that fishers have no management rights, no exclusion rights and no transferability rights (FAO, 2023). This historical failure to include resource users in meaningful decision-making was identified as one of the causes of the worldwide fisheries crisis (Pita et al., 2010). Hence, the human dimension is a key component for successful fisheries management and needs to be addressed (Jentoft and McCay, 1995; Kaplan and McCay, 2004) to help design policies that not only protect the resource but also cause less conflict, inspire higher compliance and minimise the costs associated with resource protection (Marshall, 2007). However, there is a growing understanding of the urgency to incorporate resource users in management processes, not only for effective management but also for achieving the goals outlined in the 2030 Agenda for sustainable development (FAO, 2023). Including resource users in the decision-making helps to establish trust, increase stakeholders' responsibility and accountability, promote the legitimacy and acceptance of management practices and decisions, and contribute to more effective enforcement of rules and regulations by increasing the likelihood of compliance (Perez de Oliveira, 2013; Pita et al., 2010). Particularly, user compliance plays a fundamental role in the effectiveness of implemented management (Hatcher and Pascoe, 2006; Oyanedel et al., 2020). Understanding the perception of resource users regarding the legitimacy of management strategies and their willingness to adopt new strategies helps predict compliance levels (Oyanedel et al., 2020). Hence, including users' experience, knowledge and perceptions of management strategies can be of great value in evaluating their effectiveness (Bennett, 2016).

The European stalked barnacle fishery presents a unique opportunity to investigate the perception harvesters have on the effectiveness of fisheries management practices in Spain, Portugal and France, because stalked barnacle harvest is practised very similarly among these countries, but the co-management systems and the social-economic importance of the resource vary significantly (Geiger et al. 2022, see https://www.youtube.com/watch?v=Y3CQqsu5O2w). The stalked barnacle *Pollicipes pollicipes* (Gmelin, 1791 [in Gmelin, 1788–1792]) is a sessile cirripede that grows on very exposed rocky shores along the Eastern Atlantic arc, from Senegal up to the south-western coast of the UK (Cruz et al., 2022). Throughout the Iberian Peninsula, stalked barnacles have a high cultural and economic value (Cruz et al., 2015; Molares and Freire, 2003; Rivera et al., 2014; Sousa et al., 2020). In Spain and Portugal this species is not only appreciated as a seafood delicacy, but it is also the most important fishery in the rocky intertidal (Aguión et al. 2021; Cruz et al. 2022). In Spain stalked barnacles reach up to 250-350€/kg (Cruz et al. 2022), with a mean value of 15-32.5 €/kg (Table 1), representing the highest market prices for this species among the European market (Table 1). In Portugal market prices are on an intermediate range (14-23 €/kg), while in France market prices are the lowest among the European market, ranging between 5-8 €/kg (Table 1). In the French cuisine, stalked barnacles have never been appreciated as much as other seafood species (e.g. bivalves, gastropods and decapods), which impeded the development of a more significant stalked barnacle fishery in France (Cruz et al. 2022). Nevertheless, in Brittany (France), this species is harvested extensively, although most catches are then exported to the Iberian Peninsula, where they never reach as high prices as the locally fished barnacles (Cruz et al. 2022). The management of this fishery also varies greatly among these regions, ranging from less organised and governed at large scales (>100 km) to highly participatory systems that are co-managed at small spatial scales (10 s km and less; Aguión et al., 2021). Likewise, the access to the fishery varies, with some regions including recreational harvesters, while in others the fishery is limited to professionals. In regions with advanced co-management systems, spatially-explicit management tools, such as Territorial User Rights for Fishers (TURFs) and rotation of areas have been implemented and shown to be particularly successful tools to manage stalked barnacle stocks given the sessile nature of this species (Aguión et al., 2021; Rivera et al., 2014, 2017). TURFs furthermore facilitate better surveillance and control against poachers, which can operate in regional, inter-regional and international realms and have been identified as a common threat to the stalked barnacle fisheries in Europe (Geiger et al. 2022).

The objective of our study is to investigate the perceptions stalked barnacle harvesters have regarding the effectiveness of current management strategies and their preferences for future strategies to achieve sustainability in the fishery in the six study regions. By examining stalked barnacle fisheries with varying levels of co-management development, our results provide unique insights into harvesters' priorities for promoting sustainable management across different co-management systems.

2. Materials and method

2.1. Study area and socio-economic characterization of the fisheries

The study took place in six regions, including three countries, along the Atlantic Arc: Morbihan in Brittany (France), Asturias-East, Asturias-West and Galicia (Spain), the Reserva Natural das Berlengas (RNB; natural reserve of Berlengas, Portugal) and the Parque Natural do Sudoeste Alentejano e Costa Vicentina (PNSACV; natural park in Alentejo-Algarve, Portugal) (Fig. 1). These regions vary considerably in geographic size (i.e. length of the coast - Fig. 1) and socio-economic importance (Table 1). Of the included regions, Galicia is not only the region with the longest coast line, but also presents by far the biggest stalked barnacle fishery in Europe with 1250 active harvesters in 2020, a landing volume of 325 t and value of 7.640.000 € per year on average. Morbihan presents the second longest coast line of the six regions, but in socio-economic terms, this fishery is much smaller than the Galician stalked barnacle fishery, as it only counts with 10 active professional harvesters (in 2020). Nevertheless, yearly landings in Morbihan are around 50 t, which represent approximately 90 % of all the stalked barnacle landings in Brittany (Aguión et al. 2021; Cruz et al. 2022). Due to the generally lower prices that these stalked barnacles achieve on the French and the Spanish market, the landing value is only 325.000 € per year. Although the annual landing volume in Asturias-West, with 44 t, is comparable to that of Morbihan, the fishery has a substantially higher socio-economic significance, supporting 216 active harvesters and generating an annual landing value of approximately 1.330.000 €. Although Asturias-East and Asturias-West have very similar lengths of coast, their fisheries differ considerably in size, as both, the number of active harvesters in Asturias-East, 54, and the landings per year, 11 t, are four times lower than in Asturias-West. The landing value, with 190.000 € per year even is seven times lower in Asturias-East compared to that of Asturias-West. Geographically, RNB in Portugal presents the smallest of the six study regions. Nevertheless, the size of the fishery is very similar to that in Asturias-East, with 40 active harvesters, and a yearly landing

Table 1
Socio-economic data of the study regions: numbers of professional licences and active harvesters, landings (volume and value), stalked barnacle prices (average values for the period 2013–2016 are given). *Information from personal communication with fisheries managers. The "- " symbol indicates that the data was unavailable for the fishery. List of the stalked barnacle fishery management strategies implemented in the six regions based on information from Aguión et al. (2021) and Cruz et al. (2022), with √ indicating management strategies that are generally present and X indicating those that are present as an exception in the region, while empty space indicates the management strategy is not present.

