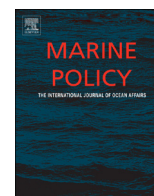




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Co-management in Europe: Insights from the gooseneck barnacle fishery in Asturias, Spain



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ABSTRACT

In recent years, cooperative management systems have received attention as a means towards sustainable fisheries. Since its inception and for the past 20 years, the gooseneck barnacle fishery in the coast of Asturias has been co-managed by assigning Territorial User Rights to fishers' associations, allowing fishers to participate actively in the management and data gathering processes. Here, 20 years of landings, in-depth interviews and focus groups were used to characterize the emergence and social-ecological properties of the system. The system consists of 7 management areas each one some tens of kilometers long. The incorporation of fishers' knowledge has successfully led to within-area fragmentation of the management units down to single rocks as small as 3 m long, which are managed according to different protection levels. The system has empowered resource users and provided an opportunity for the use of both scientific information and fishers' knowledge to be integrated in management guidelines. Results suggest the adaptive capacity provided by the co-management framework has been essential to manage this heterogeneous fishery. The gooseneck barnacle fishery and its historical developments illustrate the potential for establishing co-management systems for small-scale fisheries in Europe.

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1. Introduction

Fisheries worldwide are currently experiencing a paradigm shift from a top-down approach towards more bottom-up, community based efforts [1,2]. This requires changes in regulatory frameworks in order to address the underlying social, economic and cultural systems [3]. As part of this paradigm shift, co-management has been proposed as a promising strategy to achieve sustainable fisheries since it has the potential to strengthen community integration [4], enhance fishing stocks [5], empower resource users [6], adapt to changing conditions [7] and incorporate both fisher's knowledge and scientific information in management strategies [8].

Co-management consists in the cooperation of governments and users in the exercise of resource management [9], where both parties share authority and responsibility [10]. Co-management systems vary according to the extent of authority delegated to

each party, ranging from *instructive*, where the decision-making process is centralized and the resource users are instructed on the decisions, to *informative*, where decisions are made locally and the government agencies are informed [11]. Cooperative systems aim to create a situation in which the rewards for cooperation are greater than those for competition [12], thus avoiding the *tragedy of the commons* [13]. Furthermore, a key component in co-management systems is their inherent adaptive capacity. The concept of adaptive management was first proposed by Holling [14], it refers to a dynamic management process where policies are continuously improved according to updated information about the state of the system [15]. Recently, many successful case studies on co-management implementation have been documented [1,8,16], most of which are located in developing nations. Paradoxically, research shows that co-management has higher probability of success in areas with a high Human Development Index (HDI) [2].

European fisheries have faced increasing pressure for the past 50 years causing a depletion of stocks [17,18]. Fisheries management in Europe has focused on a top-down approach [19], where management strategies are a matter of international policy [20]. Several strategies have been employed to ensure the sustainability

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of fishing stocks in the European Union, such as the Common Fishery Policy (CFP). The CFP aims to guarantee sustainable fish stocks and the economic welfare of fishing communities. However, according to the Green Paper for the reform of the CFP, as of 2009, 88% of fishing stocks were being overexploited and sustainable management had not been achieved [21]. The lack of success of the CFP has been attributed to a number of caveats in its framework and implementation. Highlighted among these caveats are, the lack of approval by the public [22], the implementation of an open access policy and numerous subsidies which promote the race for fish [17] and a framework that deters the incorporation of scientific knowledge [23]. Furthermore, an important criticism to European policy is its focus on industrial and large scale fleets which leads to the neglect of the small-scale artisanal fishery sector [24], these small-scale fisheries comprise an important proportion of the European fleet [25] and are essential in maintaining coastal communities [26]. Most of these downfalls come from the CFPs inherent top-down approach. The EU has acknowledged the need for a regionalization of the CFP, where a greater involvement of stakeholders should be

encouraged [21]. The application of collaborative policies, such as co-management, could potentially improve EU fishery policy.

The gooseneck barnacle (*Pollicipes pollicipes*) fishery in the Asturian coast (North Spain) is currently an important component of the artisanal fleet in this area [27]. In 1994, a co-management system was implemented in the Asturian gooseneck barnacle fishery, which continues to date. According to informal observations, co-management has enabled the sustainability of the system. However, an in-depth study of the system has not been attempted. Here, the implementation and development of this co-management system are explored. Co-management has allowed for an adaptive learning-based approach and a fine-scale management of the fishery (down to 3 m; Fig. 1), thereby endorsing the match of social, biological and management scales. Thus, the co-management system aids in the sustainability of the gooseneck barnacle fishery. The illustration of the Asturian gooseneck barnacle system provides insights about the potential for co-management implementation and its prospects as a management approach in a broader European context.

