PhD thesis:

ECOLOGICAL AND SOCIAL BASES FOR A MORE RESILIENT STALKED BARNACLE FISHERY

Universidad de Oviedo

PhD Program: Biogeosciences

Department of Biology of Organisms and Systems

Tesis doctoral:

BASES ECOLÓGICAS Y SOCIALES PARA UNA PESQUERÍA DE PERCEBE MÁS RESILIENTE

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Departamento de Biología de Organismos y Sistemas

Katja Juliana Geiger

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Under the supervision of:

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RESUMEN DEL CONTENIDO DE TESIS DOCTORAL

1.- Título de la Tesis	
Español/Otro Idioma: BASES ECOLÓGICAS Y SOCIALES PARA UNA PESQUERÍA DE PERCEBE MÁS RESILIENTE	Inglés: ECOLOGICAL AND SOCIAL BASES FOR A MORE RESILIENT STALKED BARNACLE FISHERY

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RESUMEN (en español)

Las pesquerías artesanales de recursos bentónicos sedentarios marinos (S-Fisheries del inglés) son particularmente vulnerables al cambio climático, la inestabilidad socioeconómica y la sobreexplotación. Por su movilidad limitada, los organismos dependen de las condiciones ambientales locales para sobrevivir y los pescadores dependen de estas poblaciones y de los mercados locales para su sustento. Por lo tanto, es necesario aumentar la resiliencia de las S-Fisheries para garantizar su sostenibilidad a largo plazo. El objetivo general de esta tesis fue identificar posibles mejoras en la gestión de las pesquerías de percebe en regiones europeas.

Comprender la resiliencia ecológica de percebe (*Pollicipes pollicipes*) frente a la explotación es fundamental para avanzar hacia una gestión pesquera basada en los ecosistemas. Exploramos los efectos del marisqueo de percebe en la comunidad intermareal y el potencial de la recuperación de *P. pollicipes*, mediante un experimento ecológico de 2 años en la costa de Asturias. Se hizo evidente que el marisqueo de percebes afecta a la estructura de la comunidad intermareal, disminuyendo la cobertura de *P. pollicipes* y *Mytilus* spp. y aumentando la cobertura de *Chthamalus* spp. y *Corallina* spp. La diversidad ecológica disminuyó al principio hasta que la roca fue nuevamente colonizada en el proceso de sucesión, lo que condujo a un aumento posterior en la diversidad. La recuperación de las agregaciones de percebe explotadas fue lenta, pero en condiciones de jaula sin extracción, la cobertura inicial aumentó hasta un 80%. En términos de gestión, proponemos que la implementación de vedas bianuales podría contribuir a mejorar la sostenibilidad de esta pesquería.

La dimensión humana es otro aspecto clave para la resiliencia en las S-Fisheries debido a la interdependencia socioecológica. Evaluamos la respuesta de los perceberos asturianos ante fluctuaciones ecológicas y económicas hipotéticas del recurso. Las respuestas demuestran la eficacia de las estrategias comúnmente implementadas y su preferencia por proteger el recurso en respuesta a una abundancia biológica reducida. Los perceberos tienen un fuerte deseo de mejorar la rentabilidad económica de la pesquería y están dispuestos a implementar estrategias a corto plazo para influir la demanda del mercado y provocar un aumento en el precio de mercado. La gestión pesquera debería aspirar a una mayor flexibilidad en su respuesta a las cambiantes condiciones ambientales y de mercado, así como a una mayor participación de los perceberos asturianos en la toma de decisiones para mejorar la resiliencia.

La gestión de la pesquería de percebe varía ampliamente entre diferentes regiones europeas. Perceberos de pesquerías con menores niveles de gobernanza tienen mayor disposición para realizar cambios en las estrategias de gestión actuales. La elección de la estrategia más importante para la gestión sostenible variaba y no surgió una única estrategia óptima de gestión preferida por los perceberos de todas las regiones. Se detectó un efecto de "la hierba es más verde al otro lado", ya que los perceberos tienden a creer que las estrategias de gestión en otras áreas son más efectivas o deseables que las propias. Perceberos de pesquerías con altos niveles de gobernanza y derechos de uso territorial para la pesca (DUTPs) mostraron una

fuerte preferencia por restricciones espaciales. Proponemos que los DUTPs combinadas con las redes de áreas vedadas presentan una estrategia útil para promover la sostenibilidad de las poblaciones de percebe. Sin embargo, al elegir la estrategia de gestión más apropiada para cada región, es necesario considerar las necesidades y características únicas de cada pesquería.

Identificamos el furtivismo como un desafío interregional para las pesquerías europeas de percebe. Hay diferentes tipos de furtivos (perceberos profesionales, recreativos, o sin licencia) que pueden operar a diferentes escalas, desde local hasta transnacional. Las sofisticadas redes de distribución, la falta de trazabilidad y la vigilancia ineficaz fomentan el marisqueo ilegal.
Cómo responden las pesquerías a este desafío depende de los tipos de furtivos involucrados y del nivel de gobernanza que haya desarrollado una pesquería. Se encontró que una fuerte cohesión entre los perceberos y altos niveles de cooperación entre las partes interesadas ofrecen las mejores condiciones para reducir el furtivismo.

El proyecto PERCEBES formó la base para esta tesis, y representa un primer paso importante hacia el fomento de sistemas de gestión más colaborativos y transregionales entre las pesquerías europeas de percebes.

RESUMEN (en Inglés)

Small-scale fisheries that target sedentary marine benthic resources (S-Fisheries) are particularly vulnerable to climate change, socio economic instability, and overexploitation. Due to their limited mobility, these organisms rely on local environmental conditions for survival and harvesters depend on these local stocks and markets for their livelihoods. Therefore, there is an urgent need for S-Fisheries to increase their resilience and ensure long-term sustainability. The overall objective of this thesis was to identify potential improvements in the management of European stalked barnacle fisheries.

Understanding the ecological resilience of stalked barnacles (*Pollicipes pollicipes*) towards exploitation is a fundamental groundwork for transitioning towards a more ecosystem-based management. During a 2-year experiment on the Asturian coast, we explored the effects of stalked barnacle harvest on the intertidal community and the species potential for recovery. It became apparent that the stalked barnacle harvest affects the intertidal community structure. *P. pollicipes* and *Mytilus* spp. coverages decreased, while *Chthamalus* spp. and *Corallina* spp. coverages increased due to the exploitation. The ecological diversity first decreased with exploitation until the bare rock was newly covered by species in the course of succession, leading subsequently to an increased diversity. The recovery of exploited stalked barnacle aggregations was slow, but under caged non-extracted conditions the initial coverage of the species increased by up to 80%. Regarding management implications, we suggest that two-yearly harvest bans can benefit the sustainability of this fishery.

The human dimension is another key aspect for promoting resilience in S-Fisheries due to the social-ecological interdependence. We assessed the response of Asturian stalked barnacle harvesters towards hypothetical ecological and economic fluctuations of the resource. The responses demonstrate the effectiveness of commonly implemented strategies and their preference to protect the resource under reduced abundance scenarios. Harvesters also have a strong desire to improve the economic profitability of the fishery and are willing to apply short-term strategies to influence market demand and to provoke an increase in the market price. The fisheries management should aim for more flexibility in its response to changing environmental and market conditions, as well as for an increased participation of Asturian harvesters in decision-making to enhance the fisheries resilience.

Stalked barnacle fishery management varies greatly among different regions in Europe. Harvesters from stalked barnacle fisheries with lower levels of governance and management success demonstrated a greater willingness to make changes to the current management strategies. The choice for the most important strategy for sustainable management varied and no single optimal management strategy emerged that was preferred by harvesters from all regions. A "grass is greener" effect was detected, as harvesters tend to believe that

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management strategies in other areas are more effective or desirable than their own. Harvesters from fisheries with high levels of governance and Territorial User Rights for Fishing (TURFs) showed a strong preference for spatial restrictions. We propose that no-take area networks combined with TURFs, present a useful future strategy to promote sustainability of stalked barnacle stocks. However, for choosing the most appropriate management strategy for each region, it is necessary to consider the unique needs and characteristics of each fishery.

We identified poaching as an inter-regional challenge to the European stalked barnacle fisheries. There are different types of poachers (professional, recreational and unlicensed harvesters) that act on different scales from local to trans-national. Sophisticated distribution networks, a lack of traceability, and ineffective surveillance promote poaching. How fisheries respond to this challenge depends on the types of poachers involved, and the level of governance a fishery has developed. Strong cohesion among harvesters and high levels of cooperation between stakeholders were found to offer the best conditions for reducing poaching activities.

The international research project PERCEBES, which laid the foundation for this thesis, represents an important initial step towards fostering more collaborative and transregional management systems among European stalked barnacle fisheries.

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Acronyms

CFP Common Fisheries Policy

DUTP Derechos de uso territorial en las pesquerías

PPC Política Pesquera Común

PNSACV Parque Natural do Sudoeste Alentejano e Costa Vicentina

SSF Small-scale fisheries

S-fishery Small-scale fisheries targeting spatially structured sedentary stocks

TURF Territorial User Rights for Fishing

RC Rostro-carinal length is measured across the capitulum between the ends of the rostral and carinal plates of the gooseneck barnacles and is used as the standard size measurement

RNB Reserva Natural das Berlengas

CHAPTER 1

Introduction

1.1. Challenges for S-Fisheries

Fisheries today face manifold and complex challenges due to impacts of climate change, unpredictable socio-economic fluctuations, and social-political uncertainties, among others (e.g. Barange et al. 2018; Ricke et al. 2018; Bennett et al. 2020; Knight et al. 2020). Additionally, humans have been identified as selective keystone predators that can significantly alter ecosystems through their exploitation activities (Castilla 1999) to the point that severe overexploitation currently threatens the survival of many fisheries (Pauly 2009; Pomeroy 2012; Muallil et al. 2014). Studies that assess the impacts of exploitation on target species and on interspecific interactions are thus helpful for developing ecosystem-based fisheries management strategies (Crowder et al. 2008). As complex social-ecological systems, however, ecological and social factors are interdependent in fisheries (Ostrom 2009). Therefore, an integrated approach that considers the relationship between stock health and social vulnerability is necessary for their management (Ruiz-Díaz et al. 2020). The resilience of fisheries, including their ecological, socioeconomic, and governance dimensions, will play a crucial role in determining whether they can withstand future challenges (Mason et al. 2022). The resilience and adaptability of marine species in response to climate change and exploitation are highly variable and in many cases unknown (Jones and Cheung 2018). Important factors determining the ecological resilience of marine species are their mobility and other life history traits, such as reproductive strategies, age of maturity and growth rate (Adams 1980; Roff 1984; Kirkwood et al. 1994; Jennings et al. 1999). Sessile marine benthic organisms are likely to be particularly affected by the impacts of climate change, because of their low spatial mobility (Hiddink et al. 2015) and their dependence on hydrodynamic conditions and climatic factors that control larval supply and settlement (Bertness et al. 1996; Crimaldi et al. 2002; Hiscock et al. 2004). S-Fisheries[1], referring to small-scale fisheries that target spatially-structured, sedentary stocks, are thus particularly vulnerable due to the ecological limitations for the resource to escape responding to climatic changes and high exploitation pressure, as well as due to the strong dependency of fishers on local stocks and reliable markets for their livelihoods (Ruiz-Díaz et al. 2020). Hence, the urge for these S-Fisheries to maximise their resilience and long-term sustainability.

Despite their importance as a vital component of the European coastal zone, small-scale fisheries (SSFs) in Europe have traditionally received less research attention than large-scale fisheries (Guyader et al. 2013; Percy and O'Riordan 2020). However, due to the critical state of many SSFs worldwide, efforts have been made to reform management systems. This is evidenced by the adoption of the Voluntary Guidelines for Securing Sustainable Small-Scale Fisheries (SSF Guidelines) by FAO member states in 2014 (FAO 2015), as well as the European Common Fisheries Policy's shift towards promoting efficient management of SSFs as its primary focus since 2016 (Union 2016).

[1] Stocks targeted by S-fisheries are spatially structured as metapopulations of localized subpopulations typically interconnected through larval dispersal. Population dynamics are dominated by spatial heterogeneity and the effects of fishing events are localized. Many artisanal fisheries along coastal zones belong to the "S" type and support the livelihood of hundreds of thousands of fishers and their families worldwide. (Orensanz et al. 2005)

1.2. Improving S-fisheries through increased harvesters participation

Ecosystem-based management (EBM) has achieved recognition by governments and through international agreements as a useful approach for managing SSFs sustainably (Curtin and Prellezo 2010). It considers the interconnectedness and interdependent nature of ecosystem components, including human activities and their impact within these complex adaptive systems (Curtin and Prellezo 2010). The assessment of human impacts, e.g. the effects of exploitation on targeted species and interspecific interactions, can serve as base for the development of ecosystem-based strategies for fisheries (Crowder et al. 2008). Due to the reciprocality and interdependence between humans with nature, however, the ecosystem-based approach alone will not be sufficient to foster resilience and long-term sustainability. Humans act as keystone predators within the natural environment (Castilla 1999) and managing a fishery is therefore essentially managing the behaviour of fishers (Miller and Van Maanen 1979). The failure to involve resource users in meaningful decision-making has been identified as a leading cause of the global fisheries crisis (Pita et al. 2010). The human dimension, thus, is a key component for effective fisheries management (Jentoft and McCay 1995; Kaplan and McCay 2004) and the main stakeholders, specifically resource users, should be included in the decision-making process to adopt successful participatory management practices, as acknowledged by the European Commission since its reform in 2002 (European Commission 2001). This fosters trust, increases their sense of responsibility and accountability, enhances the legitimacy and acceptance of management practices and decisions, and contributes to more effective enforcement of rules and regulations by boosting compliance (Jentoft and McCay 1995; Kapoor 2001; Mikalsen and Jentoft 2001; Soma 2003; Coffey 2005; Delaney et al. 2007). Notably, user compliance is pivotal to the success of implemented management (Hatcher and Pascoe 2006; Oyanedel et al. 2020).

Gaining insights into how resource users perceive the legitimacy of management strategies at the local scale can facilitate the prediction of compliance levels (Oyanedel et al. 2020). Hence, social behaviour and perception studies can be a useful tool for providing valuable insights into the effectiveness of management strategies (Bennett 2016), due to the unique perspective on practices and valuable insights into the ecological and social impacts of their activity. Furthermore, through adaptive co-management that facilitates collaboration among stakeholder groups, such as resource users, scientists, policymakers, and managers, social learning can be enhanced leading to effective solutions to problems (Berkes 2001) and empower coastal communities to manage their fisheries sustainably (Kofinas 2009). Opportunities for knowledge exchange among stakeholders from different regions can additionally provide valuable insights into the potential for improvement in fisheries management (Geiger et al. 2022).