		Morbihan	Asturias-East	Asturias-West	Galicia	RNB	PNSACV
Nº of active harvesters		10*	54*	216*	1250*	40	80
Nº of professional licences		21*	100*	220*	1341*	40	80
Landing volume (t per year)		50	11	44	325	16	-
Landing value (thousand € per year)		325	190	1330	7640	275	-
Stalked barnacle price (€/kg)		5–8	15–18	23–32.5	23.5	23	14
Co-management	co-management	√	√	√ in law	√ in law	√ in law[a]	√
	harvest ban	√		√	√	√	√
Spatial restrictions	marine reserve	√				√	√
	TURF		[b]	√	√		
	restricted harvest time	√	√	√	√		
Temporal restrictions	harvest season	√	√	√[c]	X[d]	√	√
	harvest area rotation			X[c]	√[e]		
	minimum barnacle size (rostro-carinal length in mm)		√	√	√	√	√
Output restrictions	individual quota (kg/person/day)	√	√	√	√	√	√
	community quota (kg/rock/year)			√[d]	X[f]		
References		pers. Communication M. Barbier CRPMEM (Comité régional des Pêches Maritimes et des Élevages Marins de Bretagne) 3. March 2020; Aguión et al. (2021)	pers. Communication P. Péon (Centro de Experimento Pesquero) 1. December 2021; Aguión et al. (2021)	pers. Communication P. Péon (Centro de Experimentación Pesquera, Dirección General de Pesca Marítima) 1. December 2021; Aguión et al. (2021)	pers. Communication Susana Fandiño (Xunta de Galicia, Consellería do Mar) 24. April 2020; Aguión et al. (2021)	Aguión et al. (2021); Cruz et al. (2022)	Aguión et al. (2021); Cruz et al. (2022)

[a] Two TURFs have been implemented in Februrary 2023 - after the survey period (2020)
[b] Two TURFs have been implemented in Februrary 2023 - after the survey period (2020)
[c] The TURF in Cabo Peñas is an exception, here harvesters can work throughout the year by rotating harvest areas
[d] In some TURFs.
[e] In most, but not all TURFs.
[f] The TURF in Cangas, is an exception, here community quotas are used in the all-for-all strategy.

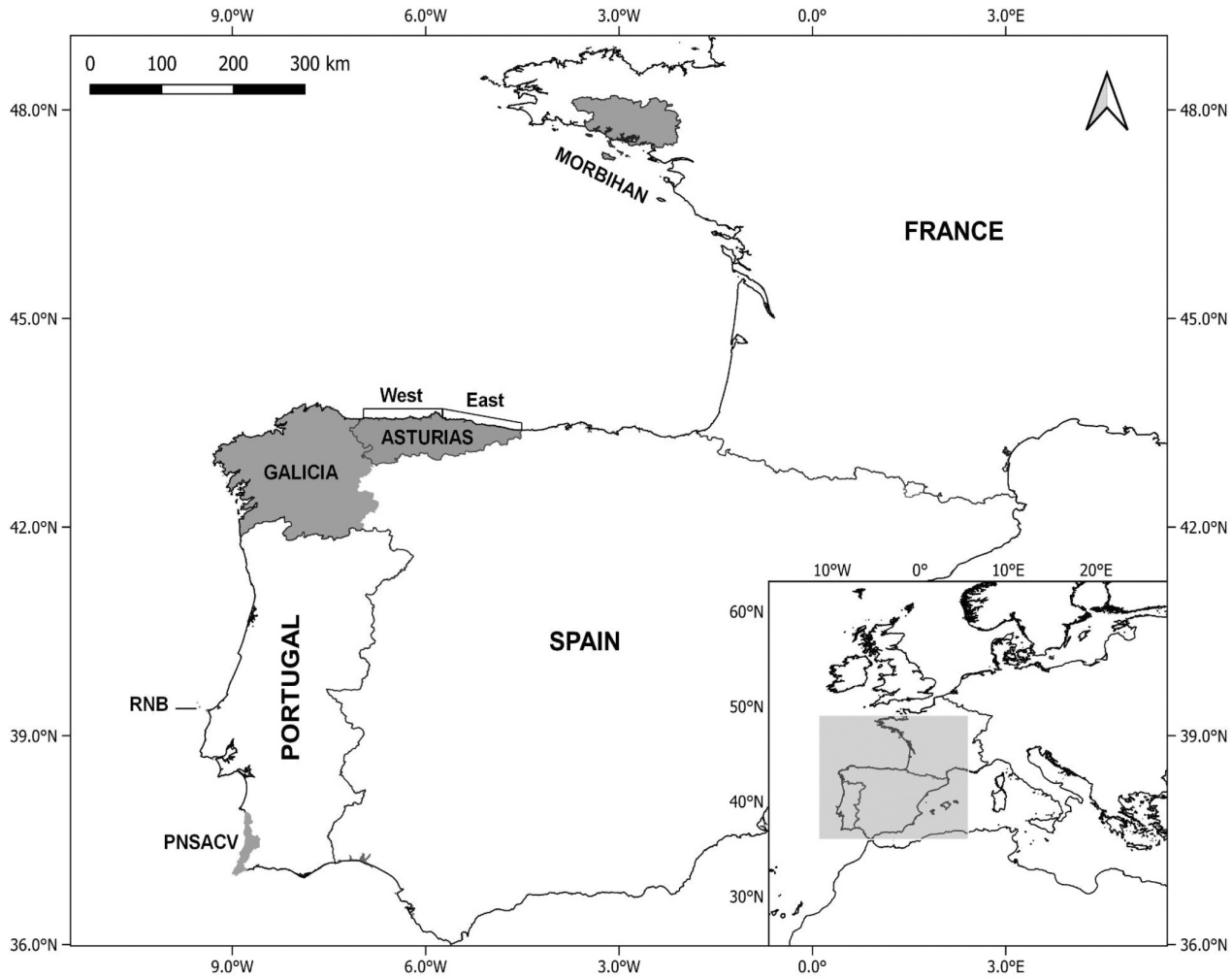

Fig. 1. The map displays regions where the survey took place: Morbihan in Brittany, France; the Spanish regions of Asturias (East and West) and Galicia; and the Reserva Natural das Berlengas (RNB) and the Parque Natural do Sudoeste Alentejano e Costa Vicentina (PNSACV) in Portugal.

of 12 t. Given the somewhat higher market prices, the landing value is higher in RNB than in Asturias-East, with 275.000 € per year. The coastline of PNSACV is the second shortest of the study regions and the fishery counts with 80 professional harvesters. The socio-economic importance of the fishery in PNSACV, however, could not be compared with the other study regions, due to the lack of data on landing volume and value.