2. Methods

2.1. Study area and settings

The Asturian co-management system is located between the Eo estuary (29T 666839 4827388 UTM) and the eastern most part of Cape Peñas (29T 667714 4827400 UTM). It is divided in 7 regions with distinct management, denominated management plans for their Spanish name, which depend on the regional government (*Principado de Asturias*) and the local fishers' associations known as *cofradías* (Fig. 1). Currently, the *Tapia-Figueras*, *Viavélez*, *Ortigaera*, *Puerto de Vega*, *Luarca*, *Cudillero-Oviñana* and *Cabo Peñas* plans are seasonal with a harvest season that starts in October and ends in April, and a total individual daily allowable catch (TAC) per fisher that varies between 6 and 8 kg. However, the *Cabo Peñas* plan, which comprises the *Luanco-Bañugues* *cofradías*, allows harvesting all year with a constant daily TAC of 8 kg per fisher.

2.2. Characterization of the system

The distribution and dimension of the Asturian gooseneck barnacle co-management plans was characterized using the *Principado de Asturias Coastal and Marine Geographic Information System*. Each co-management plan is subdivided into management zones, which can be separate rocks, groups of rocks, or small coastal strips. Furthermore, information on the commercial quality of each zone was gathered from the *Dirección General de Pesca Marítima del Principado de Asturias* (DGPM) official records. The quality of each zone was determined at the inception of the co-management plans by incorporating fishers' knowledge and was further corroborated by *in situ* inspections by personnel from the DGPM and SIGMA S.L. in 2006 and 2008 [28].

To explore the seasonality of the co-management system daily records for landings in 233 fishing zones within 6 plans were analyzed for the 1994–1995 to 2010–2011 fishing seasons. The *Luarca* plan was excluded due to gaps in the datasets. One-way analysis of variance (ANOVA) was performed to test for differences in landings among months.

Information on the yearly management of the fishing zones was obtained through the *Boletín Oficial del Principado de Asturias*. The type of ban applied to each zone for the 2000–2001 to 2010–2011 fishing campaigns was recorded. These were divided in 3 categories: total, partial or no ban. Linear regression analysis was used to test the effect of bans on next year's landings. Landings were standardized [29] by zone to make comparisons among zones. All linear regression assumptions were tested.

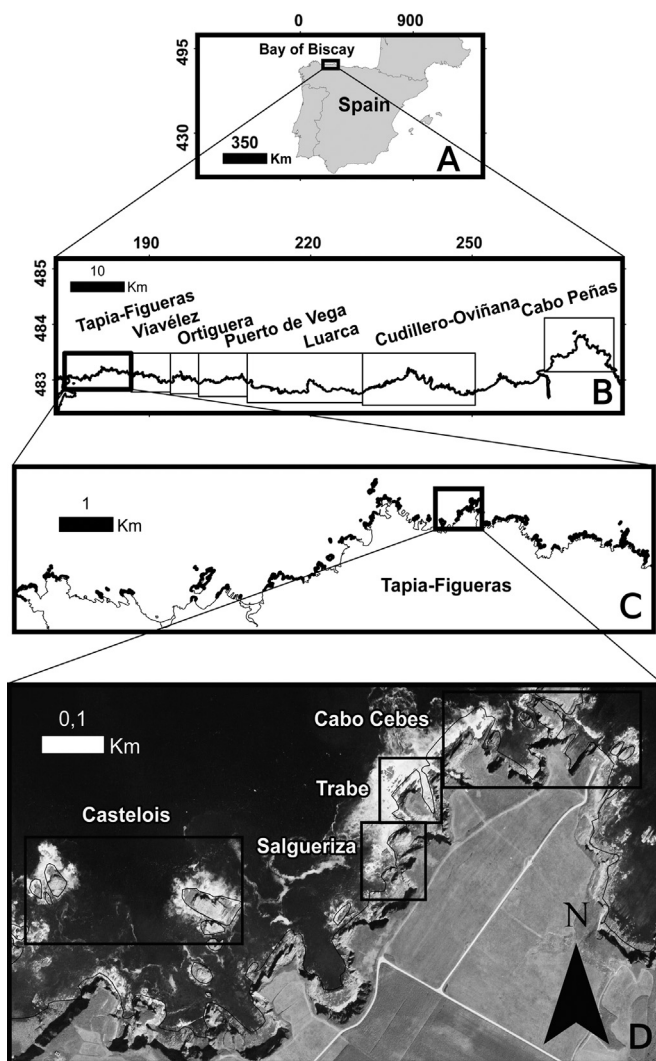


Fig. 1. (A) Location of the study area. (B) Map of Asturian coast showing the seven co-management plans. (C) Fine-scale map of the *Tapia-Figueras* plan. (D) *Castelois*, *Salgueriza*, *Trabe* and *Cabo Cebes* exploitation zones in the *Tapia-Figueras* plan. *Castelois* represents an area of regular quality which receives a no-ban management; *Salgueriza* is a good quality area which is managed by partial ban; *Trabe* is a bad quality area which also receives a no-ban treatment and *Cabo Cebes* is a good quality area managed by implementing total bans.