1.3. Europe's stalked barnacle fisheries

Pollicipes pollicipes (Gmelin, 1791 [in Gmelin, 1788–1792]) is a sessile pedunculated cirriped, commonly referred to as stalked barnacle that grows on very exposed rocky shores from the shallow subtidal to the mid-intertidal (Cruz et al. 2022). Its geographical distribution ranges from the southwestern coast of the UK down to Senegal in West Africa (Cruz et al. 2022). Stalked barnacles go through 6 nauplii and one cyprid stage before settling preferentially on adult conspecifics (Kugele and Yule 1996; Cruz et al. 2022). Populations are interconnected through extensive larval exchange primarily driven by oceanographic phenomena such as currents, upwelling systems and eddies (Nolasco et al. 2022). Furthermore, trans-generational connectivity via steppingstone populations is expected to connect populations over larger distances (Nolasco et al. 2022). Reproduction and recruitment intensity and periodicity exhibit geographic variability across the distribution range of the species, with a shorter reproductive period and lower recruitment at the northern periphery of its distribution limit (Aguión et al. 2022).

In Europe, stalked barnacles have been harvested since the Mesolithic (Álvarez-Fernández et al. 2010), and the modern fishery is of high cultural and economic value particularly on the Iberean Peninsula (Aguión et al. 2021; Cruz et al. 2022). In Spain stalked barnacles are considered a luxury item and prices in first-sales auctions can reach 200-266€/kg (Rivera et al. 2014; Ruiz-Díaz et al. 2020). Despite the fishery's cultural and socioeconomic significance, its ecological impact on the intertidal community is still not fully understood. The high market value of this species also poses challenges, because it encourages overfishing and poaching, thereby threatening the social-ecological sustainability of the fishery. Poaching has become a common and serious problem in European stalked barnacle fisheries, and even evolved into a highly sophisticated and organised international activity, in some cases (Geiger et al. 2022).

The management of stalked barnacle fisheries varies significantly across European regions, with differences in regulations, monitoring, and enforcement practices (Aguión et al. 2021). In the scope of this thesis, we include stalked barnacle fisheries from the following european regions: Spain (Asturias and Galicia), Portugal (Reserva de Berlengas – RNB, and Parque Natural do Sudoeste Alentejano e Costa Vicentina - PNSACV), and France (Morbihan in Brittany) (Fig. 1.1).

In Galicia and along the West coast of Asturias, the stalked barnacle fisheries have the highest implementation level among all regions, and are managed at a detailed spatial scale through an exclusive access structure provided by Territorial User Rights for Fishing (TURFs) (Aguión et al. 2021). Co-management is consultative-cooperative, with responsibilities and decision-making power shared between the fisher's associations, so called *cofradías*, and the local governmental body (Molares and Freire 2003; Rivera et al. 2014). Harvesters propose yearly management plans with detailed temporal and spatial indications of harvesting effort, which must then be approved by the regional fisheries administration and made publicly available for consultation (Geiger et al. 2022). Surveillance is carried out by regional and TURF guards, as well as in some cases by harvesters and National Park guards. Along the eastern coast of Asturias, the fishery was managed as a single unit, applying only general management strategies until February 2023, when two TURFs were implemented covering the entire area. Before the implementation of the TURFs, co-management was at the instructive level, representing the lowest level of co-management among the studied regions (Aguión et al. 2021). Management of the stalked barnacle fishery in Portugal varies by location. In the Reserva Natural de Berlengas, a small archipelago near the Portuguese mainland, the fishery operates similarly to a TURF due to its geography and limited number of licences for professional harvesters. In 2021, the RNB stalked barnacle fishery underwent a transition to co-management by law, representing the first legally agreed co-management case in Portugal. This has led to an increased level of co-management, greater participation by harvesters, and improved resource monitoring, with an expectation that the level of co-management will continue to increase in the future (Cruz et al. 2022).

In PNSACV recreational harvesting is allowed and surveillance is done by reduced police patrols along vast swaths of coast (Aguión et al. 2021). In the rest of mainland Portugal, management is top-down, implemented through general strategies, such as easily attainable daily licences and individual quotas, allowing recreational harvest (Aguión et al. 2021).

The co-management in Morbihan is informally agreed upon, with unofficial representatives of harvesters proposing various regulations that must then be approved by the regional fisheries committee. Recreational harvesting is allowed and, similarly to PNSACV, surveillance is scarce.

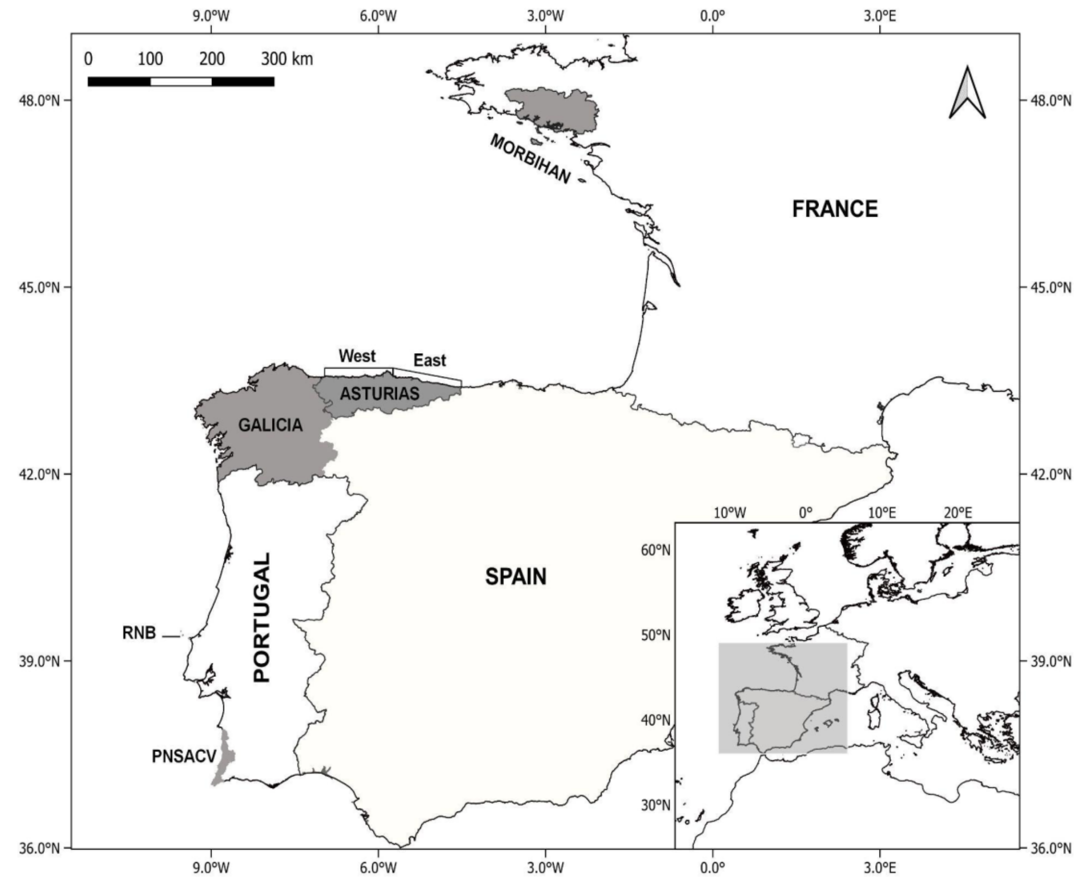


Figure 1.1. Map of regions included in the scope of this thesis: Morbihan in Brittany, France; the Spanish regions of Asturias (East and West) and Galicia; and the Reserva Natural das Berlengas (RNB) and the Parque Natural do Sudoeste Alentejano e Costa Vicentina (PNSACV) in Portugal.

Box 1.1 Notes on the biology of *Pollicipes pollicipes* (Gmelin, 1791 [in Gmelin, 1788–1792])

The stalked barnacle (*P. pollicipes*) is a cirripede of superorder Thoracica, order Pedunculata, family Pollicipedidae. *P. pollicipes* is a simultaneous hermaphrodite with cross-fertilization (Cruz 2022). Reproduction typically takes place during the spring to autumn period, although the main season and intensity exhibit variations across different geographic locales (Aguión et al. 2022). Individuals breed asynchronously and number of broods vary among geographic locations, ranging from 2 to 6 times per year (Aguión et al. 2022). The embryonic development of fertilized eggs takes 1 month and is carried out inside the mantle cavity (Cruz et al. 2010). Once hatched, the planktonic larvae are liberated into the water (Fig. 1.2 A) and go through 6 *nauplius* stages, taking another month for this until they shift into a cyprid stage that specializes in settlement (Fig. 1.2 B; De la Hoz and García 1993). Cyprids recruit heavily on conspecific adults (Barnes 1996). During their juvenile stage they gradually descent the stipe of the adult to finally settle on the rock (Fig. 1.2 C). This way adult stalked barnacles form dense aggregations (Fi. 1.2 D), which ensures cross-fertilization.

Figure 1.2. A) Initial Naupliar Larval Stage: The first of the six naupliar larval stages observed shortly after hatching. B) Cyprid larval stage ready for settlement C) Adult stalked barnacles with juveniles attached on their stipes. D) Aggregation of stalked barnacles, forming tight cluster.

1.4. Study approaches

To overcome challenges faced by stalked barnacle fisheries in Asturias and other European regions, this thesis aims to fill knowledge gaps and identify potential improvements in the management. We used an interdisciplinary approach that combines ecological and social science methodologies, enabling a more holistic understanding of the system. To create foundational scientific knowledge that facilitates a transition towards more ecosystem-based management, we conducted ecological experiments to assess the impact of the stalked barnacle harvest on the intertidal community structure and the recovery potential of *P. pollicipes*. Regarding social science methods, we applied perception studies. We propose that by incorporating the preferences of harvesters for management responses into the decision-making process, a sense of ownership can be fostered. This, in turn, can enhance their motivation to comply with the measures and ultimately contribute to a more resilient fishery. Furthermore, we carried out an international multi-stakeholder workshop as a knowledge exchange opportunity to gain additional insight into management solutions implemented across Europe. This led us to explore the potential of a multi-scale, polycentric governance system as a trans-regional framework for addressing complex challenges (e.g. poaching) through cooperation among stalked barnacle fisheries across Europe.

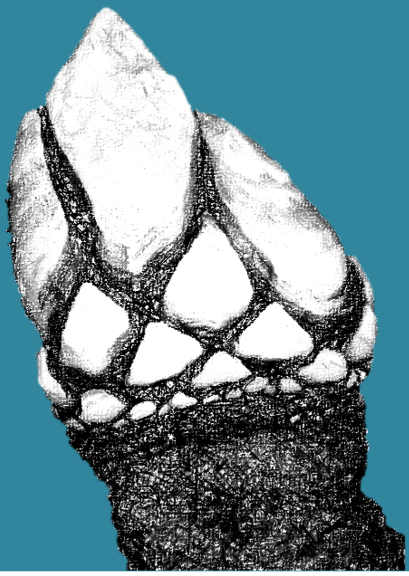
1.5. Objectives

General objective

Fill ecological knowledge gaps and investigate the perceptions and preferences of harvesters regarding management strategies, to improve the management of stalked barnacle fisheries in Europe.

Specific objectives

1. Examine the impact of the stalked barnacle harvest on the intertidal community and explore the implications for its management.
2. Explore harvesters' management strategy choices responding to hypothetical ecological and economic fluctuations of the resource.
3. Investigate harvesters' perceptions and preferences for the implemented management tools to improve the sustainability of the fishery.
4. Determine the common challenges for stalked barnacle fisheries among European regions and find possible solutions through multi-sectoral knowledge exchange.



CHAPTER 2

Effects of stalked barnacle harvest on a rocky shore intertidal community

2.1. Introduction

Human-exclusion experiments have demonstrated that exploitation can alter the structure of intertidal communities (e.g. Castilla and Duran, 1985; Castilla, 1999; Duran and Castilla, 1989; Godoy and Moreno, 1989; Moreno, 1986; Moreno et al., 1984; Oliva and Castilla, 1986; Rius et al., 2006). The resilience of intertidal organisms to exploitation is influenced by the mobility and life history traits, such as reproductive strategies, age of maturity, and growth rate (Adams, 1980; Jennings et al., 1999; Roff, 1984). Additionally, interspecific interactions and trophic level can affect a species' ability to recover after exploitation (Jennings et al., 1995; Jennings and Polunin, 1996; Koslow et al., 1988; Pauly et al., 1998). Evaluating the impact of exploitation on target species and interspecific interactions is crucial for developing ecosystem-based fisheries management strategies (Crowder et al. 2008). This is essential particularly for small-scale fishing communities that heavily rely on local marine resources for their livelihoods and that may contribute to resource overexploitation (Pomeroy 2012; Muallil et al. 2014).

In this study, we examine the sessile pedunculated cirripede, *Pollicipes pollicipes* (Gmelin, 1791 [in Gmelin, 1788–1792]) a stalked barnacle, and its associated marine community. The geographical distribution of *P. pollicipes* ranges from the southwestern coast of the UK down to Senegal in West Africa, where it typically grows on very exposed rocky shores in the shallow subtidal to the mid-intertidal zone (Cruz et al. 2022). The species forms dense clusters securely attached to the substrate by a cement-like substance (Rocha et al., 2019). *P. pollicipes* life cycle includes planktonic larval phases (nauplii and cypris) and a benthic adult phase (Molares et al. 1994; Kugele and Yule 1996). *P. pollicipes* are cross-fertilizing, simultaneous hermaphrodites and larvae recruit heavily on conspecific adults (Cruz et al. 2010), rendering the species vulnerable to overexploitation (Rivera et al. 2017b).

In Europe, particularly in Spain and Portugal, *P. pollicipes* has been harvested for thousands of years, dating back to the Mesolithic (Álvarez-Fernández et al. 2010; Cruz et al. 2022). Presently, this species is highly valued and intensively exploited, with approximately 500 t being harvested annually by around 2,100 professional harvesters in Europe, generating revenues of 10 million € (2013-2016; Aguión et al., 2021). The depletion of local stalked barnacle stocks in various parts of Spain (Molares and Freire 2003) has prompted the implementation of diverse management solutions. In the Basque Country, Bay of Biscay, a no-take marine reserve was established specifically to protect the *P. pollicipes* stocks (Borja et al. 2006), while in Galicia, a co-management system was introduced in the early 1990s. This co-management system involves regulated access through the utilization of Territorial User Rights for Fishing (TURFs) (Molares and Freire 2003) and regular stock assessments since 1992 (Macho et al. 2013). A comparison of the overall governance and sustainability level among different stalked barnacle fisheries in Europe showed that management in Galicia and Asturias-West are the most successful (Aguión et al., 2021).