2.2. Regional management

The management of stalked barnacle fisheries varies among the regions and can be classified according to the implementation level of four essential governance elements (Aguión et al., 2021). These elements include the spatial scale of management, level of co-management, harvesters' participation, and access structure. It was found that the level of implementation of these governance elements varies across regions, impacting the overall sustainability of the fisheries (Aguión et al., 2021).

We considered the following (co-)management levels: 1) High level co-management – consultative-cooperative regime and interactive or functional participation of users (see Aguión et al. 2021);2) Mid-level co-management – consultative or instructive-consultative regime with participation of users on functional or consultation level (see Aguión et al. 2021, scale modified from Sen & Nielsen 1996);3) Incipient co-management – existing mechanism for the administration to consult users, but all decisions are taken by the administration (Cruz et al. 2022); 4) Top-down – regulations are imposed by the administration without a mechanism for consultation of users (Cruz et al. 2022).

In Galicia and Asturias-West the fishery presents the highest implementation level, managed at a detailed spatial scale (< 1 km) through an exclusive access structure provided by Territorial User Rights for Fishing (TURFs), with consultative-cooperative co-management implemented in both regions since 1992 (Macho et al., 2013; Rivera et al., 2014) and a high level of participation from harvesters (Aguión et al., 2021). Harvesters belong to fishers guilds, known as *cofradías* in Spanish, with specific associations for stalked barnacle harvesters within these *cofradías* in Galicia. In both Galicia and Asturias-West, TURFs are granted to the *cofradías*, assigning exclusive access over an area and its resource to a limited number of professional harvesters. Responsibilities and the decision-making power over the resource are shared between the *cofradía* and the regional fisheries authorities, allowing harvesters to participate actively in the co-management (Macho et al., 2013; Rivera et al., 2014). Harvesters propose yearly management plans with detailed temporal and spatial indications of harvesting effort (*e.g.* rotational harvesting schemes or temporal ban areas) at scales ranging from kilometres to a few metres (Aguión et al., 2021). The management plans must then be approved by the regional fisheries administration and

made publicly available for consultation. Surveillance is carried out by regional and TURF guards, and in some cases in Galicia, by harvesters and National Park guards (Geiger et al., 2022).

RNB is a small archipelago located approximately 15 km from the Portuguese mainland and presents an intermediate implementation level, where the management operates on a small scale, due to its geographic setting. In contrast to the rest of Portugal, the access the stalked barnacle fishery in RNB is limited to professional harvesters. Given its geographic particularity and the limited number of licences for professional harvesters, the management of the fishery operates similarly to a TURF (Geiger et al., 2022). In 2021, the RNB stalked barnacle fishery underwent a transition to co-management by law (Portaria n.º 309/2021), representing the first legally agreed co-management case for the Portuguese fisheries (Cruz et al., 2022). The transition has resulted in an increased level of co-management with greater participation by harvesters, which likely will continue to increase in the near future (Cruz et al., 2022). Challenges to the fishery are poaching and poor surveillance (Sousa et al. 2020, Geiger et al. 2022).

In the other three regions, Asturias-East, Morbihan and PNSACV management is practised on a significantly larger spatial scale (> 100 km). When the surveys for this study were conducted, the management of the stalked barnacle fishery in Asturias-East was still a top-down or incipient co-management implemented in 1992, which included only a minimal exchange of information between the regional government and users. The fishery was based merely on general management measures that regulate the access, harvest season, and other strategies (see Table 1). The entire decision-making power over the resource, though, laid in hands of the regional fishery authority. In February 2023, however, two TURFs were created, following the example of TURFs in Asturias-West, reducing the spatial scale of the management area and allowing for a more participatory co-management. The number of licences for professional harvesters is limited in all regions, but, in contrast to all other study regions, in Morbihan and PNSACV recreational harvesting is allowed. The current management in PNSACV, an incipient co-management (Cruz et al. 2022), was implemented in 2006 and last modified in 2011 (Sousa et al., 2013). Despite the existence of mechanisms to consult with users, all decisions are taken by the government (Aguión et al., 2021). The identified challenges that the fishery in the PNSACV faces are: excessive exploitation, poaching, unorganized harvesting, lack of association and union among fishers, and insufficient surveillance (Cruz et al. 2022). In Morbihan, the current management was implemented in 2007 with last changes made in 2016. Here, the co-management is informally agreed upon, with unofficial representatives of harvesters proposing various regulations such as the maximum number of licences and individual harvest quotas. These proposals must then be approved by the regional fisheries committee (Comité Régional des Pêches Maritimes et des Elevages Marins de Bretagne) and validated by the French authorities, i.e. the Préfecture Maritime. Although fishers here can harvest large amounts of barnacles per day (120kg), the highest in any stalked barnacle fishery, most landings are exported to Spain and Portugal, due to the lack of a local market (Cruz et al. 2022). Another challenge is trans-national poaching, from France to Spain, incentivized by the strong link with Spanish markets and weak surveillance and control mechanisms (Geiger et al. 2022).

2.3. Implemented management strategies

In our study, we focused on ten management strategies that are considered the primary strategies implemented in various regions (Table 1). This selection of strategies, as well as the terms used and defined below, were based on previous studies (e.g. Sousa et al. 2013; Aguión et al. 2021), on the review by Cruz et al. (2022) and on discussions held among scientists from the various regions as part of the PERCEBES project. Certain management strategies, despite their presence in a region, are in place only exceptionally (in one or a few TURFs). These cases are specified in Table 1 and included in the analysis. Furthermore, a particular strategy may be present in multiple regions, but the way it is implemented differs among them. For instance, there is a significant disparity in individual quotas across different regions. Spain has a relatively low quota of 5–8 kg/person/day, whereas RNB and PNSACV have higher quotas of 20 and 10 or 15 kg/person/day for professional harvesters, respectively. In stark contrast, Morbihan allows a remarkably high quota of 120 kg/person/day for professional harvesters. We define community quota as a harvest maximum for a defined area, usually within a TURF, that is divided among a number of harvesters. This strategy is employed differently between regions, particularly with respect to the time interval used (kg/area/month, season, or year). We consider a harvest season to exist when exploitation is limited to particular months of the year on a regular basis, and extraction is otherwise prohibited, usually as a measure for stock recovery during reproduction or recruitment periods. Regarding marine reserves, we only consider permanent "no-take" areas as marine reserves, excluding the Parque Nacional das Illas Atlánticas in Galicia, since no specifically restrictive regulations exist for the stalked barnacle fishery and thus, the harvest of the resource remains the same inside and outside the park.