2.3. Description of the market

Gooseneck barnacles sales were analyzed to detect a potential effect of the co-management system. Data on all sales carried out in the 17 major fish markets within Asturian territory from January 1st 2001 to December 31st 2011 were examined. The effect of a seasonal component or the known market cycles (high, mid and low) on the mean daily price/kg was determined by one-way ANOVAs. The high market period for gooseneck barnacles occurs during the month of December, mid sales period includes October, November and January–April and the low season goes from May to September.

2.4. Fishers' knowledge and perceptions

Individual semi-structured interviews were carried out with gooseneck barnacle fishers, government officials and key members of the *cofradías* ($n=12$) as a way to understand the general perception of the co-management system and its implementation. With the information obtained from the interviews, focus groups were performed in the 7 co-management plans from October to December 2012. Focus group sizes were around 5 persons and aimed to assess fishers' participation in the management system, adaptability of the system and the way fishers' knowledge and scientific information were incorporated. In each focus group there was at least one representative of the resource users and one of the government officials.

3. Results

3.1. Description and history of implementation

Before the early 1990s gooseneck barnacles in Asturias were only harvested sporadically by a few fishers. In 1994, the Asturian government through the *Dirección General de Pesca Marítima del*

Principado de Asturias (DGPM) saw the opportunity to exploit this previously under-marketed resource in the area. They approached a number of *cofradías* with a proposal for a pilot gooseneck barnacle exploitation program. The program consisted in collaborative management of the resource between DGPM and the *cofradía*. The pilot program was carried out in the *Ortiguera cofradía* that same year (Fig. 1). By 2001 seven co-management plans between DGPM and 10 *cofradías* had been established in the Asturian coast, making it one of the first examples of a fishery managed since its early stages and without an important crisis driving its reform.

The system consists of assigning exclusive Territorial User Rights for Fishing (TURFs) to each management plan. Under the TURF arrangement, only licensed members of the plan are allowed to exploit their assigned territory, in return for detailed data gathering by the *cofradías* (Fig. 2). The *cofradías* report daily landings and effort data for each fisher and zone in the plan, providing an important source of up to date information. At the beginnings of the co-management system the *cofradías* were actively involved in the distribution, selection and classification of extraction zones. Currently, there is a constant participation of the *cofradías* in the management, surveillance and commercialization of the resource. Once the *cofradías* and DGPM have agreed on the guidelines for the fishing season these are published in the *Boletín Oficial del Principado de Asturias*, the official newsletter responsible for publishing new legislation.

3.2. Resource management

The co-management system has enabled the subdivision of the plans into detailed management units, denominated as zones, which span from single rocks 3 m long up to 3.3 km extents of coastline. The system encompasses a total of 267 zones in approximately 200 km of the Asturian coastline and surrounding



Fig. 2. Description of the Asturian gooseneck barnacle co-management system. Image of the resource (A), fishers harvesting the resource (B), landings weight-in (C), separation of the resource by commercial quality (D) and the *Cabo Peñas cofradía*, where first sale auctions take place (E). In (D), a cooperative management approach, where fishers share the harvest, is observed.

islands. Moreover, each zone has been classified according to the commercial quality of gooseneck barnacles it renders (Table 1). The spatial detail of management exhibited in this fishery can only be obtained through a co-management system, were all the resources users aid in the collection of data. Maintaining such an exhaustive database would be impossible in an open-access regime, due to the high enforcement costs and lack of workforce.

The management of the fishing zones is also handled at a small-scale, by establishing bans at the beginning of the campaign through legal closures. These can either be total bans, closed for the entire fishing season, or partial bans where rocks are only opened for a few months, generally during the high season. These bans are distributed heterogeneously across the co-management plan with a large number of partial bans in all plans and a few, alternating total bans in 5 plans (Fig. 3). Partial bans are set to reserve zones for when the market demand is at its peak and the greatest profit will be gained. Total bans are generally applied to good quality zones to maximize profits for the next year and prevent overexploitation. The bans are initially proposed by the DGPM after a general inspection of the zones during the summer. However, these are not established until they have been approved by the *cofradías*, demonstrating a clear example of continuous collaboration between the government and the stakeholders, intrinsic to a co-management system. According to the fishers who participated in focus groups, bans are essential in sustaining the resource hence their active participation in the selection process. Furthermore, the positive effect of the bans can be corroborated in the relationship between the bans for the previous year and standardized landings; fishing zones with a total ban will have greater landings than those with partial or no ban (Fig. 3). An increase of 0.51 standard deviations over the mean is expected in zones a year after a total ban (linear regression; $p < 0.0001$). Thus, the collaborative and detailed process of establishing a particular ban in each zone driven by co-management has aided in the sustainability of the gooseneck barnacle fishery.