In Asturias (Fig. 2.1), the management of the stalked barnacle fishery is carried out through a combination of general regulations applied throughout the entire region (Gobierno del Principado de Asturias 2022), as well as an adaptive co-management system along the west coast since 1992 (Rivera et al. 2014). The general regulations include a designated harvest season (from October until the end of April), a limited number of licenses for professional harvesters, specific time restrictions for the harvest activity (2 hours before high tide until 1 hour after), individual harvest quotas (kilograms per person per day), restrictions on harvest tools, and a minimum commercial size for the stalked barnacles (≥18 mm Rostro-carinal length (RC); Sestelo and Roca-Pardiñas, 2007) (Gobierno del Principado de Asturias, 2022). Similar to Galicia, the co-management system in Asturias-West follows a regulated access approach using TURFs (Aguión et al., 2021; Rivera et al., 2014). Additionally, harvest bans are frequently implemented as a management strategy within the co-management system in Asturias (Gobierno del Principado de Asturias 2022). Total bans involve the complete closure of specific areas for the entire season, while partial bans allow for a limited number of designated harvest days per season (Rivera et al., 2014). Stock assessments done on a yearly base, help to decide whether harvest bans need to be implemented in specific locations. This fishery has proved remarkable resilience and sustainability by employing adaptive management strategies, particularly during critical periods such as the economic crisis in 2008 (Rivera et al. 2017b). It holds significant socio-economic importance for Asturias (Rivera et al. 2014; García-de-la-Fuente et al. 2016; González-Álvarez et al. 2016), contributing around 38-50 million € annually through the harvest of approximately 55 tons (2013-2016; Aguión et al., 2021). However, to date, no prior human exclusion experiment has been conducted to examine the ecological impact of this fishery on the intertidal community.

This study aims to investigate the effects of *P. pollicipes* harvesting on the structure and ecological diversity of the intertidal community along the West coast of Asturias. The objective is to determine the resilience of *P. pollicipes* to harvesting by evaluating the recovery potential of the species within a two-year period. Ultimately, the study aims to contribute to the development of ecosystem-based fisheries management strategies for the stalked barnacle fisheries to ensure ecological sustainability.

2.2. Material and methods

Study location

The experiment was conducted in Asturias, North Spain, at three locations on the south shore of the Bay of Biscay: *La Cruz* (43°33N, 7°01W), *Las Salsinas* (43°35N, 6°14W) and *Las Llanas* (43°33N, 6°06W) (Fig. 2.1). All locations were situated within co-managed TURF areas (Rivera et al. 2014), with Las Salsinas and Las Llanas in Cudillero-Oviñana TURF and La Cruz in Tapia-Figueras TURF.

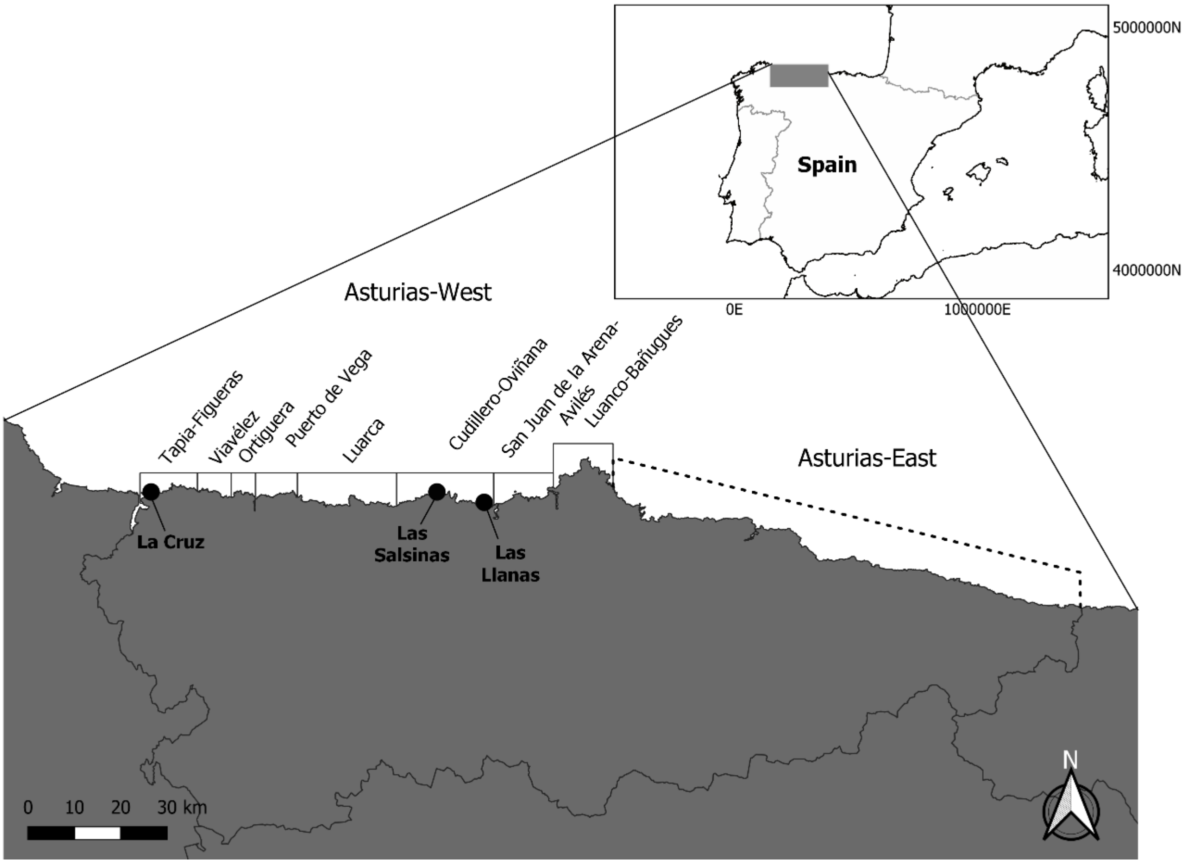


Figure 2.1. Map of Asturias (North Spain) including the 8 TURFs located along the West coast. The three locations where the experiment took place are marked as black dots.

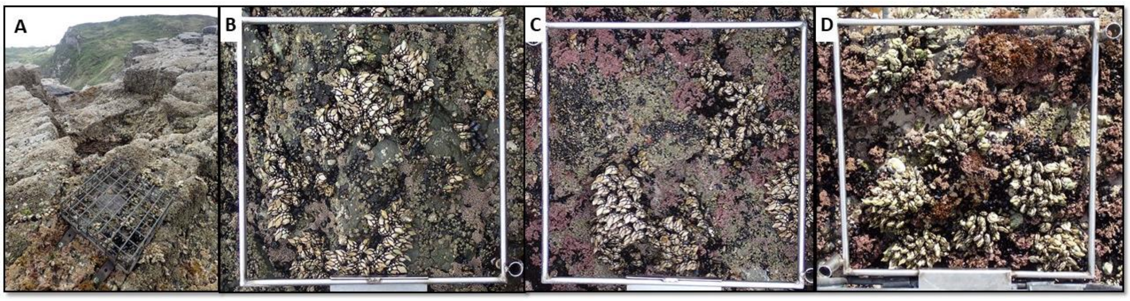


Figure 2.2. Images of a cage (A) and examples of experimental plots with *P. pollicipes* aggregations (B: *Las Llanas*, C: *Las Salsinas*, D: *La Cruz*; Photos: Katja Geiger).

Experimental design

The experiment was conducted on 35 x 35 cm square plots that were located within the middle of the vertical distribution of *P. pollicipes* populations, at the interface between the lower, algae-dominated intertidal and the mid invertebrate-dominated intertidal (Fig. 2.2). The plots were placed randomly among areas with an approximately uniform coverage of *P. pollicipes* (15-20%) and were required to include individuals of commercial size (Fig. 2.2). The approximate coverage of 15-20% was chosen to achieve a comparable coverage among plots and locations at the start of the experiment. Rock pools and deep crevices were avoided wherever possible. The experiment consisted of four factors:

Location (random factor): The three locations (*La Cruz*, *Las Salsinas* and *Las Llanas*) were randomly chosen due to the following characteristics: good accessibility by foot, enough space to place 24 experimental plots with an appropriate coverage of *P. pollicipes*, and with suitable rock surface to firmly attach cages to withstand heavy wave action. Exposure to waves, harvest pressure, harvest bans, and other factors influencing the intertidal community in the selected locations may have varied, much like they would in any other randomly chosen location.

Experiment duration (fixed factor): We used the same experimental setting in two different years and with distinct durations. The first setting started in July 2017 and ended in July 2019 (2-years experiment duration) (Fig. 2.3). The second setting started in July 2018 and also ended in July 2019 (1-year experiment duration).

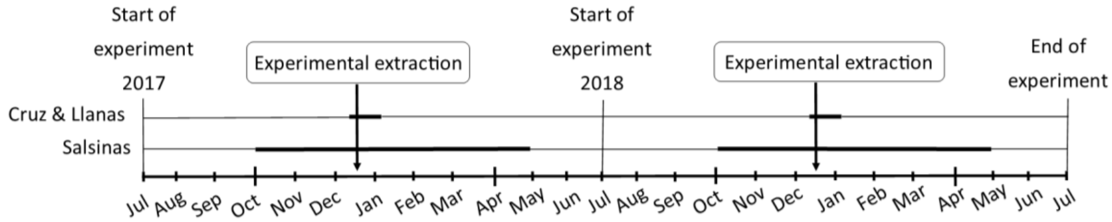


Figure 2.3. ***P. pollicipes*** **harvest schedule at the three experimental locations. Unbolded lines indicate harvest is not allowed due to the closure of the season (May until October), or due to location-specific harvest bans agreed to by the co-management of the TURFs; bolded line indicates that harvest is allowed (Only 15 days per year in** ***Cruz*** **and** ***Llanas*****). Experimental extraction events are indicated with arrows.**

Cage (fixed factor): We covered half of the plots with cages to prevent exploitation (caged, *C+*) and left the other plots uncovered to allow for exploitation by harvesters (uncaged, *C-*). The cages were built with electro welded, galvanised steel wire mesh (4 mm diameter) to avoid decomposition by the salt water and were attached with heavy duty chemical bolts to withstand strong wave action. Cages measured 12 x 35 x 35 cm with a mesh size of 5 cm (Fig. 2.2). This gap allows the passage of scraping tools, but is sufficient to deter the harvest, because harvesters have limited time during the low tide.

Experimental extraction (fixed factor): In half of the plots, both caged and uncaged, we conducted experimental extraction (*E+*). This experimental extraction conducted by us scientists was done as similarly as possible to the way professional harvesters harvest stalked barnacles in terms of methodology and timeframe. Only individuals above a minimum allowed harvest size were removed using a scraper, detaching the animals directly at the base where they attach to the rock to avoid damaging them. We conducted two experimental extraction events for the 2-years experiment. The first extraction was done in winter of 2017/2018 and the second extraction in winter 2018/2019, while the 1-year experiment duration plots were extracted experimentally only once, in winter 2018/2019. The exploitation intensity was not predetermined, but instead estimated retrospectively based on the removal of stalked barnacles detected through image analysis. We will use the term exploitation intensity referring to the degree of extraction of barnacles from experimental plots over the course of the experiment, based on the frequency and extent.

In Asturias the season for harvesting stalked barnacles opens in the beginning of October and closes at the end of April. Along the west coast, where the fishery is managed by TURFs (Fig. 2.1), areas can have more restricted harvest periods. As the experimental locations were situated within TURFs, the experimental extraction conducted by us scientists was conducted during the open period of these locations (Fig. 2.3).

The experimental design had 3 replicate plots for each combination of location, cage, extraction and duration, totalling 72 plots.

Hypothesis testing

The first step in the hypothesis testing examined whether the experimental extraction, done by scientists, was equivalent to that done by harvesters. To detect an extraction bias, open experimental plots in which only harvesters extracted (treatment *C-E-*) needed to be compared to other open experimental plots in which scientists and possibly harvesters extracted *P. pollicipes* (treatment *C-E+*). Treatment *C-E+* also served to ensure exploitation in at least half of the open experimental plots, as we could not guarantee that harvesters would harvest in all open experimental plots.

If no statistically significant difference exists between the communities of treatments *C-E+* and *C-E-*, the cage effect must be examined, testing *C+E+* versus *C-E+*. In case no cage effect is detected, the natural test to answer the main objective of this study would be the comparison between *C+E-* and *C-E-*, looking for differences in structure of the intertidal community among exploited (by the harvesters only) and unexploited (caged) areas. If the comparison between *C+E+* and *C-E+* results statistically significant, a cage effect cannot be excluded, leaving only one possible comparison between *C+E+* and *C+E-* to examine changes in the community structure among exploited and unexploited areas.

Image analysis

To document changes over time, all experimental plots were photographed at the beginning of the experiment and on a monthly basis thereafter. Before and after the experimental extraction, each plot was also photographically documented. Photographs were taken using a camera positioned as perpendicular to the surface area as possible and at waist height (approximately 70 cm from the ground) to achieve a realistic representation of the coverage of each species with minimum distortion. Organisms were identified to the lowest taxonomic level possible, and in cases where image analysis did not allow a distinction at the species level, the genus was used. In this study, *Corallina* spp. comprised *Corallina* species and *Ellisolandia elongata* (formerly known as *Corallina elongata*). All present species were recorded, and their percentage cover was quantified using the point intercept method. A 100-point grid was overlaid on the picture of each plot in Adobe Photoshop, and species present but without detectable cover were assigned an arbitrary 0.1% cover. The net coverage change (%) of *P. pollicipes* was calculated as

$$100 \times \frac{(final\ coverage - initial\ coverage)}{initial\ coverage}$$

The exploitation intensity was estimated by calculating the cumulated removal throughout the entire experiment, detected with the image analysis.

Data treatment and statistical analysis

Before conducting any type of analysis the underlying assumptions were tested. Non-parametric tests were used instead of their parametric counterparts, when appropriate. A p-value of <0.05 was considered to indicate a significant result in all statistical tests. To assess whether the experiment resulted in significant changes in *P. pollicipes* coverage, we conducted a paired-sample Wilcoxon test to compare the initial and final coverage. Hypotheses regarding changes of the intertidal community structure were tested applying analysis of variance (ANOVA) with permutation tests for *P. pollicipes* cover and Shannon-Wiener diversity index data (using Euclidean distance matrix), and permutational multivariate analysis of variance (PERMANOVA) for the community data. For the latter, a semi-matrix of Bray Curtis dissimilarities was calculated on untransformed species coverage and a Type III sum of squares was applied. Pooling of non-significant interactions involving random factors was done where possible to increase the power of the test (Winer 1971). The Shannon-Wiener index was applied to measure ecological diversity and similarity percentage (SIMPER) was used to determine the species, which were responsible for the differences. Non-Metric Dimensional Scaling (nMDS) was conducted with *R* computing software (R Core Team 2022) using the Bray Curtis dissimilarities matrix calculated on untransformed species coverage. Software PRIMER 6 & PERMANOVA+ was used to perform statistical procedures of ANOVA, PERMANOVA and SIMPER (www.primer-e.com; Anderson et al., 2008). The ggplot2 package (Wickham 2016) in the *R* computing software was used to create graphics (R Core Team 2022).

2.3. Results

The species observed in the intertidal community are listed in the appendix (Table A1 see appendix A) and original species coverage data of this study are available at Mendeley Data (Geiger et al. 2023). Due to storms during the first winter, two replicates of the 2-year treatment were lost (one *C+E+* and two *C+E-* plots), leading to an unbalanced design. The missing replicates were substituted with the average of the two remaining replicates of the same treatment groups and one degree of freedom for every missing replicate was subtracted from the residuals in the ANOVA, as recommended by Winer (1971).