2.4. Survey

The survey questions were originally developed in 2019 for the stalked barnacle fishery in Asturias, where we had extensive discussions with scientists, government officials, and professional harvesters. We then extended the study range by including the fisheries in Morbihan, Galicia, RNB and PNSACV. After consulting fisheries experts of these regions, we carefully adapted and translated the survey for each region. In Asturias, a pre-test of the survey was conducted with six professional harvesters to ensure that the questions were clear and understandable, and that the time required to answer them was reasonable (less than 30 min). The final survey consisted of two main parts. The first part explored the demographics such as gender, age, education level and main income source used as explanatory variables in the analysis. The second part of the survey consisted of questions to assess respondents' perceptions of the effectiveness of the management strategies currently in place, their willingness to change the management and their preferred management strategies for a sustainable fishery (see Supplementary Information 1). To facilitate comprehension of the management strategies included in the survey, we provided a brief description within the "Perception of local management strategies" section for the harvesters. To evaluate the perceptions of the effectiveness of implemented fishery management strategies for a sustainable fishery, we utilised a Likert scale with scores ranging from 1 to 5, where 1 represented a strategy to be completely ineffective and 5 represented a strategy to be very effective. Their preferred management strategy was assessed through a rank system (with scores from 1 to 3), in which harvesters choose the three strategies they considered most important for acquiring sustainability of the fishery for the future. Finally, only the most important management strategies, scored as "1" by the harvesters, were used in the analysis.

2.5. Data Collection

Each region was treated as an independent population, and the minimum number of surveys required was determined using Cochran's formula for small populations (Cochran, 1977), with a confidence level of 89 %. We administered a total of 184 surveys from October 2019 to September 2020. The surveys were conducted both before and during the COVID-19 pandemic, necessitating adjustments in our data collection methods. In Asturias-West, we carried out on-site data collection in TURFs and at auction sites between October 2019 and March 2020. However, in Asturias-East, Galicia and Morbihan data collection coincided with the initial stages of the pandemic, spanning from March 2020 to July 2020, when COVID-19 restrictions were in place. To

Table 2
Number of surveys per region and demographic data of the participating harvesters obtained in the survey: gender, age, educational level and main income source (presented in percentages).

Nº of surveys (total = 184)		6	24	54	48	25	27
Gender	Male	100	100	100	81.25	100	100
	Female	0	0	0	16.67	0	0
	NA	0	0	0	2.08	0	0
Age	18–35 years	33.33	26.00	37.04	18.75	0	3.70
	36–50 years	16.67	70.83	44.44	37.50	60.00	62.96
	> 50 years	33.33	0	9.26	22.92	40.00	29.63
	NA	16.67	4.17	9.26	20.83	0	3.70
Educational level	University	0	16.67	7.41	2.08	4.00	3.70
	Professional degree	50.00	37.50	37.04	33.33	4.00	0
	High School degree	16.67	41.67	48.15	41.67	20.00	40.74
	Elementary School degree	0	0	3.70	10.42	48.00	55.56
	NA	33.33	4.17	3.70	12.50	24.00	0
Main income source	Stalked barnacles	33.33	58.33	50.00	52.08	56.00	51.85
	Shellfishing	33.33	25.00	0	18.75	0	3.70
	Fishing	16.67	8.33	44.44	29.17	16.00	14.81
	Other	16.67	8.33	3.70	0	16.00	25.93
	NA	0	0	1.85	0	12.00	3.70

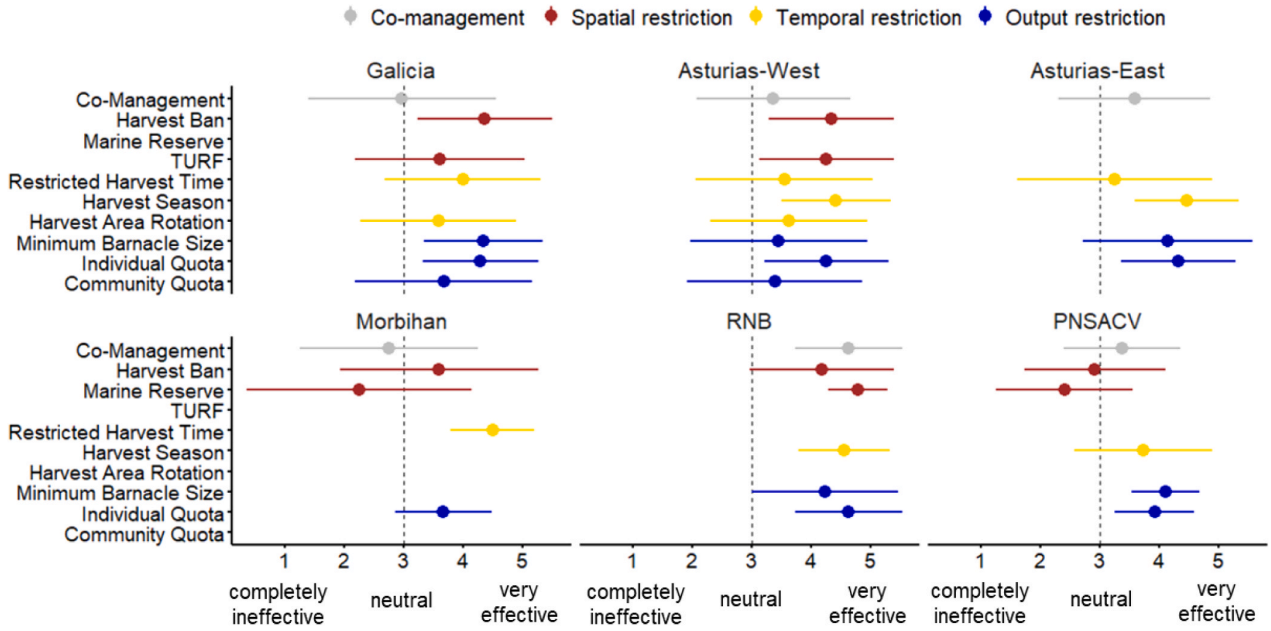

Fig. 2. Mean Likert scale values with standard deviations for the perception of effectiveness of the regionally implemented management strategies. Note: blank means that the management strategy is not in place in the fishery.

accommodate the circumstances, we provided various options for survey completion. Harvesters had the choice to fill out the survey by hand in a written format, complete it online, or opt for an oral interview conducted with the assistance of a scientist via telephone. In the RNB and PNSACV regions, all surveys were exclusively conducted via telephone throughout July and September 2020, respectively.