3.3. The market

The effect of the co-management system reaches beyond the extraction of the resource and also impacts the market. Currently gooseneck barnacles are viewed as a luxury item in Spain and Portugal with first sale market values reaching 266 euros/kg in Asturian markets. Moreover, the quality of the resource, which has been determined for each zone, also translates into economic profit. The commercial quality of gooseneck barnacles depends on the relationship between the length, width and weight of the barnacle [30]; fishers select barnacles with greater amount of muscle in their peduncle (proportion of edible area). An average difference on daily price per kilogram of 51.95 ± 0.83 (mean \pm standard error) euros in first sale Asturian markets was observed. However, this difference can vary up to 259 euros depending on the season. A strong monthly and seasonal component was identified in gooseneck barnacle sales (ANOVA; both $p < 0.0001$), which coincides with the monthly seasonality present

in landings (ANOVA; $p < 0.0001$) determined by the fishing campaign (Fig. 4). The Christmas holiday period (December) can be considered the high season for gooseneck barnacle sales, where the mean sales price is 43 ± 0.19 euros/kg. For the remaining months of the seasonal fishing campaign (November and January–April) the mean price is 25.97 ± 0.07 euros/kg and 17.94 ± 0.12 euros/kg from May to September (Fig. 4). As is expected, the greatest mean monthly landings occur during the high season (December) (Fig. 4), where there is greater demand. There is also a peak in mean landings at the beginning of the campaign (October), which is not observable in the mean sale price. The annual exploitation cycle and market prices are likely influenced by the availability of fishing grounds, determined by legal bans and fishing seasons established through collaborative management, as well as market demand. Thus, the co-management system is exerting an effect upon market prices.

3.4. The resource users

Considering the fine-scale and heterogeneous management of the plans, it is important to assess the role of the fishers. Fishing licenses are allotted to each co-management plan proportionally to the percentage of exploitable area within the plan (Table 1). Of these quotas 75% must belong to the local *cofradía* and the other

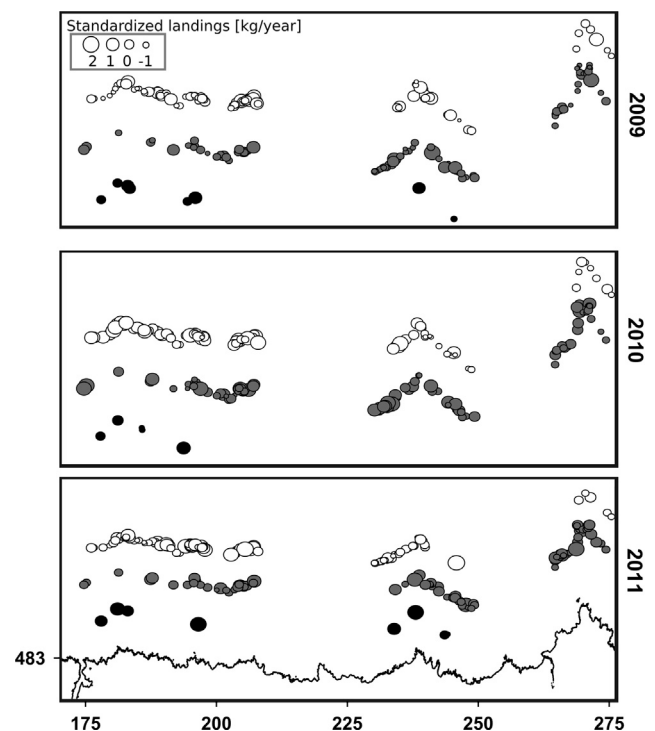


Fig. 3. Map showing standardized yearly landings for the 2008–2011 fishing seasons and bans for the previous year. Black dots represent total bans, gray partial bans and white no ban.

Table 1
Asturian gooseneck barnacle co-management system general information.

	All plans	Tapia-Figueras	Vivavélez	Ortiguera	Puerto Vega	Luarca	Cudillero-Oviñana	Cabo Peñas
Extension [km]	≈ 184.4	30.6	16.6	16.6	16.5	36.6	45.5	22
Total zones	267	28	20	28	46	34	70	41
Good quality zones [%]	47.6	53.6	40	28.6	26.1	58.8	30	65.9
Regular quality zones [%]	36.7	35.7	25	28.6	52.2	35.3	38.6	29.3
Bad quality zones [%]	21.7	10.7	35	42.8	21.7	5.9	31.4	4.9
Mean landings [kg/year]	≈ 45,104	9415.1	3602.2	5300.5	5580.5	–	14946.7	11432.7
Fishers in the 2013–2014 fishing season	189	27	11	13	18	23	55	42