Initial conditions

At the start of the 2-year experiment in July 2017, significant differences in *P. pollicipes* coverage were observed among locations (ANOVA, $p_{Location} = 0.001$; Geiger et al., 2023). The initial *P. pollicipes* coverages of the plots used in the 1-year experiment (average coverage 20.2±9.1%) were generally higher than in the 2-years experiment (average coverage 14.5±5.2%), however, no statistically significant differences among locations were found. The intertidal community composition varied among locations, with *La Cruz* exhibiting a denser coverage and less bare rock than the other locations. The most prevalent species in all three locations were the cirripedes *Chthamalus* spp. and *P. pollicipes*, along with the calcareous algae *Corallina* spp. in *La Cruz* and *Las Salsinas*. In *La Cruz*, in addition, *Mytilus* spp. were dominant, while in *Las Llanas* the algae *Ralfsia verrucosa* was abundant. Trigo et al. (2018) identified *Mytilus galloprovincialis* as the sole mussel species present on the north coast of Spain. Nevertheless, we refer to *Mytilus* spp. in our study, as the image analysis we employed does not allow us to distinguish between different mussel species.

Effects of exploitation on the coverage of P. pollicipes

Significant differences of net change in *P. pollicipes* coverage was found among treatments (Table 2.1). The detailed comparison among treatments showed no cage artefact for the observed changes in *P. pollicipes* coverage (Table 2.2). The differences between the non-extraction treatment (*C+E-*) and the extraction treatments were significant (Table 2.2). The percent cover of *P. pollicipes* in plots protected by a cage and not extracted experimentally (*C+E-*) showed an increase after both 1-year and 2-year experiment durations, despite losses due to storms and poaching (Fig. 2.4A). The *P. pollicipes* coverages removed through the extraction done by scientists were similar to those removed through a combination of the exploitation by harvesters and minor losses due to other predators or storms (Fig. A1 see appendix A). As expected, we observed a decrease in the average *P. pollicipes* coverage regardless of the type of exploitation: by scientists only (*C+E+*), by both scientists and harvesters (*C-E+*), or by harvesters only (*C-E-*) (Fig. 2.4B). The average net change of *P. pollicipes* coverage was negative in all treatments, except for the *C+E-* treatment, where the average increase reached up to 80% after 2 years (Fig. 2.4B).

Table 2.1. Results of ANOVA comparing net change of *P. pollicipes* coverage among treatments. *: p<0.05; **: p<0.01; ***: p<0.001

	Df	Sum Sq	Mean Sq	F value	Pr(<F)
2-years Treatment					
Cage (C)	1	109773	109773	7.977	0.010*
Experimental Extraction (E)	1	55872	55872	4.060	0.057
Location (L)	2	23502	11751	0.854	0.440
C x E	1	17295	17295	1.257	0.275
C x L	2	14010	7005	0.509	0.608
E x L	2	28920	14460	1.051	0.367
C x E x L	2	12371	6185	0.449	0.644
Residuals	21	288995	13762		
1-year Treatment					
Cage (C)	1	33018	33018	8.107	0.009**
Experimental Extraction (E)	1	69366	69366	17.033	0.0003***
Location (L)	2	70088	35044	8.605	0.001**
C x E	1	12609	12609	3.096	0.091
C x L	2	759	379	0.093	0.911
E x L	2	25	13	0.003	0.997
C x E x L	2	6561		0.806	0.458
Residuals	24	97741	4073		

Table 2.2. Results of Tukey-Kramer post-hoc pairwise test of *P. pollicipes* coverage net change data. *: p<0.05; **: p<0.01

	Treatments			P-value	Interpretation
2-Years Experiment Duration	*C-E+*	vs	*C-E-*	0.780	No effect of experimental extraction in plots without cages
	C-E+	vs	*C+E+*	0.447	No cage artefact
	C+E-	vs	*C+E+*	0.081	No effect of experimental extraction in cages
	C+E-	vs	*C-E+*	0.002**	Combined extraction effect
	C+E-	vs	*C-E-*	0.019*	Effect of extraction by harvesters
1- Year Experiment Duration	*C-E+*	vs	*C-E-*	0.360	No effect of experimental extraction in plots without cages
	C-E+	vs	*C+E+*	0.760	No cage artefact
	C+E-	vs	*C+E+*	0.026*	Effect of experimental extraction in cages
	C+E-	vs	*C-E+*	0.002**	Combined extraction effect
	C+E-	vs	*C-E-*	0.117	No effect of extraction by harvesters

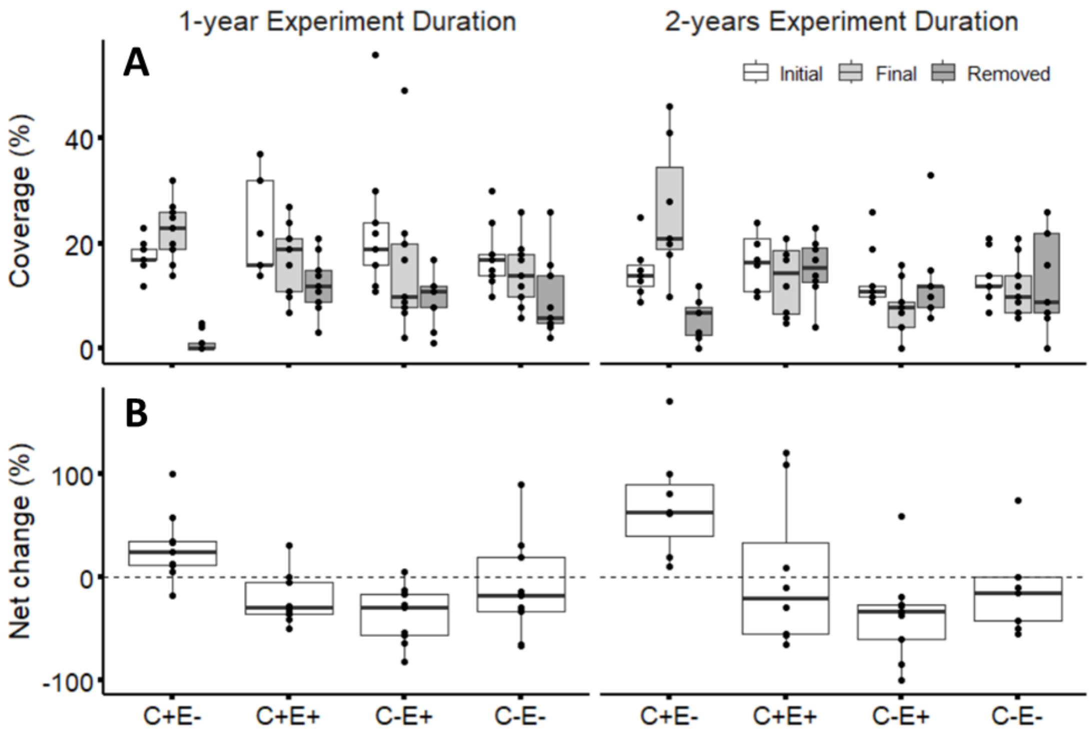


Figure 2.4. A) *P. pollicipes* coverages (dots represent replicates and boxplots represent average coverages of all three locations with standard errors) at beginning (white boxplots) and end (light grey boxplots) of the experiment in the 1-year experiment duration (July 2018 to July 2019) and 2-years experiment duration (July 2017 to July 2019), and cumulated removal of *P. pollicipes* coverages throughout the study period by scientific extraction and/or harvesters, including minor losses due to predators or storms (dark grey boxplots). B) Net change of *P. pollicipes* (dots represent replicates and boxplots represent average coverages of all three locations with standard errors) from beginning to end of the experiment.

Effects of exploitation on the structure of the intertidal community

A significant interaction between the experimental extraction and the cage treatments was detected ($P_{\text{Experimental Extraction x Cage}}$= 0.031, Table 2.3 (A)). A post-hoc pairwise test revealed no significant differences between open plots with harvest by harvesters only (*C-E-*) and open plots exposed to both harvesters and experimental extraction (*C-E+*; $P_{\text{C-E- vs C-E+}}$= 0.155, Table 2.4). This suggests that the effect of the experimental extraction conducted by scientists is equivalent to the effect of harvest done by harvesters. However, a significant difference was found between caged (*C+E+*) and open (*C-E+*) plots that were experimentally extracted ($P_{C-E+ \text{ vs } C+E+}$= 0.031; Table 2.4; see the relevant tests in methods), indicating a methodological cage artefact. Therefore, to evaluate the effect of exploitation on the intertidal community structure, it is necessary to compare the caged, experimentally extracted (*C+E+*) with the caged non-extracted (*C+E-*) treatments. This comparison revealed a significant difference ($P_{C+E- \text{ vs } C+E+}$= 0.047; Table 2.4).

Table 2.3. Results of the PERMANOVA (A) Multivariate species coverage and the ANOVA (B) Shannon index. Note that for the community data the three-way interaction Location x Cage x Experimental Extraction (non-significant: p > 0.98) was pooled with the residual to increase the power of the test. *: p<0.05; **: p<0.01

	Source of variance	df	Error term	MS	Pseudo-F	P (perm)	Error term	MS	Pseudo-F	P (perm)
			(A) Multivariate species coverage				(B) Shannon index			
(a)	Location (L)	2	(q)	2472,3	4,0182	0,001**	(p)	0,178	5,97	0,006**
(b)	Cage (C)	1	(e)	7010,2	10,012	0,081	(e)	0,006	0,1	0,796
(c)	Experimental Extraction (E)	1	(f)	1066,7	2,0028	0,185	(f)	0,007	0,26	0,601
(d)	Experiment Duration (D)	1	(g)	688,77	1,3302	0,327	(g)	0,011	1,36	0,44
(e)	L x C	2	(q)	700,26	1,1381	0,331	(p)	0,068	2,28	0,122
(f)	L x E	2	(q)	532,33	0,86518	0,555	(p)	0,029	0,97	0,393
(g)	L x D	2	(q)	517,66	0,84133	0,595	(p)	0,008	0,27	0,774
(h)	C x E	1	(q)	1699,6	2,7623	0,031*	(k)	0,023	1,66	0,322
(i)	C x D	1	(l)	632,23	0,81434	0,506	(l)	0,062	6,35	0,118
(j)	E x D	1	(m)	260,02	0,76539	0,51	(m)	0,011	0,41	0,59
(k)	L x C x E	2					(p)	0,014	0,46	0,653
(l)	L x C x D	2	(q)	776,55	1,2621	0,267	(p)	0,01	0,32	0,74
(m)	L x E x D	2	(q)	338,87	0,55075	0,841	(p)	0,026	0,86	0,419
(n)	C x E x D	1	(o)	299,06	0,46276	0,699	(o)	0,059	36,88	0,032*
(o)	L x C x E x D	2	(q)	646,41	1,0506	0,399	(p)	0,002	0,05	0,944
(p)	Residual (Res)	45		615,57				0,03		
(q)	Pooled term (Res + L x C x E)	47		615,29						

Table 2.4. Post-hoc pairwise test comparing the different treatments using raw species coverage data at the end of the full experiment (1 and 2-years experiment durations). *: p<0.05 and ** p<0.01.

Treatments			t	P (perm)	Interpretation
C-E+	vs	*C-E-*	1.280	0.155	No effect of experimental extraction
C-E+	vs	*C+E+*	3.527	0.031*	Cage artefact
C+E-	vs	*C+E+*	1.609	0.047*	Extraction effect
C+E-	vs	*C-E-*	3.527	0.001**	Not relevant (confounds cage & exploitation effects)

Changes in the species composition

At least 80% of the dissimilarity in the intertidal community composition between all treatments could be attributed to the coverage of *P. pollicipes*, *Mytilus spp.*, *Chthamalus* spp. *Corallina* spp. and *Ralfsia* spp., as well as the amount of bare rock (Tables 2.5 & 2.6). At the species level, dissimilarities varied across treatments and duration. The coverage of *P. pollicipes* and *Mytilus spp.* decreased in harvested plots (Table 2.5) and increased in the caged plots, with larger and more significant differences after two years (Table 2.5).

In the 1-year experiment treatment, the caged plots with (*C+E-*) and without experimental extraction (*C+E+*) exhibited a significant difference in bare rock coverage, with the latter having a higher percentage due to the removal of *P. pollicipes* (21.3% dissimilarity; Table 2.5). However, by the end of the 2-year experiment, the dissimilarity among caged plots was mainly due to the increase in *P. pollicipes* coverage in the treatment with no experimental extraction (21.2%, Table 2.5). The coverage of *Mytilus spp.* was consistently higher in the plots without experimental extraction regardless of the

experiment duration (14.6 to 16.1% of the dissimilarity; Table 2.5).
The cage effect was noticeable in the 2-years experiment duration, with both *P. pollicipes* and *Mytilus spp.* being more abundant in the caged plots, compared to the uncaged plots, despite extraction in both treatments. In contrast, *Chthamalus* spp. and *Corallina* spp. occupied more available space in the uncaged plots, with an increase in *Chthamalus* spp., which was more apparent after two years (Table 2.6).

Table 2.5. Results of the SIMPER analysis on the contribution of the different species to the dissimilarities in community structure between caged with (*C+E+*) and without experimental extraction (*C+E-*).

	Coverage (%)				
Species	**C+E-**	**C+E+**	**Average Dissimilarity**	**Contribution (%)**	**Cumulative Contribution (%)**
Complete experiment					
Rock	19.5 ± 7.0	28.6 ± 10.9	6.4	16.9	16.9
Pollicipes pollicipes	24.1 ± 9.1	17.4 ± 11.0	6.1	16.1	33.0
Mytilus spp	15.8 ± 11.2	10.5 ± 7.7	5.9	15.5	48.5
Chthamalus spp	12.1 ± 7.7	12.5 ± 8.7	4.6	12.1	60.6
Corallina spp	6.6 ± 7.8	8.2 ± 9.1	4.4	11.6	72.2
Ralfsia verrucosa	10.4 ± 5.8	10.8 ± 5.6	3.3	8.6	80.8
1-year Experiment Duration					
Rock	19.7 ± 6	31.2 ± 12.9	7.8	21.3	21.3
Mytilus spp	14.1 ± 10.1	8.4 ± 6.4	5.4	14.6	35.9
Corallina spp	8.4 ± 8.9	9.0 ± 11.1	5.3	14.5	50.4
Chthamalus spp	13.3 ± 8.4	12.1 ± 6.2	4.4	12.0	62.4
Pollicipes pollicipes	22.4 ± 5.4	17.3 ± 6.4	4.0	10.8	73.2
Ralfsia verrucosa	9.8 ± 3.5	9.8 ± 5.9	2.8	7.6	80.8
2-years Experiment Duration					
Pollicipes pollicipes	26.3 ± 12.0	17.4 ± 14.6	8.4	21.2	21.2
Mytilus spp	17.9 ± 12.3	12.9 ± 8.3	6.4	16.1	37.3
Rock	19.3 ± 8.2	25.6 ± 7.0	5.1	13.0	50.2
Chthamalus spp	10.4 ± 6.5	13.0 ± 10.8	4.8	12.1	62.4
Ralfsia verrucosa	11.3 ± 7.7	12.0 ± 5.1	4.0	10.1	72.4
Corallina spp	4.1 ± 5.2	7.3 ± 5.9	3.3	8.3	80.8

Table 2.6. Results of SIMPER analysis on the contribution of the different species to the dissimilarities in community structure between open plots with experimental extraction (*C-E+*) and caged plots with experimental extraction (*C+E+*).