Moreover, in response to the mobility limitations imposed by COVID-19, we implemented a snowball sampling method to collect surveys from Galicia. Initially, we contacted with one administrator in charge of the fisheries in a number of *cofradías* and three technical assistants, known as "barefoot biologists" (see Macho et al., 2013), employed directly by *cofradías*, who all then passed on the survey to the stalked barnacle harvesters affiliated to these *cofradías*. Additionally, the administrator facilitated the distribution of the survey among administrators responsible for the fisheries in other *cofradías*, as well as among barefoot biologists, who all subsequently distributed it in their network of harvesters. For the surveys conducted in Asturias-East, we utilised an anonymized list provided by the regional fisheries administration, which facilitated direct telephone communication with the harvesters. In Morbihan, an official fisheries meeting served as an opportunity to distribute the surveys among the harvesters, providing them with the choice to be contacted via telephone for added convenience in participating. In RNB and PNSACV, a pre-existing contact list of harvesters compiled from previously conducted surveys was available to the scientists, which facilitated the survey by telephone during the pandemic restrictions.

2.6. Data treatment, statistical analysis and modelling

Survey data used in this study (Geiger et al., 2024) are available in Mendeley Data and can be accessed at: https://data.mendeley.com/datasets/xsk5r3z7r9/1. Prior to conducting data analysis and modelling, we checked for the most common statistical assumptions. We Table S1 performed Kruskal-Wallis tests on data from the two regions in Asturias

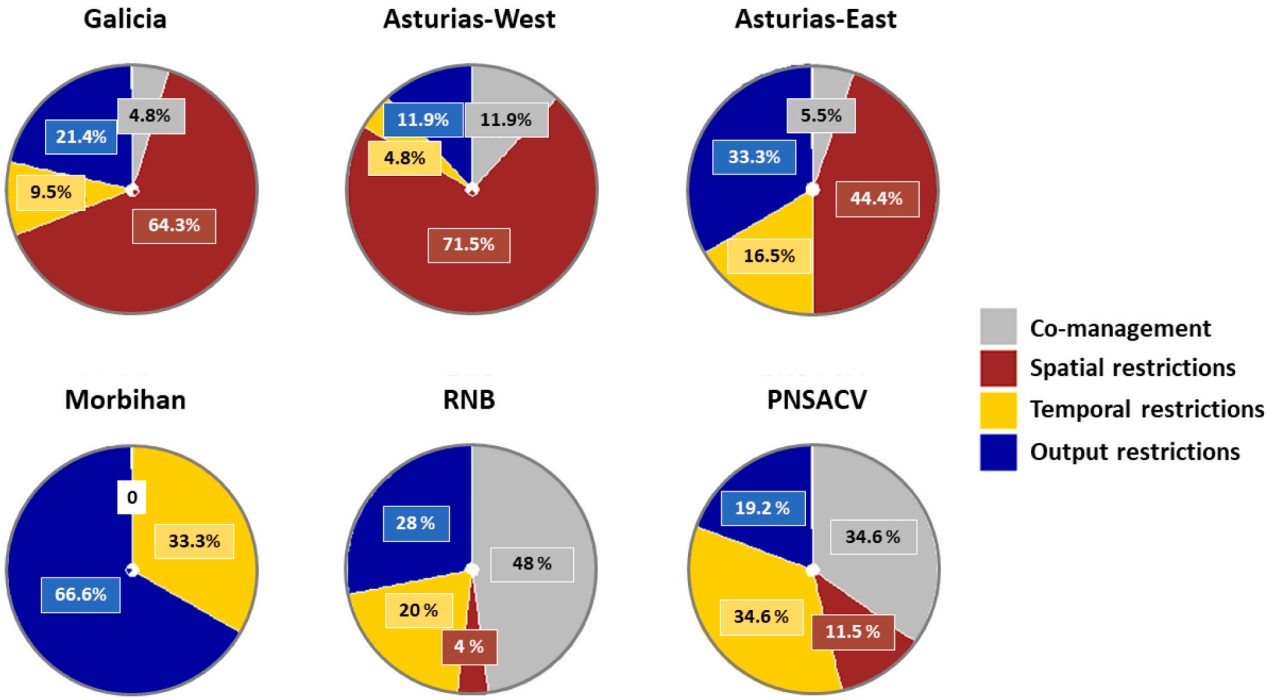

Fig. 3. Pie charts representing regional harvesters' preferences for co-management, output, temporal and spatial restrictions in percentages. Specific strategies were grouped in the following categories: Output restrictions - community quota, individual quota and minimum stalked barnacle size; Temporal restrictions - harvest season, harvest area rotation and restricted harvest time; Spatial restrictions - TURFs, harvest ban, marine reserve.

Table 3
The different models used in the AIC model selection analysis with four management strategy categories (co-management, spatial restrictions, temporal restrictions and output restrictions) as dependent variables. K = number of estimated parameters for each model; AICc = information criterion requested for each model; ΔAICc = appropriate delta AIC component depending on the information criteria; AICcWT = the Akaike weights, measures indicate the level of support (i.e., weight of evidence) in favour of any given model being the most parsimonious among the candidate model set; Cum.WT= the cumulative Akaike weights; LL = log-likelihood of each model.