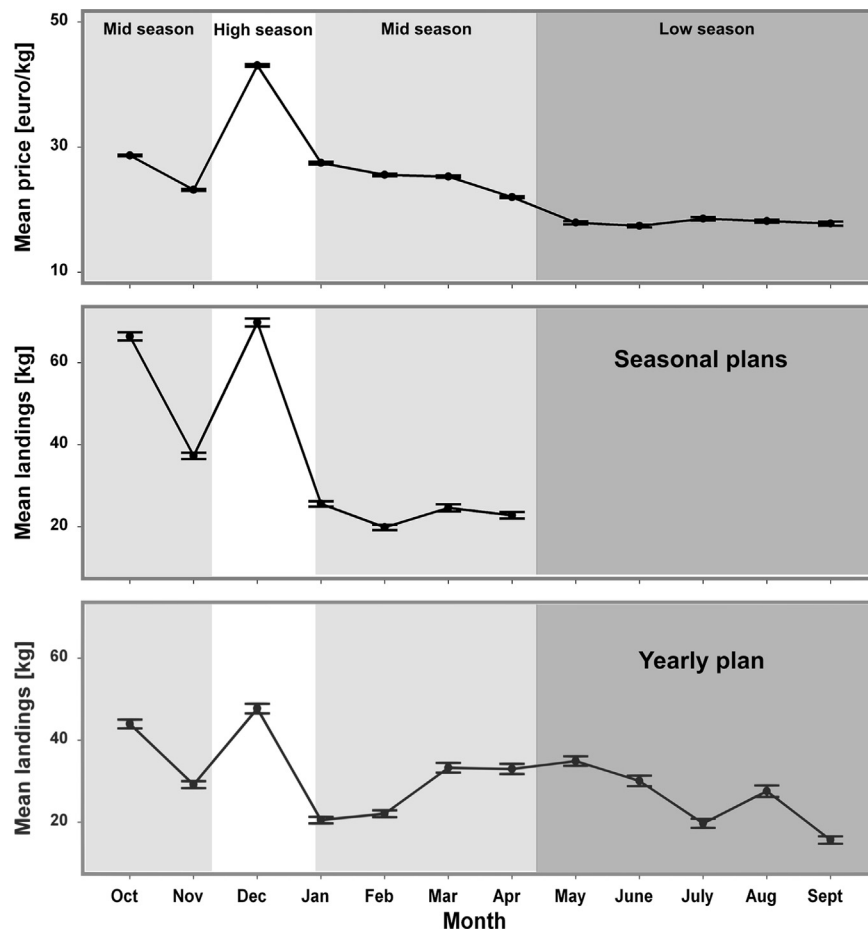


Fig. 4. Monthly trends for mean price (2001–2011) and mean landings (1994–2011) in the seasonal plans (*Tapia-Figueras, Viavélez, Ortiguera, Puerto Vega, Luarca and Cudillero-Oviñana*) and the yearly plan (*Cabo Peñas*). Bars represent the standard error.

25% is filled by members of other *cofradías*. By leaving a 25% non-local quota the DGPM gives an opportunity to fishers from *cofradías* without co-management systems who are eager to join the plans. There is high foreign and local demand to join the co-management plans; all plans have a waiting list to issue new licenses. In the interviews, stakeholders stated global and local measures had to be taken to control fishing effort. This concurs with the measures adopted by the DGPM; fishers must have completed 20 days at sea in the previous campaign and be active members of an Asturian *cofradía* to renew their license. The *cofradías* have also established their own criteria in accepting new fishers, the *Cabo Peñas* plan members unanimously decided to only allow one new member for every three that leave the plan and others set a moratorium on issuing new licenses until they reach their target size. According to the focus groups, the fishers perceive their opinion on management guidelines is valued and enforced. The joint approach to control fishing effort in Asturias can only be possible through a co-management system. Moreover, this approach also aids in including the fishers in the management process and generates a sense of empowerment.

One of the main concerns expressed by fishers during the focus groups was the presence of poachers who exploit their TURFs, particularly during the closed season or in banned areas. The DGPM finances one surveillance officer per management plan who works a daily shift. Due to the surveillance effort several poaching cases have been documented and sanctioned by local authorities. However, according to the resource users many cases go unpunished or receive relatively small fines. Fishers expressed a sense of entitlement, characteristic to exclusive rights systems,

and saw an imminent need to protect their resource. Thus, in *Cudillero-Oviñana, Luarca* and *Puerto de Vega* all members have agreed to personally carry out a few days of surveillance in special interest areas.

In the interviews and focus groups multiple resource users expressed concern to the constraints in compatibility between target species. The gooseneck barnacle fishery is legally compatible with shellfish pot, eel fishing sieve and hook and line fishing. However, compatible gears can vary among plans. Nonetheless, to exploit incompatible resources, those that require passive-fishing gears such as gillnets and trammelnets, the fishers must resign their license for the rest of the fishing campaign. During the focus groups fishers that belong to a professional fishing vessel conveyed the most apprehension towards these measures, they generally only work for the first half of the campaign (October–December) and then depart to other fisheries. This generates a partition of gooseneck barnacle fishers into two groups, *professional fishers* and *autonomous fishers* who do not belong to a professional vessel and only have an individual license, with different exploitation seasonality. The *autonomous* group exploits gooseneck barnacles exclusively, working throughout the entire campaign and in some cases combining it with work on land. They extract fewer kilograms per day than those who work on boats but work for a longer period. The *professionals'* strategy is extracting as much as possible during the high season to get the most benefit. The divergence in gooseneck barnacle fishing strategies causes competing interests among the groups, which were put forth in the focus groups. The *professionals* seek a shorter fishing season that adapts to their needs, no more than 3 months. On the

contrary, the *autonomous* group is interested in year-round exploitation. In these circumstances it is up to the government agency to mediate terms that will be beneficial for both parties, such as a 7-month campaign. The co-management system is ideal in these situations, since in a community management system these disagreements would be hard to mediate without an objective external agent and in an exclusively government managed system the implications of the disagreements would not be fully understood.