	Coverage (%)				
Species	**C-E+**	**C+E+**	**Average Dissimilarity**	**Contribution (%)**	**Cumulative Contribution (%)**
Complete Experiment					
Rock	29.1 ± 10.5	28.6 ± 10.9	6.1	15.9	15.9
Chthamalus spp	18.7 ± 9.9	12.5 ± 11.0	6.0	15.6	31.6
Pollicipes pollicipes	11.9 ± 11.0	17.4 ± 7.7	5.9	15.4	47.0
Corallina spp	11.7 ± 13.6	8.2 ± 8.7	5.9	15.4	62.4
Mytilus spp	3.9 ± 2.8	10.5 ± 9.1	4.1	10.7	73.1
Ralfsia spp	10.6 ± 5.0	10.8 ± 5.6	3.0	7.9	80.9
1-year Experiment Duration					
Rock	27.7 ± 11.0	31.2 ± 12.9	6.9	17.8	17.8
Corallina spp	12.3 ± 16.4	9.0 ± 11.1	6.9	17.8	35.5
Chthamalus spp	16.6 ± 12.5	12.1 ± 6.2	6.0	15.3	50.8
Pollicipes pollicipes	16.0 ± 14.0	17.3 ± 6.4	5.6	14.4	65.2
Mytilus spp	4.5 ± 3.2	8.4 ± 6.4	3.2	8.1	73.3
Ralfsia spp	9.1 ± 4.5	9.8 ± 5.9	2.9	7.5	80.9
2-years Experiment Duration					
Chthamalus spp	20.8 ± 6.5	13.0 ± 10.8	6.4	16.9	16.9
Pollicipes pollicipes	7.8 ± 5.0	17.4 ± 14.6	6.0	15.9	32.8
Rock	30.4 ± 10.5	25.6 ± 7.0	5.4	14.4	47.2
Mytilus spp	3.3 ± 2.2	12.9 ± 8.3	5.2	13.8	61.0
Corallina spp	11.0 ± 11.2	7.3 ± 5.9	4.8	12.6	73.6
Ralfsia spp	12.0 ± 5.3	12.0 ± 5.0	2.9	7.6	81.2

Effects of the exploitation intensity on the community structure

The nMDS (non-Metric Dimensional Scaling) graph provides a visual representation of the relationship between the experimental factors and the species composition. The graphs show that there are two distinct groups corresponding to the cage and open plots (Fig. 2.5A), and reflect an increase in exploitation intensity (Fig. 2.5B). The composition of the intertidal community shifts from being dominated by *P. pollicipes* and *Mytilus spp.* at lower extraction intensities (represented by plots of *C+E-*) and protected by cages to a higher coverage of bare rock, *Corallina* spp. and *Chthamalus* spp. in unprotected conditions with higher extraction intensities (represented by plots of *C-E+* and *C-E-*) (Fig. 2.5A&B).

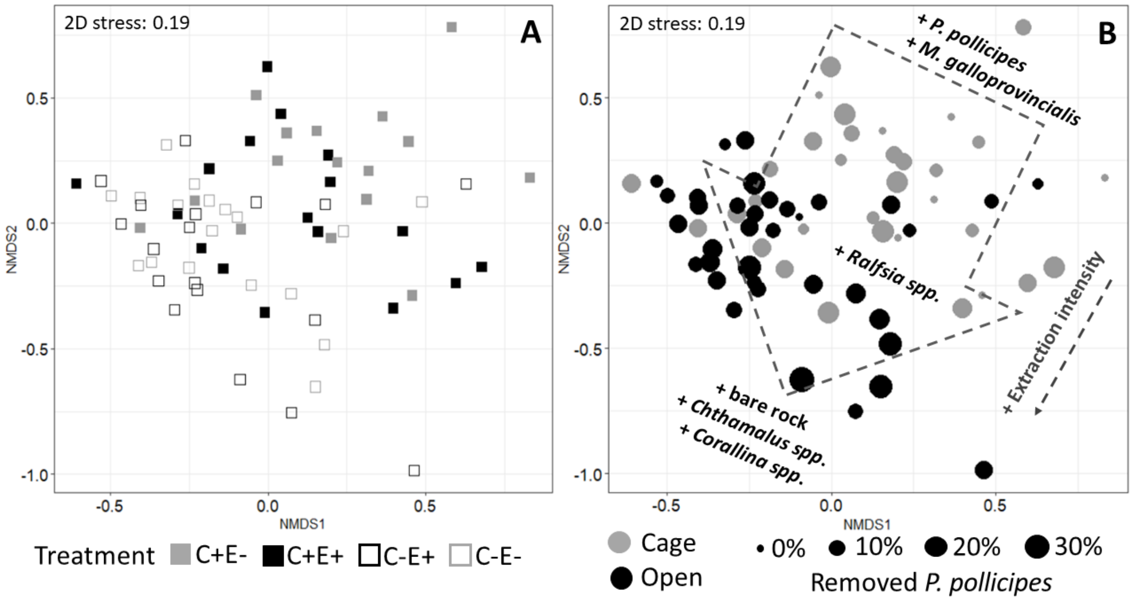


Figure 2.5. nMDS of the intertidal community data with symbols indicating (A) combinations of extraction and cage treatments and (B) extraction intensity in terms of % *P. pollicipes* removal.

Effects on the ecological diversity

ANOVA revealed differences in the Shannon-Wiener index among treatments based on a three-way interaction (Table 2.3 (B)). Experimental extraction, cage usage and experiment duration in combination, thus have a significant impact on the ecological diversity. In the 1-year experiment duration the caged, non-extraction treatment (*C+E-*) showed the highest Shannon index (Fig 2.6), while values among the other treatments were similar to each other (Fig. 2.6). For the 2-years experiment duration the Shannon index was similar among all treatments, with the caged non-extraction treatment (*C+E-*) presenting the lowest value (Fig. 2.6).

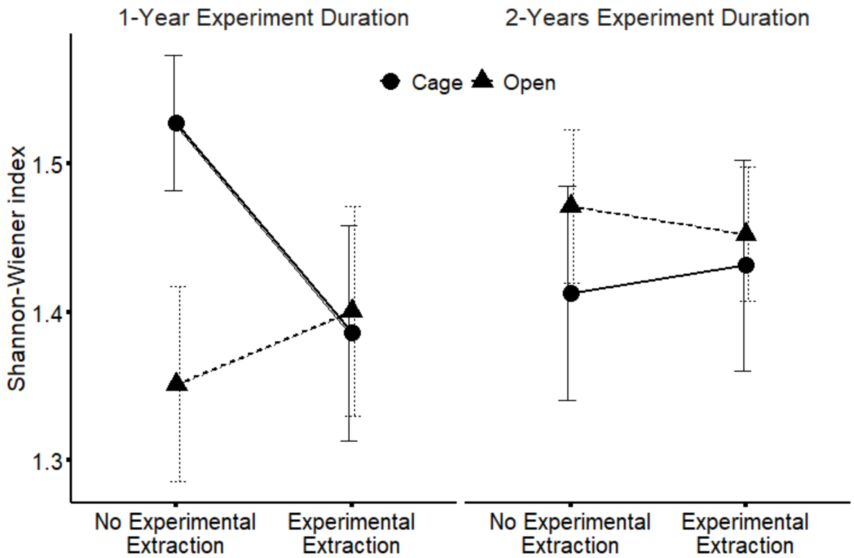


Figure 2.6. Differences in community diversity. Symbols represent averages and error bars indicate standard errors.

2.4. Discussion

To our knowledge this is the first study to assess the response of the intertidal community to the harvest of *P. pollicipes*, an important, highly-valued resource in Southwest Europe (Aguión et al. 2021). Stalked barnacles grow on very exposed rocky shores, making the study environment particularly challenging for experimentation, especially when cages are involved. In our experiment, the presence of cages had an influence which could not be neglected and was possibly due to a reduction in wave action (Miller and Gaylord 2007) and predator pressure (Hayworth and Quinn, 1990; Wootton, 1993, 2001). Thus, although the cages generally withstood storms and vandalism and successfully controlled exploitation, future experiments should simulate human exclusion in no-take areas rather than using cages, to avoid artefacts. Harvesters stepping on the intertidal community can also impact the open but not the caged plots (Addessi 1994) and there may be differences in the extraction methods used by scientists and harvesters. Scientists followed selective harvesting for market-sized individuals and avoided removing entire clusters, whereas harvesters have time limitations and extract clusters with individuals of all sizes, selecting the larger ones for sale afterwards. In spite of the cage artefact and the very small percentage of the plot area affected by the harvest (less than 15%), we were able to detect significant changes in community structure.

The extraction initially decreased the diversity during the first year, but as new organisms settled and covered the bare rock during the second year, diversity increased. Essentially, extraction opened space for species to settle during the course of succession. In contrast, in the absence of exploitation, diversity increased during the first year until *P. pollicipes* and *Mytilus spp.* became dominant in the second year. This led to a subsequent decrease in the diversity index of primary space occupiers. Dynamic changes in the intertidal community, as observed in our study, are commonly observed during the course of ecological succession which follows perturbations due to human exploitation (Duran and Castilla 1989; Dye 1992). As noted in other studies, intermediate disturbance levels can lead to greater ecological diversity within the rocky intertidal community (Levin and Paine 1974; Paine and Levin 1981). Throughout the Iberian Peninsula, humans are undeniably the most significant predators of *P. pollicipes*, and they can be viewed as selective keystone predators (Castilla 1999) who promote ecological diversity through regular disturbance resulting from the stalked barnacle harvest. However, it is unclear whether this apparent higher ecological diversity is a sign of a more diverse community, as we only focused on primary space occupiers and did not include highly mobile and cryptic species. We want to point out that there is a current knowledge gap concerning the diversity of cryptic species associated with the three-dimensional structure created by *Pollicipes* and *Mytilus* reefs.

Previous studies in a comparable ecosystem on the Pacific East coast documented the entire succession process during 5-10 years in cleared gaps within established mussel beds due to storm events (Paine and Levin 1981; Wootton 2001). *Mytilus californianus* outcompeted *Pollicipes polymerus* and dominated the intertidal community due to its large size and ability of adult individuals to resettle once detached (Wootton 1993; Wootton 2001). However, the duration of the current study was too short to describe a complete succession, validate whether the succession process was slow or dynamic, and determine the final stable community structure. Whether *Mytilus spp.* can outcompete *P. pollicipes* in the European and African coasts is unknown, because competition for space is not the only factor that determines the dominance of species within rocky shore intertidal communities. Physical factors such as the substrate inclination, height within the intertidal and wave exposure also play a determinant role in the final stable structure of the community (Paine and Levin 1981). The coexistence and direct interaction between stalked barnacles and mussel species, however, appear to be a general pattern (Barnes and Reese 1959; Paine and Levin 1981; L. Hoffman 1989; Wootton 1993; Barnes 1996; Kameya and Zeballos Flor 1998; Cruz et al. 2022). While between *P. polymerus* and M. *californianus* predominantly competitive interaction have been observed (Paine and Levin 1981; Wootton 1993; Wootton 2001), our study results suggest a positive interaction among *P. pollicipes* and *Mytilus* spp. Our study provides evidence that reducing the exploitation intensity of *P. pollicipes*, while utilizing cages, leads to higher coverages of both *P. pollicipes* and *Mytilus* spp. We observed a cage artefact in the community analysis Table 2.4), which may indicate a protective effect of the cages on mussels, as this artefact did not show up in the *P. pollicipes* net change analysis (Table 2.2). Our experimental findings suggest that the presence of adult individuals from both *P. pollicipes* and *Mytilus* spp. facilitates the recruitment of both species. The favourable physical structures created by these individuals likely provide suitable environments for larval settlement, thereby contributing to a mutual enhancement of species coverages.

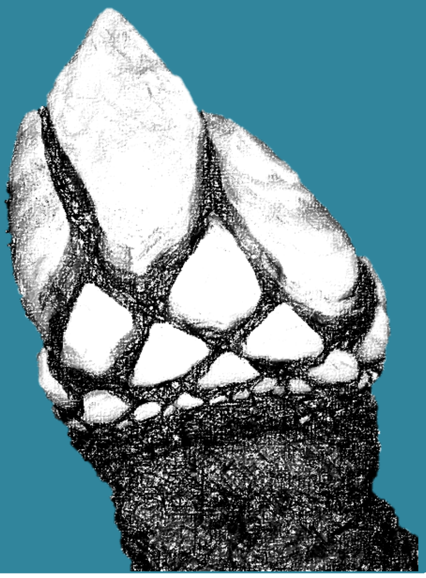
Throughout the 2-years experiment duration, the exploitation intensity resulted somewhat higher than in the 1-year experiment, because of the cumulated removal of all commercially sized stalked barnacles by both scientists and harvesters, spanning both years (Fig. 2.4 and Fig. A1). However, the overall exploitation intensity was not simply doubled in the 2-year experiment because the extraction conducted during the second year was not as extensive as in the first year. This was due to the time required for stalked barnacles to grow. Since the initial extraction, fewer barnacles had reached the minimum harvest size, resulting in a reduced extraction in the second year. Additionally, at the beginning of the experiments, the total barnacle coverage was higher in the 1-year experiment compared to the 2-years experiment. Consequently, the 1-year experimental plots allowed for a higher initial extraction due to the increased number of barnacles available.

The recovery potential of exploited *P. pollicipes* aggregations was variable (Fig. 2.4). A study on *P. polymerus* in British Columbia also found a high variability in the speed of recovery of stalked barnacles (Edwards 2020). In that study *P. polymerus* were entirely cleared from plots of different sizes which were then followed during 14-months. The recovery of *P. polymerus* was generally low (12% of the initial biomass after 14 months), and varied greatly among plots, while other barnacle species and mussels recovered faster (Edwards 2020). Despite the variability in our study, we observed an increasing trend of up to 80% of the initial *P. pollicipes* coverage in non-exploited conditions and a decreasing trend down to 30% of the initial coverage after two years in exploited conditions. Hence, *P. pollicipes* populations have the capacity to recover within two years when undisturbed, at least in terms of surface cover. This is likely due to the growth of larvae attached to adults rather than the settlement and growth of new individuals on bare rock, since *P. pollicipes* larvae recruit preferentially on the stalks of conspecific adults (Franco 2014). Thus, the recovery of exploited *P. pollicipes* stocks will ultimately require a combination of time and availability of conspecific adults. It is likely that, below a certain *P. pollicipes* coverage threshold, a much longer period would be required for stock recovery.

Current management of the stalked barnacle fishery in Asturias-West involves yearly harvest bans that can be extended (Gobierno del Principado de Asturias 2022). The decision to lift or renew a harvest ban for the following season is based on the outcomes of stock assessments in the banned areas. Our results suggest that extended harvest bans can be a useful measure for the recovery of exploited stalked barnacle stocks and contribute to the sustainability of the fishery. However, further research is necessary to determine the minimum coverage percentage of *P. pollicipes* required to initiate and sustain the recovery of the stock. Long-term studies are needed to characterize the complete succession process, determine the final stable species composition of this intertidal community, and establish the time scale of the recovery process.