Variables included in model	K	AICc	Δ AICc	AICcWt	Cum. Wt	LL
Region	18	348.54	0.00	0.83	0.83	−153.19
Region & Age	21	351.85	3.30	0.16	0.99	−150.65
Age	6	357.65	9.10	0.01	1.00	−172.48
Educational level	12	361.37	12.88	0.00	1.00	−167.35
Region & Educational level	27	361.42	12.88	0.00	1.00	−146.30
Age & Educational level	15	362.65	14.10	0.00	1.00	−164.22
Main income source	15	367.12	18.57	0.00	1.00	−166.45
Age & Main income source	18	369.19	20.65	0.00	1.00	−163.52
Region & Main income source	30	371.88	23.34	0.00	1.00	−146.55
Educational level & Main income source	24	374.70	26.15	0.00	1.00	−157.63
Region & Age & Main income source	33	376.63	28.33	0.00	1.00	−143.63
Age & Main income source & Educational level	27	376.87	28.33	0.00	1.00	−154.02
Region & Main income source & Educational level	39	390.09	41.55	0.00	1.00	−138.71
Region & Age & Main income source & Educational level	42	396.70	48.16	0.00	1.00	−135.59

where surveys were conducted before and during the COVID-19 pandemic to examine whether changes in data collection due to lockdowns biased the data (Table S1). This confirmed that no significant differences in responses among data collection methods used before and during the pandemic existed (Table S1). The reliability of answers to inquiry questions was examined using Cronbach's alpha on perceived efficiency of management strategies. Furthermore, we assessed the association between categorical variables using Fisher's exact tests to select the most relevant variables for the multinomial model (Table S1).

We developed multinomial logistic models to identify patterns that drove the differences in harvesters perceptions of the most important management strategy for a sustainable fishery. To facilitate the interpretation of the results, the dependent variable (most important management strategy: ranked by harvesters first of the three most important strategies to acquire sustainability of the fishery) was grouped into four categories: Co-management, Spatial restrictions, Temporal restrictions, and Output restrictions. Except for the co-management category all categories consist of three specific management strategies (see detailed description of these categories in Table 1). Although we recognize that co-management is a comprehensive management system rather than a specific management tool or strategy, we included it in the survey to understand harvesters' perceptions of its usefulness. Hence, harvesters were asked for their perception on the efficiency of co-management implemented in their region and given the option to choose co-management as the most important strategy for a sustainable fishery, as for the other nine management strategies. For statistical accuracy, we only used data from surveys with complete information for the models. Prior to using variables in the model, we checked for multi-collinearity of the independent variables by applying a Kendall rank correlation test. The independent variables included in the model were region, main income source, age, and educational level. We excluded gender from the model as it was highly correlated with region (Table S1 & Fig. S1). To determine the model that best described the association between the independent variables (region, age, main income source, educational

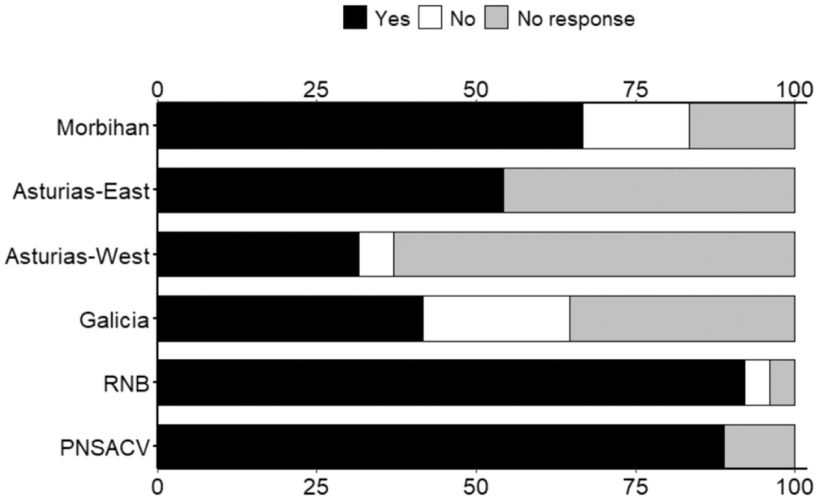

Fig. 4. Relative frequency (%) of harvesters willingness for changing the management strategies in each region.

level), with the dependent variable (most important management strategy), we employed the Akaike Information Criterion adjusted for small sample sizes (AICc; Cavanaugh and Neath, 2019). Subsequently, we conducted a Pearson's Chi-square goodness-of-fit test to assess the reliability of the chosen model.

We used *R* computing software (R version 4.2.2.; R Core Team, 2020) for all data analyses and graphical displays (ggplot2 package; Wickham, 2009).

3. Results

3.1. Characterization of harvesters

The fishery is dominated by men and only in Galicia a small percentage (16.7 %) of women participated in the survey (Table 1). Harvesters in Asturias (East and West) were younger and presented a higher educational level than those in other regions, particularly than in the Portuguese regions (RNB and PNSACV; Table 2). In Morbihan, stalked barnacle harvesting was not the main income source for the majority of harvesters (33 %) and the highest percentage of main income from other sources than fishing was found in PNSACV (25.9 %; Table 2).

3.2. Perception of local management strategies

The perceptions of the most effective management strategies in place for a sustainable fishery varied among regions, with answers demonstrating an acceptable level of reliability (Cronbach's alpha 0.64). Overall, most implemented strategies were perceived as effective, with mean values of > 3 on the Likert scale, or very effective, with values of > 4, with a few exceptions (Fig. 2). Marine reserves were considered ineffective (value <3) in both Morbihan (2.3 points) and PNSACV (2.4 points). Harvest bans in PNSACV (2.9 points) and co-management in Morbihan (2.8 points) were perceived as slightly ineffective. However, in Galicia, harvesters attributed a neutral effect to co-management (3 points; Fig. 2). The strategy that was voted the most effective in Morbihan was maximum time for harvesting (4.5 points). Harvest season (4.5 points) was considered the most effective strategy in Asturias-East and -West, followed by harvest ban (4.4 points), TURF (4.3 points), and individual quota (4.3 points) in Asturias-West and individual quota (4.3 points) and minimum stalked barnacle size (4.2 points) in Asturias-East (Fig. 2). In Galicia, harvest ban (4.4 points) was voted the most effective strategy, closely followed by the minimum stalked barnacle size and the individual quota (both 4.3 points). In RNB, harvesters had a very positive perception of the effectiveness of the implemented strategies in their region, with all scores ranging between 4 and 5 on the Likert scale (Fig. 2). Marine reserve, co-management, individual quota, and harvest season reached the highest scores in RNB. In PNSACV, the minimum stalked barnacle size was considered the most effective (4 points), followed by individual quota and harvest season (3.9 and 3.8 points, respectively).