3.5. Adaptive capacity

Co-management systems allow for the incorporation of adaptive management into the guidelines. In the gooseneck barnacle fishery, which displays a high level of heterogeneity in the resource (Table 1; Figs. 1 and 3) and in resource users (see preceding section), stakeholders agree that the flexibility of the system has been key in its performance. Constant modifications have been done throughout the 20-year history of the plan (Table 2). One example is the length of the fishing season. It is discussed before each campaign and will only be modified if there is a unanimous consensus in the entire plan and the DGPM. For example, during the Prestige oil spill the *Cudillero-Oviñana* and *Cabo Peñas* plans had an early closure of the fishing season to avoid any possible contamination in the resource. There have also been a couple of successful attempts to close the fishing season a few months ahead of time in certain *cofradías* (Table 2).

The fine-scale in which the plan is organized has been ideal for the implementation of its adaptive management regime. Fishers' knowledge has led to a detailed fragmentation of the management units (Section 3.2) unique to collaborative systems, which coincides with the small-scale dispersal (tens of km) of gooseneck barnacle larvae in the Cantabrian Sea [31]. Before each campaign the *cofradías* and the DPGM determine where a fishing closure would be beneficial, with a level of detail down to 3 m (Table 2). The decision on what ban to apply to each zone depends on the status of the rock during the past campaign, information that relies mainly on fishers' knowledge. The different management strategies for each zone require continuous and adaptive management as well as detailed up to date information on each zone. This can be observed in Fig. 5 where the trends for 3 different zones are represented, these are *Cabo Cebes*, *Maste* and *Picones*. The areas vary in size and location; nonetheless, they are all found in the *Tapia-Figueras* plan and are categorized as good quality zones. A different management strategy has been taken for each rock either alternating total bans with no ban (*Cabo Cebes*), partial bans (*Maste*) or no bans (*Picones*). All three zones exhibit positive trends however this is more pronounced in the alternating total ban strategy. Still, it is important to take into account that due to the total bans few data points are available for the *Cabo Cebes* zone. To ensure the flexibility of the plan, the fishers hold emergency meetings throughout the fishing season to determine the status of the plan and the measures necessary to sustain the resource (Table 2). Thus, the incorporation of the community in the management process empowered the resource users, by providing

Table 2
Adaptive capacity characteristics of the Asturian gooseneck barnacle co-management system.

Characteristic	Examples
Versatile effort management	Fishing season length varies among plans. Fishing season length may vary yearly. Daily TAC adjusted between plans. Daily TAC adjusted in the 2004–2005 fishing season. Compatible fisheries vary among plans. Conditions for license bestowal depend on the <i>cofradía</i> . Conditions for license renewal.
Flexible management of bans	Yearly determination of bans for each zone. Regular meetings to determine condition of zones. Emergency closures to prevent overexploitation.
Incorporation of life history traits	Fishing season adapted to species' reproductive cycle. Daily TAC adapted to species' settlement strategy.
Matching biological, social and management scales	Fine-scale distribution of the resource based on fishers' knowledge. Management scale adapted to resource dispersal range. Management adapted to the social context of each plan.

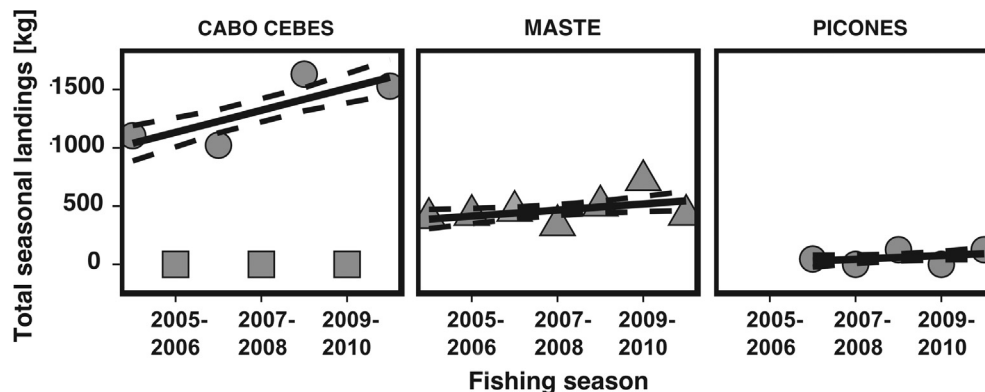


Fig. 5. Seasonal landings in 3 good quality zones of the *Tapia-Figueras* plan. Total, partial and no bans are represented by squares, triangles and circles, respectively. Trend lines (solid line) and standard errors (dotted line) are shown for each zone.

them with a key role in the decision-making process as was expressed during the focus groups, and endorsed the integration of fishers' knowledge in the guidelines.