2.5. Conclusions

Our study confirms that harvesting stalked barnacles leads to changes in the species composition of the rocky intertidal ecosystem. Regular exploitation increased the proportion of *Corallina spp*. and *Chthamalus spp*, while significantly reducing the coverage of *P. pollicipes* and *Mytilus spp.* Although, ecological diversity in exploited plots initially decreased, it increased again after two years when new organisms re-colonised the bare rock. In contrast, the unexploited community showed higher dominance of *P. pollicipes* and *Mytilus spp.*, resulting in a lower diversity. Despite variable recovery potential of *P. pollicipes* aggregations, an increase of up to 80% of initial coverage was observed after two years of no extraction. Therefore, prolonged harvest bans of at least two years can be an effective recovery measure for exploited stalked barnacle stocks, promoting the sustainability of the fishery. To better understand the long-term effects of this fishery on the intertidal community and acquire conclusive results regarding community succession towards a stable state, human-exclusion studies in no-take zones lasting at least 5 years are required.



CHAPTER 3

Characterising the response of stalked barnacle harvesters to biological and economic uncertainty

3.1. Introduction

Climate change threatens the sustainability of fisheries globally (Barange et al. 2018) and can have adverse social, political and economic consequences (Ricke et al. 2018). Small Scale Fisheries (SSFs) are particularly vulnerable to climate change, because the livelihoods of fishers depend strongly on the sustainability of local resources (Allison et al. 2009; Kittinger et al. 2013). The resilience and adaptability of marine species in response to climate change are highly variable and in many cases unknown (Jones and Cheung 2018). Marine benthic organisms are likely to be particularly affected by the impacts of climate change, because of their low spatial mobility (Hiddink et al. 2015) and their dependence on hydrodynamic conditions and climatic factors that control larval supply and settlement (Bertness et al. 1996; Crimaldi et al. 2002; Hiscock et al. 2004). Therefore, SSFs of sedentary resources will potentially be among the most impacted types of fisheries (Ruiz-Díaz et al. 2020). Additionally, fisheries are also severely threatened by anthropogenic causes beyond climate change, such as overexploitation and environmental degradation, which put resources at risk and deter ecological resilience (Lotze et al. 2006). Furthermore, economic fluctuations affect fisheries by changes in demand (Delgado 2003) and by increasing fishing costs (Cochrane 2000). Economic crises, like that of 2008, can lead to decreases in price of luxury products, such as highly valued marine resources (Guillen and Maynou 2014). Moreover, dramatic social-political uncertainties may happen suddenly, such as the COVID pandemic (Bennett et al. 2020; Knight et al. 2020) and the current war in Ukraine, leading to social impacts and economic consequences that are difficult to foresee. As complex social-ecological systems (Ostrom 2009) fisheries need to adapt to these ever growing environmental and socioeconomic challenges. Since external impacts are unavoidable in fisheries, managers should focus on aspects that can be controlled, such as the human dimension. As already pointed out by Miller and Van Maanen (1979), managing a fishery is essentially managing the behaviour of fishers. Hence, the human dimension is a key component for effective fisheries management (Jentoft and McCay 1995; Kaplan and McCay 2004) and needs to be addressed to help design policies that not only protect the resource but also cause less conflict, inspire higher compliance and minimise the costs associated with protecting the resource (Marshall 2007; Perez de Oliveira 2013). Whether fisheries will overcome future problems will depend on their social-ecological resilience (Gibbs 2009), which can be promoted by adaptive management (Rivera et al. 2016; Ojea et al. 2017; Rivera et al. 2017b).

The stalked barnacle *Pollicipes pollicipes* (Gmelin, 1791 [in Gmelin, 1788–1792]) is a sessile cirripede that grows in the intertidal range on exposed rocky shores from Senegal to the southwestern coast of England (Cruz et al. 2022). In Spain and Portugal this species is considered a delicacy, which achieves high market prices and is intensively harvested (Molares and Freire 2003; Rivera et al. 2014; Jacinto et al. 2015; Sousa et al. 2020). In Asturias (North Spain), this fishery represents an important component of the artisanal fleet and is of socio-economic importance for the region (Rivera et al. 2014; García-de-la-Fuente et al. 2016; González-Álvarez et al. 2016). Harvesters risk their life while collecting stalked barnacles on the wave-beaten rocky shores (Franco 2014). The market price is extremely variable and changes daily due to a variety of reasons (Rivera et al. 2014; Rivera et al. 2016). Supply and demand, as well as the quality of the stalked barnacles play a role in these market fluctuations. The quality of stalked barnacles tends to be best at the start of

the harvest season, at the beginning of October in Asturias, and after partial harvest bans have been lifted from areas (Rivera et al. 2014; Rivera et al. 2016). In Spain the consumption of stalked barnacles traditionally increases during the end of year holidays, leading to price peaks caused by the increase in demand (Rivera et al. 2014). Additionally, adverse weather conditions during winter often hinder the harvest, decreasing the supply and raising the prices. Therefore, this fishery in particular is highly vulnerable to both climatic and economic impacts.
The stalked barnacle fishery in Western Asturias has been co-managed at multiple scales since 1992 (Rivera et al. 2017a), which improves its resiliency (Rivera et al. 2016; Aguión et al. 2021). There is a general management frame for the Asturian stalked barnacle fishery, which determines input control rules such as number of licences, restrictions in harvest time and season, and gears and output control rules, such as harvest quotas (Gobierno del Principado de Asturias 2022; Table 3.1). In addition, the fishery in Western Asturias is managed by a Territorial Use Rights for Fishing (TURFs) scheme that works on local (areas of a few km up to 10 s of km) and patch spatial scales (single rocks of a few metres up to areas of 1 km; Aguión et al. 2022; Table 3.1).

The resilience of a fishery is conditioned by the dynamic interactions of gradually changing (e.g. climate, traditions) and rapidly changing (e.g. weather variations, local market) variables (Chapin et al. 2009). Hence, knowledge on the reactions of harvesters towards ecological and economic fluctuations of the resource may help design sustainable management strategies (Béné and Tewfik 2001; Daw et al. 2012) leading to a resilient fishery (Yletyinen et al. 2018). A common problem in SSF management though, is the non-compliance with rules and regulations by resource users (Oyanedel et al. 2020), which can substantially compromise the effectiveness of the management (Hatcher and Pascoe 2006; Loquine 2010). The participation of resource users in management decisions can motivate their compliance (e.g. Kaplan and McCay 2004; Perez de Oliveira 2013; Puley and Charles 2022) by increasing their influence on management outcomes. This, in turn, enhances the acceptance of the implemented strategies (Marshall 2007). Here we inquired harvesters regarding their preferred management strategies in different hypothetical scenarios related to reductions in resource abundance and changes in market value. We argue that taking into consideration their preferences into management responses can promote a sense of ownership over the decision-making process, provide innovative solutions to fisheries management, and help increase the fisheries resilience towards biological and economic impacts.

3.2. Material and Methods

Study area

The study took place in Asturias (North Spain). During the time this study was conducted, the eastern Asturian coast was managed as a single unit with general management strategies (Fig. 3.1; Table 3.1; (Aguión et al. 2021). Since February 2023, two TURFs have been implemented (Gobierno del Principado de Asturias 2023). Along the west coast a TURF based co-management system is employed for the stalked barnacle fishery which is comprised by eight management regions (TURFs) located between the Eo estuary (7.035831 W, 43.529291 N) and Cape Peñas (5.770935 W, 43.689880 N; Fig. 3.1; Table 3.1). These management regions are subdivided in 304 zones (SIGMA unpubl.) according to the quality of the resource (zones can be as small as 3 m) and the historical division of fishing sites. Catch monitoring is done at this small patch scale within the TURFs (Rivera et al. 2014; Aguión et al. 2021). In the 2019–2020 harvesting season 270 stalked barnacle harvesters were active in Asturias, with 216 in Asturias-West and 56 in Asturias-East (Peón unpubl.).

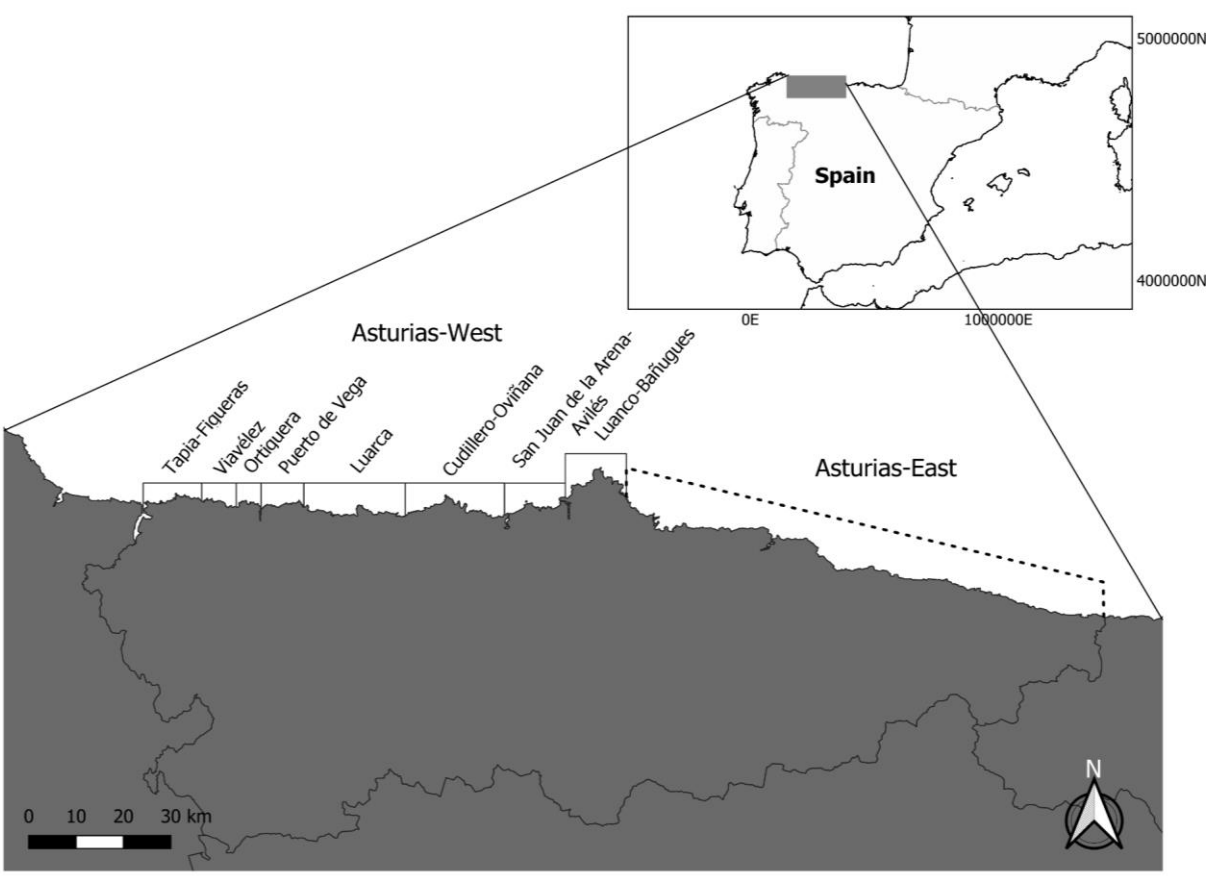


Figure 3.1. Map of the Asturian coast (North Spain). Asturias-East, managed as a single management region and Asturias-West, comprised by eight management plans (TURFs): Tapia-Figueras, Viavélez, Ortiguera, Puerto Vega, Luarca, Cudillero-Oviñana, San-Juan de la Arena-Avilés and Luanco-Bañugues (Cabo Peñas).

Since the regulated commercial stalked barnacle fishery was established in Asturias, the regional fisheries management administration (Dirección General de Pesca Marítima del Principado de Asturias; DGPM), has been working with the harvesters in a co-management regime (Rivera et al. 2014). In Asturias-West, the management implemented through collaboration with the harvester associations, hereafter referred to as *cofradías* for their name in Spanish, is participatory and uses diverse strategies (Table 3.1). Harvesters in Asturias-West develop their own management plans, which must be approved by the regional Ministry of Rural Development and Territorial Cohesion and made public. The DGPM ultimately determines harvest days and bans as part of the yearly management plan, in collaboration with the harvesters of each TURF. In Asturias-East, harvesters are also affiliated with *cofradías* but could harvest stalked barnacles anywhere along the Asturias-East coast until February 2023, when two TURFs were implemented. However, lack of surveillance and enforcement is a common problem in both regions (Geiger et al. 2022), with only 12 surveillance officers responsible for patrolling 401 km of coastline, and one to two surveillance officers are assigned to each *cofradía* in Asturias-West. This lack of surveillance was exacerbated in Asturias-East until 2023 due to a shortage of additional patrolling personnel. However, with the establishment of two TURFs in Asturias-East, an additional surveillance officer is assigned to each *cofradía* in this area.

Table 3.1. Stalked barnacle fisheries management strategies implemented in Asturias.

Implemented management strategies	Asturias-East	Asturias-West
Professional licence for stalked barnacle harvest	√	√
Limited number of professional licences	√[a]	√
Harvest season (October until April, both included)	√	√[b]
Limited number of harvest days		√[c]
Harvest time (2h before high tide until 1h after)	√	√
Territorial Use Rights for Fishing (TURFs)		√
Harvest bans (partial or total)		√
Harvest site rotations		√
Limited number of quotas per harvesting site		√[c]
Individual harvest quota (kg/person/day)	√	√
Harvest tool restrictions	√	√
Minimum commercial size of stalked barnacles	√	√

[a] No concrete limit, but new licences are not being issued since 2018.
[b] The TURF in Cabo Peñas is an exception, here harvesters can work throughout the year by rotating harvest areas.
[c] In some TURFs.

Survey

We applied a stratified sampling method (Cochrane 1976) for the data collection, treating Asturias-East and Asturias-West as subpopulations due to the differences in management among the two regions. Survey questions were developed after careful discussion with stalked barnacle fishery experts (e.g. scientists, government officials, and stalked barnacle harvesters). Six harvesters pre-tested the survey to ensure that questions were properly worded, comprehensible, and the time needed to answer them was reasonable. The final survey consisted of five questions based on three possible future scenarios. The suggested scenarios described changes in resource abundance and market price:

Reduced abundance scenario: This scenario describes a reduction in the abundance of the resource by 50% from the usual abundance at the end of the season. Scenario duration can be 1 or 2 seasons.

Reduced price scenario: This scenario describes a reduction in the market value of the resource by 50% from the average value, taking as average the value of the last three seasons. Scenario duration can be 1 or 2 seasons.

Mixed scenario: This scenario describes a reduction in the abundance of the resource by 50% from the usual abundance at the end of the season with an increase in the market value by doubling the average value, taking as average the value of the last three seasons.