3.3. Harvesters preferences for future management

Regarding the preferred management strategies in terms of categories, in Asturias-West (71.5 %), Asturias-East (44.4 %), and Galicia (64.3 %) harvesters considered Spatial Restrictions (TURFs, Harvest Ban and Marine Reserve) to be the most important management category for ensuring a sustainable fishery for the future. In Morbihan, the majority of harvesters (66 %) voted for output restrictions as the most important category, while in RNB, co-management was chosen by 48 % of harvesters as the most important category (Fig. 3). Harvesters in PNSACV identified two categories as equally important, with both co-management and time restrictions receiving 34.6 % of the votes for the most important category (Fig. 3).

Clear preferences for single management strategies emerged in Asturias-West and RNB. In Asturias-West, over half of the respondents (54.8 %) preferred harvest bans, while in RNB, almost half of the respondents (48 %) voted for co-management (Table S2). In PNSACV, the majority of respondents (34.6 %) also preferred co-management, followed by rotation of harvest areas (23.1 %). In Asturias-East, about a third of the respondents (33.3 %) chose TURF as the most important single management strategy. In Galicia, marine reserves were preferred by 26.2 % of the respondents, closely followed by harvest bans (23.8 %) as the most important management strategy (Table S2).

3.4. Modelled harvesters preference for management

Based on the AIC model selection analysis results (Table 3), the model with the single variable region explained 83 % of the cumulative model weight. The variable region was the best predictor of the trends in management strategy preferences, and presented a highly significant goodness-of-fit result ($p < 0.001$), suggesting that regional differences play a significant role in shaping these preferences.

3.5. Harvesters willingness to change strategies

The results show that the majority of harvesters in RNB (92 %), PNSACV (88 %), Morbihan (67 %) and Asturias-East (54 %) were in

favour of making changes in the management strategies (Fig. 4). In Galicia and Asturias-West only 42 % and 32 % of harvesters, respectively, indicated to be willing to change the management strategies, while 23 % and 6 %, respectively, were opposed (Fig. 4). It is worth noting that a significant proportion of harvesters in Asturias-West (63 %), Asturias-East (46 %), and Galicia (35 %) did not answer the question on their willingness to change (Fig. 4).

4. Discussion

Our study aimed to investigate stalked barnacle harvesters perceptions on fisheries management strategies, to identify key insights for improving the sustainability of the fishery. The significant variability in the implementation of co-management, from incipient to high level, across the stalked barnacle fisheries studied poses challenges in drawing definitive conclusions about the effectiveness of specific management strategies. Nevertheless, the choices made by harvesters regarding the most effective strategies to achieve sustainability reflect the differences in regional management systems demonstrating how regional contexts shape their preferences and perceptions. Our findings reveal that the harvesters from regions with less developed co-management systems—characterized by lower decision-making power and participation, such as Asturias-East, Morbihan, PNSACV, and RNB (see Aguión et al., 2021)— demonstrated a strong willingness to make changes in the fisheries management (Fig. 4). This willingness indicates that harvesters in these regions recognized shortcomings in the current management and can be seen as a crucial step towards enhancing fisheries management (Cinner et al., 2009). This study also found no clear trend emerged regarding a single "optimal" management strategy preferred by harvesters across regions. Given the considerable differences in fisheries management practices, as well as cultural and socio-economic characteristics among the regions, this lack of consensus is not surprising. In fact, our multinomial model selection analysis confirmed that region was the most significant variable for explaining the patterns in the selection of the most important management strategy for achieving sustainability in the fishery. This highlights the relevance of considering regional differences in the development of co-management systems when devising management strategies. Furthermore, more developed co-management systems, involving TURFs, tend to have higher levels of harvester participation and decision-making power (Aguión et al., 2021), leading to preferences for more restrictive and spatially explicit strategies. In contrast, regions with less developed co-management systems lean towards general input and output restrictions or increased involvement in co-management, reflecting their aspirations for greater stewardship and effective management.

In Morbihan, where the management of the stalked barnacle fishery lacks fundamental restrictions (e.g. a very large individual quota exists, but no minimum stalked barnacle size or community quota (Comite Regional Des Peches Maritimes, 2019; Préfet de la Région Bretagne, 2020)), harvesters are aware of this deficiency and opted for implementing output and temporal restrictions to obtain a sustainable fishery (Fig. 2; Table S2). The management strategy chosen as the most important for sustainability in RNB and PNSACV was co-management, reflecting harvester's desire for more participation in the management. The interest to participate in the fisheries management has increased over the years until a co-management pilot project was launched 2018 in RNB, to which harvester's interest and proactive initiative have contributed (Sousa et al., 2020). Moreover, as co-management was being implemented legally during the time of the survey, it was rated as highly efficient (Fig. 3) and voted as the most important management strategy to ensure fishery sustainability in RNB. Harvesters here were experiencing a positive change through the implementation of co-management, allowing for more participation. In PNSACV respondents perceived it to be implemented less effectively than desired, with a rating slightly above neutral. Nevertheless, 34.6 % of respondents still believed it to be the most important management strategy for a sustainable fishery. In Galicia and Asturias-West harvesters may be dissatisfied with the implementation of co-management, have unrealistic expectations, or, more likely, take the advanced co-management system for granted. Given that co-management in these two regions has been in place for decades and deeply integrated into their practices, harvesters may not be fully aware of its effects or appreciate its significance. Harvesters in Galicia and Asturias-West rated spatial restrictions as the best management approach for ensuring a sustainable fishery, which corresponds with the implemented highly detailed spatial management strategies in these regions (Aguión et al., 2021; Rivera et al., 2014). Harvest bans are commonly used in TURFs, and are considered the most crucial strategy for achieving sustainability by the majority of harvesters in Asturias and many in Galicia which might be due to their experience with TURF-based managed fisheries (Afflerbach et al., 2014; Rivera et al., 2017). Moreover, Galician harvesters chose the most restrictive management strategy, marine reserves, as the most important management strategy for ensuring a sustainable fishery. This reflects a strong sense of stewardship over the resource among harvesters in both Galicia and Asturias-West, where co-management is characterized by a high degree of participation and the use of TURFs. This development of stewardship is congruent with common-property and co-management theories, which anticipate that securing access and sharing control over the resource can create incentives for fishers to manage and fish collectively and sustainably (Ostrom and Schlager, 1996). According to Afflerbach et al. (2014), resource users who possess territorial user rights, have a greater motivation to manage their resources sustainably and undertake conservation efforts, including the establishment of marine reserves (permanent no-take areas). In Morbihan, RNB and PNSACV, in contrast, where marine reserves with permanent no-take zones are established, but where TURFs are absent, only a small percentage of harvesters perceived marine reserves as the most important approach to achieve a sustainable fishery. In fact, in Morbihan and PNSACV, most harvesters considered marine reserves an ineffective management strategy. The economic benefits of marine reserves, however, may be limited without exclusive ownership of surplus resources and effective enforcement (Afflerbach et al., 2014). Therefore, additional management actions such as TURFs could be a necessary previous step for harvesters to be aware of the benefits of no-take areas (Afflerbach et al., 2014). Thus, there is an increasing recognition of the potential benefits of creating "TURF-reserves", which combine TURFs with marine reserves (Costello and Kaffine, 2010; Gaines et al., 2010; Gelcich et al., 2008, 2015). However, their effectiveness will depend on the matching of spatial scales of larval dispersal, which was estimated to be up to 200 km along the Iberian Peninsula (Nolasco et al., 2022), with the area of the "TURF-reserve". Hastings and Botsford (2003) have proposed reserve networks as the optimal arrangement for no-take areas to increase fisheries yield while ensuring population sustainability for species with pelagic larval stages and sessile adults. Similarly, Rivera et al. (2014) have recommended this approach specifically for *P. pollicipes* along the Cantabrian Sea by implementing temporal total bans instead of permanent no-take zones. These areas can serve as small-scale temporarily protected areas, allowing larvae to disperse among reserves and ensuring the population's persistence.