Furthermore, the adaptability of a co-management plan permitted the careful incorporation of gooseneck barnacle life history traits into the guidelines and the development of innovations within the plans (Table 2). Before the establishment of the co-management system research on the distribution and life history traits of the resource was carried out to determine its exploitation potential [32], it is complemented each year by follow-up research performed by the DGPM. Careful attention is placed to protect juveniles in the co-management system by setting a minimum harvest size of 4 cm. Nonetheless, according to fishers' knowledge and scientific information *P. pollicipes* larvae usually settle on the adults [33], thus by-catch is unavoidable. The system adapted by allowing a few individuals below size as long as they do not surpass a 10% of the landings. Another important trait is *P. pollicipes* reproduction occurring asynchronously during the summer, from April to September [34,35]. Once the government officials obtained this information, a fishing season from October to April (both inclusive) was proposed to allow juveniles to settle during the summer. After negotiation all the *cofradías* agreed to the fishing season. However, according to the *Cabo Peñas* stakeholders in the focus group and interviews, the seven-month fishing campaign was no longer suitable to the needs of the plan. Consequently, since the 2004–2005 season *Cabo Peñas* exploits one third of their area during the summer.

Another example of the co-management system's capacity to adapt to changes is the change in daily TAC implemented in the 2004–2005 campaign (Table 2). Due to decreased landings observed by the DGPM and the *cofradías*, daily TAC was reduced from 8 to 6 kg for most of the campaign with the exception of the high season (December), where it would remain at 8 kg. However, the *Cabo Peñas* *cofradía* petitioned to maintain the 8 kg TAC, it was agreed that they would harvest 8 kg during pre-established dates determined at the beginning of the season.

4. Discussion

The Asturian gooseneck barnacle co-management system provides an interesting example of the establishment of collaborative management in small-scale European fisheries. The implementation of TURFs in Asturias, much like in other areas, brought with it a series of positive cascading effects [5]. Among the most evident effects is the incorporation of fishers' knowledge in management guidelines, the empowerment of stakeholders by making them active participants in the decision making process, a matching of scales between resource dynamics and management, an effect over market forces, improved scientific information on the resource and an increase in adaptive capacity of the system. These characteristics of co-management systems demonstrate its potential to be incorporated in the great variety of small-scale fisheries encompassed in the wider European context.

4.1. Fine-scale management

The Asturian co-management system is unique, in that its clearly defined management units reach a highly detailed scale. These types of units have been endorsed as a determinant factor in the success of co-management systems [2,8]. In the Asturian co-management system the users and the resource are well-defined, creating an optimal situation for fishers to develop a sense of entitlement. Furthermore, the fine-scale provides an added bonus to scientific research in the area. The effective and continuous incorporation of local and scientific knowledge in a management

system is a key driver for its success [16,36] and the lack thereof an element for its failure [23]. The yearly follow-up research performed by the DGPM acts as a reference for the development of management guidelines, contributing to the sustainability of the system. Additionally, the spatially explicit information on fishing stock, quality and conservation status gathered by the *cofradías* has vast research potential.

4.2. Fishers' knowledge and empowerment

The incorporation of the fine-scale management system was a consequence of the implementation of fishers' knowledge. The *cofradías* and its members were responsible for subdividing the plans into zones, according to the zones historical distribution. Furthermore, they characterized each zone by the quality of gooseneck barnacles it yields. The application of fishers' knowledge in the fishery reinforced the generation of new knowledge in the community by allowing users to become more acquainted with the resource. Currently, fishers recognize each zone by name and monitor its status along fishing seasons providing them with new knowledge. This positive feedback mechanism and progressive accumulation of knowledge have been identified as key factors to successful adaptation in management systems [37]. Moreover, acknowledging the fishers' knowledge empowers the resource users, producing greater involvement and acceptance of the management system [38,39]. In the gooseneck barnacle co-management system, fishers' knowledge has been considered since its beginnings and currently there is great involvement of the *cofradías* in all management aspects. An example of this is the reaction of fishers towards poachers. Management and protection of the resource are viewed as a personal interest by the fishers, thus generating a sense of empowerment. Hence, the fishers are invested in the resource and do not hesitate in implementing their own surveillance. The same phenomenon occurred in the loco fishery in Chile [8], where it reduced costs and allowed for a more effective control. These events demonstrate how the implementation of the co-management system has aided in creating social capital, which is essential to the success of any fishery [4,40].

4.3. Co-management as a driver for market forces

The co-management system exerted an effect in markets when it first started commercializing barnacles and it still continues to drive market cycles. Gooseneck barnacles in Asturias have evolved since the establishment of the system from being an under-commercialized resource to reaching prices of over 200 euros/kg in Asturian markets. Through the establishment of a co-management system with spatial property rights the fishery managed to avoid the *tragedy of the commons* [13] found in open access markets, the common system in European fisheries, by incentivizing the exploitation and stewardship of a pristine resource.