Harvesters could choose from six semi-open answers to describe their preferred management strategy for each scenario:

A: Change the management (explain which strategy you would implement)

B: Stop harvesting stalked barnacles (exit the fishery)

C: Reduce effort (explain how)

D: Increase effort

E: No changes

F: Other, explain:

Ethics Statement

Prior to conducting the surveys, we informed the participants about the study's purpose and the intended use of the data. All participants provided verbal consent before beginning the survey. Additionally, to ensure anonymity, we only collected de-identified data. The survey and study objectives underwent examination and approval by the research ethics board of the University of Oviedo.

Data collection

Data were collected before and during the Covid-19 pandemic, which urged a modification in our data collection methods. In Asturias-West, we carried out on-site data collection in the eight TURFs between October 2019 and March 2020. In Asturias-East, data collection coincided with the COVID-19 restrictions during the initial stages of the pandemic between March 2020 and July 2020. Therefore, these surveys needed to be done online or by telephone. Overall, we administered 78 surveys, representing 29% of all active stalked barnacle harvesters in Asturias during the 2019/2020 season. In Asturias-West 54 surveys were answered and in Asturias-East 24, representing 25% and 44% of the harvesters in each region, respectively.

Data treatment and statistical analysis

We checked for common statistical assumptions and as the data did not follow a normal distribution, we conducted Kruskal-Wallis one-way analyses of variance to determine statistical differences between responses from harvesters working in the two management areas (Asturias-West and Asturias-East), as well as to analyse differences between scenario durations of one versus two seasons. Additionally, we performed Kruskal-Wallis tests to examine whether the impacts of the COVID-19 pandemic and changes in data collection methods due to lockdowns biassed the data (see Table B1 in appendix B). We used descriptive analysis to identify trends in management strategies for each scenario. To determine the specific strategies suggested by the harvesters, we applied a semi-quantitative analysis using the RQDA package (Huang 2014). All analyses were performed using *R* computing software (R Core Team 2020) and graphical displays were created using the ggplot2 package (Wickham 2016).

Management strategy viability analysis

After identifying the preferred responses of harvesters to the three scenarios, we carried out a literature review to assess the prior implementation and success of these management strategies in the stalked barnacle fishery. We used Google Scholar to search for the key terms:

- *Pollicipes pollicipes* + Asturias + harvest ban
- *Pollicipes pollicipes* + Asturias + quota
- *Pollicipes pollicipes* + Asturias + harvest season
- *Pollicipes pollicipes* + Asturias + enforcement
- Asturias + fishery + quality label

We only included articles that described the effects of management strategies implemented within the study region. Conference proceedings and data that were not available online were excluded from the analysis. To obtain information on the management system that was not available in the literature, we consulted Asturian stalked barnacle management authorities between May 2019 and March 2022.

3.3. Results

The most frequently selected strategy, without distinguishing between the different scenarios, was the “reduce effort” strategy with 39.7% of all responses. The “stop harvesting” and “no changes” strategies were both selected by 17.2% of the participants, followed by the “change management” (11.3%) strategy. The “other” and the “increase effort” strategies were chosen with similar frequencies (4.6% and 4.1%, respectively). Harvesters opted not to answer 7.8% of all questions.

When the usual abundance of stalked barnacles was hypothetically reduced, 55.8% of the harvesters chose to protect the stock by selecting the “reduce effort”, “stop harvesting” (14.1%), or “change the management” (12.2%) strategies (Fig. 3.2). Responses to the other scenarios were more variable (Fig. 3.2). In response to a decrease in the market value of the resource, participants selected the “stop harvesting” (25.6%), “reduce effort” (23.1%), “no change” (21%) and “change the management” (11.5%) strategies (Fig. 3.2). Under the mixed scenario, the most frequently selected strategy was “reduce effort” (44%), followed by the “no change” (35%) strategy (Fig. 3.2). These results indicate that, according to harvesters, protecting the stock under reduced abundance takes precedence over pursuing market gain.

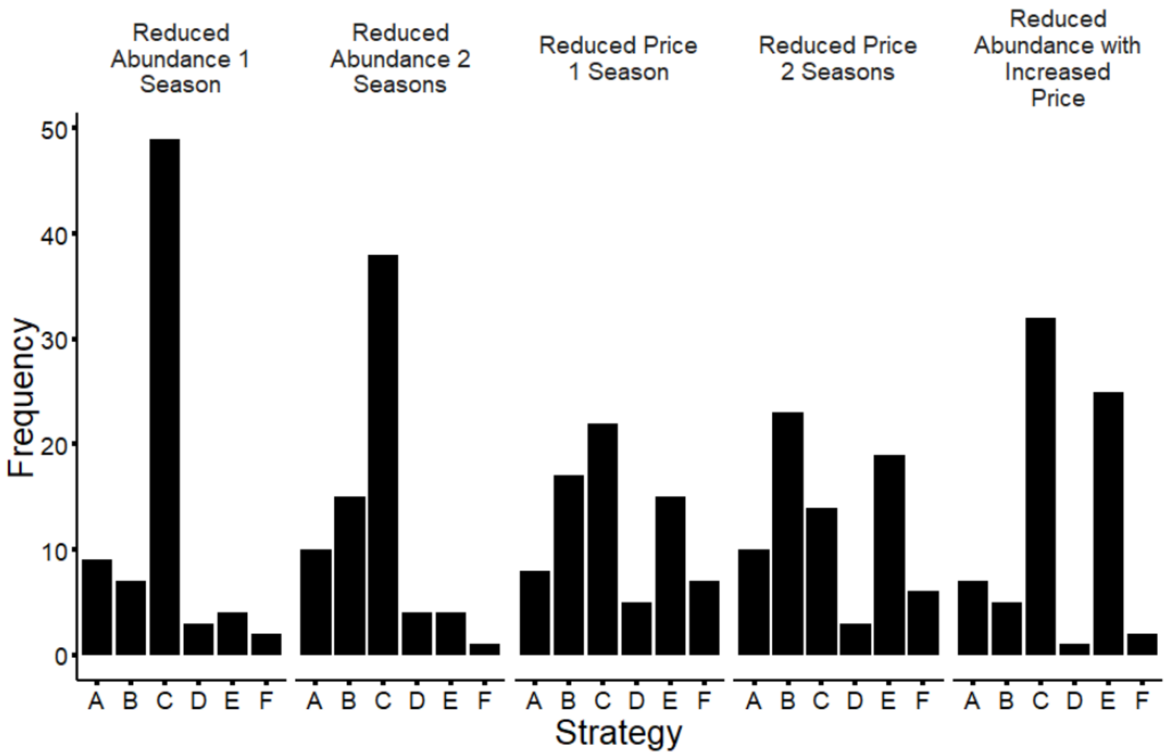


Figure 3.2. Frequencies of harvesters' choices regarding management strategies under hypothetical scenarios: reduced abundance (1 and 2 seasons), reduced market price (1 and 2 seasons), mixed scenario - reduced abundance with increased market price of stalked barnacles. Response options: A) "change the management", B) "stop harvesting", C) "reduce effort", D) "increase effort", E) "no changes", F) "other".

Differences in scenario durations and management regions

Statistically significant differences among results of scenarios with distinct durations (1 or 2 seasons) were found (Table 3.2), hence, they were analysed individually. The majority of harvesters chose the "reduce effort" strategy under reduced abundance scenarios, but responses varied according to the duration of the impact (Fig. 3.2). For a duration of 1 season, 62.8% selected this strategy, while for a duration of 2 seasons, 48.7% of the participants did so. The "stop harvesting" strategy was preferred in the longer duration scenario (2 seasons) compared to the shorter scenario (1 season; 19.2%, 9.0%, respectively). The choice of strategy also varied according to duration in the scenario of reduced market price. When lasting for 1 season, more harvesters opted for the "reduce effort" strategy (28.2%) compared to the longer duration scenario (18.0%). Whereas harvesters were more likely to "stop harvesting" (29.5%) or to choose the "no change" (24.4%) strategy in response to a reduction in price occurring for 2 seasons compared to the shorter duration (21.8%, 19.2%, respectively).

Statistically significant differences among the responses of harvesters from the two management areas (Asturias-West or Asturias-East) were only found for the scenario with reduced price lasting for 2 seasons (Table 3.2). These differences were due to the harvesters from Asturias-West choosing the "no change" (32.0%), "stop harvesting" (30.1%) or "reduce effort" (18.5%) strategies, while harvesters from Asturias-East primarily selected the "reduce effort" (36.9%), "change the management" (26.1%), or "stop harvesting" (19.6%) strategies (Fig. 3.2).

Table 3.2. Results of the Kruskal Wallis tests determining statistical differences among responses regarding the scenario durations (one vs two seasons) and the management regions (Asturias-West vs Asturias-East).

	Scenario	Chi-squared	df	p-value
Duration	Reduced Abundance	36.025	6	2.73e-06***
	Reduced Price	39.741	7	1.41e-06***
Management region	Reduced Abundance 1 Season	0.090	1	0.76
	Reduced Abundance 2 Seasons	0.101	1	0.75
	Reduced Price 1 Season	2.099	1	0.15
	Reduced Price 2 Seasons	3.859	1	0.05*
	Reduced Abundance with Increased Price	0.271	1	0.60

* p<0.05 ** p<0.01 *** p<0.001

Specific management strategies proposed by harvesters

Harvesters proposed five strategies for reducing the effort: harvest ban, reducing harvest time (days, hours), reducing individual quota, reducing number of licences and implementing quotas for harvest areas (Fig. 3.3). The most frequently selected strategy to reduce effort was to implement harvest bans (34.3%), followed by reducing harvest time (31.5%) and reducing individual quota (25.3%). In the scenario of reduced abundance, harvest bans were the most popular strategy to reduce effort, followed by reducing individual quotas and harvest time (Fig. 3.3). Decreasing the effort by reducing the harvesting time was the most popular strategy in a scenario of reduced price (Fig. 3.3), and decreasing individual quotas and harvest time were the two preferred strategies for the mixed scenario of reduced abundance with increased price (Fig. 3.3).

Harvesters proposed six alternative management strategies to "change the management", which include improving the profitability of the fishery (e.g. through minimum selling price, quality label, selective harvesting for high quality resource), increasing surveillance and enforcement, changing the harvest season, increasing harvesters' participation in management, rotating harvest areas, and providing environmental education for harvesters (Fig. 3.3).
The most selected alternative strategies was improving the profitability of the fishery (32.1%) especially through quality selection of the harvest or by implementing a minimum market price in response to the reduced price scenario (Fig. 3.3). The second most preferred strategy was increasing surveillance and enforcement (30.4%) in response to the reduced abundance scenario (Fig. 3.3). However, no clear alternative strategy preference was observed under the mixed scenario (Fig. 3.3).

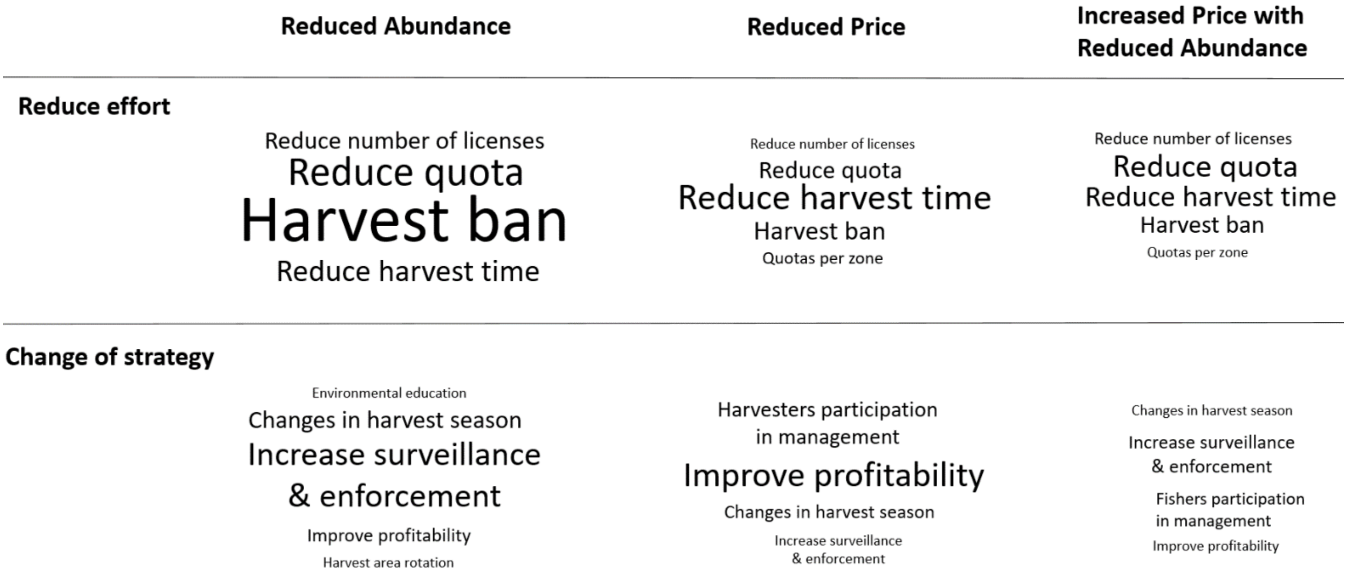


Figure 3.3. The word cloud displays the specific management strategies proposed by harvesters to reduce effort and to change management under the three scenarios. Letter size is proportional to the absolute frequencies of the chosen strategies.

Experience with proposed management strategies

Many of the strategies suggested by the harvesters in the "changes in management" and "reduction of effort" categories are already implemented in the current fishery management, as described in Table 3.3. The most commonly proposed strategies for reducing effort were restrictive measures, such as implementing harvest bans, both partial and total, which have been effective in the past (Table 3.3). Total bans consist of closing areas for the entire harvest season, allowing the resource to recover. Whereas partial bans, the temporary closure of specific areas, are used to maximise harvesters' benefits by reserving high quality barnacles for the peaked season in December, ensuring the best quality resources are sold at the highest price (Table 3.3).

Reducing the number of harvest days was widely accepted as a strategy for decreasing effort in all hypothetical scenarios in this study. Another measure that was accepted by resource users was reducing the individual quota, which was implemented after the 2004–2005 campaign, when a decreasing trend in the landings had been observed (Table 3.3). For most of the campaign, the daily total allowable catch was reduced from 8 to 6 kg, except for the high season (December), where it remains at 8 kg. This quota proved to be at a sustainable level for the stalked barnacle stock in Asturias-West (Table 3.3).

The limitation of licences to a maximum number was an effective measure to control the effort in Asturian TURFs, while this measure was lacking in Asturias-East. However, since 2018, there has been a moratorium in Asturias-East, temporarily inhibiting the issuance of new licences, which has scaled down the number of harvesters in recent years (Gobierno del Principado de Asturias 2018).

To maximise their profit in low market price scenarios, harvesters proposed two strategies to improve the profitability of the fishery. The first was to select for high quality barnacles, which is a very common practice among harvesters during the extraction process and after the harvest, by removing smaller and low quality barnacles before selling (Table 3.3). The other strategy suggested was to establish a legally mandated minimum market value (Table 3.3). Despite the existence of legally implemented minimum prices for food products in Spain (Law 12/2013, 2nd of August, Article 185, BOE-A-2013-8554, Modification in 2020 of measures to improve the functioning of the food chain), fixed minimum selling prices currently do not exist in the Asturian fishery.