The survey revealed that some harvesters prioritised strategies that were not currently implemented in their region as the most important strategy for sustainable fishery management in the future. In Asturias-East, harvesters perceived TURFs as the key strategy to improve their fishery, likely influenced by the success of the fishery management in Asturias-West. Despite the low level of co-management in Asturias-East stalked barnacle fishery the implementation of two TURFs in the beginning of 2023 (Gobierno del Principado de Asturias, 2023) validated our results of harvesters determination to implement TURFs in this region. Similarly, in PNSACV and RNB, where co-management systems are incipient to mid-levelled (Cruz et al., 2022), harvesters demonstrated a desire to raise the level of co-management. It is likely

that Portuguese harvesters from these two regions were motivated and influenced by their interactions with Galician harvesters in recent years. Insights into the successful management approaches and strategies implemented by Galician harvesters may have influenced their own aspirations for their fisheries. The interest of harvesters in management strategies implemented in other regions highlights the potential for knowledge exchange and cross-regional learning, where harvesters in different regions draw inspiration from successful strategies implemented elsewhere (Geiger et al., 2022). Trans-regional and trans-sectorial knowledge exchange through mutual learning from trial-and-error experiences, fosters collaboration by sharing best practices among harvesters and regions, which is crucial to develop innovative solutions for common challenges faced by fisheries across regions (Geiger et al., 2022; Trimble and Plummer, 2019). Efforts to promote trans-regional management for the European stalked barnacle fisheries are already underway through joint workshops and research (Geiger et al., 2022; Nolasco et al., 2022). As fisheries management is a complex and ever-evolving process, there is no one-size-fits-all solution for a sustainable management (Bianchi et al., 2009; Degnbol et al., 2006; Jentoft and Bavinck, 2014), and it should be an open-ended and dynamic process rather than a fixed condition (Torre-Castro and Lindström 2010). By acknowledging the preferences and aspirations of harvesters for specific management strategies, policymakers and stakeholders can work towards aligning management practices with the expectations, needs and readiness of the fishing communities, promoting more effective and region-specific approaches to sustainable fishery management.

Although we recognize that co-management is a comprehensive management system rather than a specific management tool, we included it in the survey to understand harvesters' perceptions of its usefulness. The significant variability in the implementation of co-management across the stalked barnacle fisheries studied poses challenges in drawing definitive conclusions about the effectiveness of specific management strategies. Nevertheless, the choices made by harvesters regarding the most effective strategies to achieve sustainability reflect the differences in regional management systems demonstrating how regional contexts shape their preferences and perceptions.

5. Conclusion

This study enhances our understanding of the effectiveness of management strategies in European stalked barnacle fisheries by examining the perceptions of harvesters. Our findings indicate that harvesters from fisheries with less developed co-management, lower levels of governance, and lower overall sustainability are willing to make changes to current management strategies, reflecting their recognition of the need for improvement. The study shows that harvesters prioritize different management strategies based on the level of co-management development and their proximity to more advanced stalked barnacle fisheries. Participatory co-management systems, particularly those incorporating TURFs, encourage harvesters to favour more restrictive and spatially explicit management strategies. To achieve effective and sustainable fisheries management, it is crucial to tailor management strategies regularly to align with the evolving development of co-management systems.

CRediT authorship contribution statement

José Luis Acuña: Funding acquisition, Supervision, Project administration, Writing – review & editing. **Alba Aguión:** Investigation, Writing – review & editing, Validation. **Antonella Rivera:** Conceptualization, Supervision, Validation, Methodology, Writing – review & editing. **Eric Thiébaut:** Project administration, Writing – review & editing, Resources, Validation, Funding acquisition. **Elsa Vázquez:** Funding acquisition, Writing – review & editing, Project administration. **Marine Barbier:** Investigation, Writing – review & editing. **Lucía García-Flórez:** Validation, Writing – review & editing. **Gonzalo Macho:** Writing – review & editing, Validation. **Teresa Cruz:** Funding acquisition, Supervision, Validation, Investigation, Project administration, Writing – review & editing. **Susana Fandiño:** Resources, Writing – review & editing, Validation. **Paloma Peón Torre:** Validation, Writing – review & editing, Resources. **Geiger Katja Juliana:** Conceptualization, Formal analysis, Visualization, Data curation, Investigation, Writing – original draft. **Francisco Neves:** Investigation. **Nélia Penteado:** Investigation.

Declaration of Competing Interest

We declare that the work described has not been published previously and is not under consideration for publication elsewhere. Its publication is approved by all authors and explicitly by the responsible authorities where the work was carried out. If accepted, it will not be published elsewhere in the same form, in English or in any other language, including electronically without the written consent of the copyright-holder.

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This is a contribution of the Asturias Marine Observatory.

Appendix A. Supporting information

Supplementary data associated with this article can be found in the online version at doi:10.1016/j.fishres.2025.107566.

Data availability

I have included the link to the publication of the data used in the study within the manuscript. The data has been published as Mendeley Data.

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