The fishing season was established based on fishers' knowledge and scientific information available, particularly *P. pollicipes* reproductive cycle. Moreover, the fishing season and market cycles have mutually affected each other. A relationship between supply and demand was observed and has been incorporated into the guidelines by maintaining fishers' daily TAC in 8 kg during the peak market season (December). Despite these measures there is not enough supply to meet the increased demands of the season resulting in a pronounced mean price increase. For the rest of the campaign supply and demand are balanced and prices stabilize. During the summer period, only the *Cabo Peñas* plan remains open, while market prices decline with regard to those in the high or mid seasons.

Another characteristic of the system that drives market forces is the establishment of bans. Good quality zones with higher

commercial value are submitted to partial bans and are only harvested during the high season. This strategy ensures that the best resource will be sold at the highest price thus raising market prices. An effect of fishers short-term decisions on market demands has been documented in other small-scale fisheries [5,41]. According to Gutiérrez et al. [2], in the most accomplished co-management systems the market is influenced by the fishers, as is the case in Asturias.

4.4. Adaptive management

Adaptive management has been broadly accepted as a desirable condition for natural resource management systems [39], it enhances the resilience of managed natural resources by accounting for their unpredictability [39]. The Asturian co-management system is continuously renewing its management guidelines through careful assessment, whether it is through fishers' knowledge or scientific information. Bans are adapted to the distribution and the particular spatial dynamics of each zone. The flexible management of bans, particularly total bans, has been effective controlling landings. Much like in agricultural systems where lands are left fallow to improve productivity, in the gooseneck barnacle fishery high quality areas are left unharvested for a year (total ban) to improve next years' landings. Additionally, if reductions in landings are perceived immediate measures are taken, the affected zones are banned for the rest of the season. In the case of the gooseneck barnacle fishery, when a continuous reduction in global catches was determined by the DGPM and perceived by the fishers, a reduction in daily TAC was implemented. According to stakeholders of the seasonal management plans, adaptive management has enabled the sustainability of the plans and produced an increase in yield.

Within the Asturian co-management system important differences among management plans exist. Particularly the *Cabo Peñas* plan, which has developed different harvesting strategies and guidelines than other plans. However, these measures are not always beneficial. For example, harvesting zones during the reproductive period of a species that settles on conspecifics [33] might be detrimental to the stock. In a top-down system it would have been very difficult to find a solution however in a flexible collaborative system, such as the gooseneck barnacle co-management, compromises were found. The campaign was adapted for the *Cabo Peñas* plan, its territory was divided into three sub-areas; two are exploited during the fishing season and one during summer months. This way the fishers are still able to harvest all year without affecting recruitment for the entire plan. Also, excess in effort due to greater TAC and a longer campaign in *Cabo Peñas* could lead to reduced prices [5] and overexploitation of the population [42]. However, in the Asturian co-management system the excess in landings was accounted for by reducing *Cabo Peñas*' effort to specific days. As in other collaborative systems, the downfalls in the gooseneck barnacle management were mitigated through cooperation among stakeholders [43]. Interviews and focus groups shed light on the different social context and perceptions of the *cofradías*, particularly *Cabo Peñas*. Thus, any fishery management strategy that encompasses all *cofradías* must have the adaptive capacity present in co-management systems.

4.5. Implementation of co-management

When the co-management system was first proposed there was no particular *critical juncture* motivating the fishers towards a change in policy, differing from most cases where collaborative management has been implemented [3]. On the contrary, the emergence of co-management was triggered exclusively through the foreseen benefits of having exclusive rights to market an

unexploited resource. The success of the pilot program generated a *domino effect* throughout the western Asturias coast, demonstrating the influence of spatial dynamics on a social system. Such interdependencies in fisheries management have been previously documented [4], although, it is usually focused on the downfalls and not the advantages this might represent in a social system. The Asturian gooseneck barnacle co-management case reveals that windows of opportunity can be created when the actors involved feel invested in the new management scheme and both parties work towards a common goal, in this case making *P. pollicipes* a marketable and sustainable resource.

4.6. Co-management and Europe

Three main advantages of co-management documented in the literature and present in the gooseneck barnacle case study could be of relevance for European Union policies. First, the building of social capital and empowerment of fishers, which incentivizes the preservation of stocks and promotes collaboration among stakeholders [40]. Second, co-management has enabled the incorporation of both scientific and fishers' knowledge, making management guidelines more robust [8,44]. Finally, decentralized management with a focus on adaptive capacity has allowed to confront ongoing challenges posed by these complex social-ecological systems [7]. If co-management is to become a gateway to sustainable fisheries in Europe, there is an urgent need to create learning platforms where government, local stakeholders and researchers can co-construct knowledge and innovate upon the opportunities of engaging in multi-scale collaborative natural resource management.

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