Table 3.3. Results of the literature review on specific management strategies proposed by the harvesters to reduce effort and to make changes.

Strategy	Specific Strategy	Experience with Strategy	Outcomes of Strategy	References
Reduce effort	**Harvest ban** Partial bans: temporal closures of harvest areas during some months of the harvest season; Total bans: closures of harvest areas for the entire season	Commonly used in Asturian TURFs to preserve the stock. Partial bans reserve zones for high season to achieve greatest profit. Total bans implemented to maximize profits for following year, prevent overexploitation, or to help recover overexploited areas.	• Accepted by harvesters • Sustainability of stock • Increased landings	Rivera et al. 2014
	Reduced harvest time	Restricted number of harvesting days per year in TURFs: Cabo Peñas, San Juan de la Arena and since two years in Luarca.	• Accepted by harvesters • Sustainability of stock	Rivera et al. 2016, Personal communication (P. Peón) March 2022
	Reduced quota	Since 2004 general reduction from 8 to 6 kg/person/day (except for December, which remains at 8 kg/person/day).	• Accepted by harvesters • Sustainability of stock • Positive landings trend	Rivera et al. 2016
	Reduce number of licences	In Asturias-East there are currently no new licenses issued.	• Reduction of effort by decreasing number of harvesters • Accepted by harvesters	Personal communication (P. Peón) November 2021
	Implement harvest quotas per area	In Tapia-Figueras and Viaveléz TURFs specific harvest areas have a maximum number of quotas divided by the harvesters of the TURF.	• Proposed by harvesters	BOPA 2018
Change strategy	**Increase surveillance and enforcement**	Generally perceived to lack by the harvesters. In Asturias-West one additional surveillance officer per *cofradía*.	• Better control in Asturias-West than in Asturias-East • Appreciated by harvesters	Rivera et al. 2014; Rivera et al. 2016; Rivera et al. 2019; Geiger et al. 2021; Personal communication (P. Peón) November 2021
	Harvest area rotation	In Cabo Peñas TURF a rotation scheme alternates harvest areas between summer and the rest of the year.	• Accepted by harvesters • Sustainability of stock	Rivera et al. 2014; Rivera et al. 2017
	Changes in harvest season	Early closure of harvest season in some TURFs in 2002 due to Prestige oil spill. Early closure of harvest season in some TURFs to avoid overexploitation.	• Accepted by harvesters, avoidance of contaminated harvest • Preservation of stock	Rivera et al. 2014
		In Cabo Peñas TURF harvesters work year-round alternating harvest areas between summer and the rest of the year.	• Accepted by harvesters • Sustainability of stock	Rivera et al. 2014; Rivera et al. 2017
		Between 2015 and 2017 all TURFs opened harvest in certain areas during June with regular stock assessments, to monitor the stock.	• Stock decreased • Recovery of stock delayed	Rivera et al. 2017; Personal communication (P. Peón) March 2022
	Promotion of fishery	Minimum selling price - no experience.	No information available for Asturian stalked barnacle fishery	
		Quality label - no experience in stalked barnacle fishery, but the octopus fishery in Asturias has the Marine Stewardship Council (MSC) eco-label since 2016.	No information available for Asturian stalked barnacle fishery Information for Asturian octopus fishery: • Price premium of between 15.2% and 24.6% • Sustainable practices • Appreciated by fishers	Sanchez, Polanco & García 2020
		Selective harvesting for quality - commonly done by harvesters to achieve good selling prices.	• Strategy to increase selling price	Rivera et al. 2014
	Environmental education	Science outreach programs in 2017.	• Improved education has led to more responsibility and integration of harvesters in decision making	Rivera et al. 2017; Rivera et al. 2020
	Increased participation of harvesters in management	High degree of harvesters participation in Asturias-West TURFs.	• Improved co-management with sense of ownership for resource • Appreciated by harvesters	Rivera et al. 2014; Rivera et al. 2019; Aguión et al. 2021

3.4. Discussion

This study aimed to identify effective management strategies for the Asturian stalked barnacle fishery by assessing harvesters' response to hypothetical biological and economic scenarios. The results showed that harvesters responded similarly in both management regions, with scenario duration affecting their responses. Harvesters preferred restrictive measures, such as harvest bans, to protect the resource and requested increased enforcement and surveillance under reduced abundance scenarios. In contrast, market value changes led to more variability in responses than resource abundance reduction. For instance, harvesters in Asturias-East suggested reducing the individual quota and harvest time to increase the market price by generating higher demand through limited supply. Negative economic trends, especially if they persist over time, increased the likelihood of harvesters abandoning the fishery. Therefore, promoting stable market values is crucial for ensuring the fishery's long-term sustainability. Additionally, the study highlights the importance of incorporating user preferences in decision-making to enhance compliance with management tools and improve the fishery's adaptive capacity and resilience.

Harvesters expressed a strong desire to improve the profitability of the stalked barnacle fishery and a higher willingness to exit the fishery in response to the reduced price scenarios. This indicates that economic profitability is critical for the future of the fishery. Currently, local first sales in fish markets have the greatest influence on the profitability of the fishery. Market dynamics often involve short-term fluctuations, which harvesters can influence to a certain extent (see example in Rivera et al. 2014). We found that in response to the reduced price scenario, Asturian stalked barnacle harvesters opted to decrease the individual quota and harvest time, with the aim to provoke an increase in the market price by generating higher demand through limited supply. This self-regulating behaviour indicates that resource users have a high level of knowledge of the market and utilise strategies to influence it (Salas et al. 2004). Such strategies, based on harvesters' short-term decisions on market demands, have been documented in other small-scale fisheries as well. For example, in some artisanal cooperatives in Yucatan (Mexico), each fishing trip is directed to fulfil a certain economic threshold, with the biggest catches of highly valued species on Thursdays and Fridays to earn enough money for the weekend when they tend to cease their fishing activity (Defeo and Castilla 2005).

However, to successfully influence local markets, resource users need to be well-organised and work collectively (Defeo and Castilla 2005). This usually only occurs in the most accomplished co-management systems (Gutiérrez et al. 2011; Geiger et al. 2022), as is the case in Asturias-West (Rivera et al. 2014; Aguión et al. 2021). To ensure profitability, harvesters suggested introducing an official minimum market value, although this is unlikely given that stalked barnacles are a luxury product with high economic value (González-Álvarez et al. 2016), which is not included in the initiative of the Spanish government to guarantee minimum prices for food products (Law 12/2013, 2nd of August, Article 185, BOE-A-2013-8554, Modification in 2020 of measures to improve the functioning of the food chain). While eco-labelling has successfully generated price premiums in certain small-scale fisheries, as demonstrated by the Asturian *Octopus vulgaris* fishery (Sánchez et al. 2020; Table 3.3), it may not be economically feasible for all artisanal fisheries and premiums may only be obtained by accessing new international markets. Additionally, the demand for eco-labelled products depends on consumer environmental awareness, which varies by region (Wakamatsu and Wakamatsu 2017). Given that stalked barnacles are mainly a delicacy in the Iberian Peninsula, their demand in international markets may be limited. Nonetheless, Vázquez-Rowe et al. (2013) propose that certificates of origin could enhance the stalked barnacle fishery's market value on the national market.

The mixed scenario, where resource abundance decreases and market prices increase, is a common phenomenon in high-value species (Casselman 2003; Collette et al. 2011; Burgess et al. 2017). As scarcity leads to higher prices, some harvesters continue to harvest despite the potential risks to the resource, while others choose to reduce their efforts to protect it (Fig. 3.2). Similar behaviour has been observed in other small-scale fisheries (Oyanedel et al. 2020). Harvesters who prioritise personal short-term profits over the risk of overexploitation and long-term sustainability choose inaction in response to the mixed scenario, while others decrease their quota and harvest time to balance profit-making and resource conservation. Contrary to the reduced abundance scenario, where they choose to implement harvest bans to reduce effort.

The duration of the impacts, whether economic or biological, also influenced harvesters choices, resulting in increased variability in strategy preferences with a higher likelihood of abandoning the fishery in scenarios of two seasons (Fig. 3.2). Other small-scale fisheries have also shown an increasing willingness to exit the fishery as the resource stocks decline (Cinner et al. 2009; Daw et al. 2012). Although opportunities for harvesters to participate in co-management differ between the two regions in Asturias (Aguión et al. 2021), both groups responded similarly to the hypothetical fluctuations. The majority of harvesters from both regions showed concern for the sustainability of the resource in scenarios of reduced abundance, indicating a willingness to temporarily sacrifice their economic benefits for the long-term sustainability of the fishery (Fig. 3.2; Table 3.3). This is especially important when overexploitation of a resource requires long-term management measures for its recovery (Jamieson 1993). Unexpectedly, in the scenario of reduced abundance and increased price, some harvesters from the TURFs in Asturias-West chose to prioritise profit over the sustainability of the resource. This shows that despite the strong conservation ethic generated by participatory co-management in this region, perceptions among harvesters from Asturias-West are heterogeneous (Rivera et al. 2016). This highlights the importance of understanding the various factors that contribute to harvesters' willingness to make short-term sacrifices for long-term sustainability in order to effectively manage and conserve high-value species.

Management recommendations

The current strategies in place are largely accepted by harvesters, as seen in Table 3.3. Nevertheless, involving harvesters more in the decision-making process could be benefitial, particularly in Asturias-East where harvesters have not been integrated into the co-management process. The implementation of two TURFs along the eastern coast of Asturias is expected to provide more opportunities for harvesters to participate in the co-management.

The recurring request for improved surveillance and enforcement by harvesters could be addressed by providing higher budgets for the regional administration and involving fishers (through community surveillance committees) and other environmental law enforcement agencies in surveillance efforts (Rivera et al. 2019). Internal control mechanisms, chosen by harvesters such as graduated sanction schemes (Geiger et al. 2022), could reduce poaching and overharvesting by members of the TURFs. With higher user compliance, motivated by increased collaboration of harvesters in the management efforts, internal poaching activities would decrease. This, in turn, could lead to greater efficiency in surveillance, as it would primarily focus on external poachers.

Given that the choices harvesters make vary according to changes in the market (Fig. 3.2), it is crucial for managers to be aware of market trends and fluctuations when selecting strategies to protect the resource (Fryxell et al. 2017). While legally established minimum selling prices are not possible, harvesters could be encouraged to make internal agreements on an acceptable minimum price among themselves. Moreover, managers could consult with harvesters to find adequate solutions and allow for collective actions in response to prolonged negative market tendencies.

The extreme peak in the harvesting activity around Christmas time, in response to high consumer demand based on cultural traditions, is a recurring trend in the fishery (Rivera et al. 2014). To deseasonalize the demand and obtain good prices throughout the harvest season, local markets could promote the resource through special sales initiatives, such as "Stalked Barnacle Weeks" or festivals. Managers could facilitate knowledge exchange meetings between Asturian and Galician cofradías, similar to the international stakeholder workshop organised by Project PERCEBES 2020. Such meetings could promote cohesive and highly organised systems like the TURF of the Cofradía of Cangas (Galicia), where harvesters work as a team by dividing up various harvesting activities and negotiating the entire harvest in advance with buyers to avoid overexploitation (Geiger et al. 2022). Adaptable management measures that respond to harvesters' needs and protect the resource are essential. Compliance with effort-reducing rules is easier to achieve through input-based restrictions, such as harvest bans or harvest time restrictions, rather than output-based restrictions such as harvest quota reductions (Nielsen and Mathiesen 2003). Therefore, we recommend that fisheries managers prioritise these strategies, as they are broadly accepted among harvesters and easier to implement and control.

3.5. Conclusions

The Asturian stalked barnacle fishery provides an example of adaptive co-management through social and institutional learning, even in cases where where co-management is not strictly implemented (i.e. Asturias-East). Harvesters' choices demonstrate the effectiveness of commonly implemented strategies, fostering cooperation and resilience within the co-management system. However, market fluctuations can prompt less sustainable responses from harvesters, highlighting the need for regular market monitoring and adaptable management measures. Managers in this region should involve local harvesters in decision-making to enhance compliance and sustainability. This study underscores the importance of participatory approaches in fisheries management and the need for flexibility in response to changing environmental and market conditions. By implementing these recommendations, the Asturian stalked barnacle fishery can continue to thrive while ensuring the long-term sustainability of this valuable resource.

CHAPTER 4

Comparing the management preferences of harvesters across European stalked barnacle fisheries

4.1. 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). The social and economic value of the contribution of SSFs to societal well-being has generally been underestimated, since 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). 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 has made efforts to improve SSF management across Europe by prioritising the promotion of efficient management of SSFs in Europe (CFP). One approach to improve SSF 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 SSF 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 (Pita et al. 2010; Perez de Oliveira 2013). Specifically, user compliance plays a fundamental role in the effectiveness of implemented management (Hatcher and Pascoe 2006; Oyanedel et al. 2020). Understanding resource users' perception of the legitimacy of management strategies and their willingness to adopt new strategies at the local scale 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).

This study aims to investigate the perception of stalked barnacle harvesters regarding the effectiveness of fisheries management practices in Spain, Portugal and France. This study aims to investigate the perception of stalked barnacle harvesters regarding the effectiveness of fisheries management practices in Spain, Portugal and France. Stalked barnacles (*Pollicipes pollicipes*, Gmelin, 1791 [in Gmelin, 1788–1792]) are sessile cirripedes that grow on very exposed rocky shores along the 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 (Molares and Freire 2003; Rivera et al. 2014; Cruz et al. 2015; Sousa et al. 2020). In Spain stalked barnacles are considered a luxury item and market prices can reach 200-266€/kg (Rivera et al. 2014; Ruiz-Díaz et al. 2020). For this study, we sampled six regions within the Atlantic arc, presenting almost the full extent of stalked barnacle management in Europe. The management of this fishery 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 (10s km and less; Aguión et al., 2022). Due to the sessile nature of this species, stocks can be managed particularly well by spatially-explicit management tools such as territorial user rights (TURFs) and rotation of areas, which facilitate better surveillance and control against poachers. This has been demonstrated by fisheries in Galicia and Asturias (Spain), which successfully manage the stalked barnacle stocks using detailed spatial management under participatory co-management (Rivera et al. 2014; Rivera et al. 2017a; Aguión et al. 2021).

The objective of our study is to investigate the harvesters' perception of the effectiveness of current management strategies. In addition, we collected information from harvesters on their preferred management strategy to achieve sustainability in the fishery. Finally, we used multinomial model selection to identify the patterns that drive the perceptions harvesters have of the management. These results provide useful information on the harvesters' psyche, which can help improve fisheries management if integrated.

4.2. Material and Methods

Study area and regional management

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; Portugal) and the Parque Natural do Sudoeste Alentejano e Costa Vicentina (PNSACV; Portugal. Fig. 1.1, see introduction).

The management of stalked barnacle fisheries 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).

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 associations, 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. Due to its geography and the limited number of licences for professional harvesters, access to RNB is limited. As a result, RNB's fishery management operates similarly to a TURF. 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).

In Asturias-East, Morbihan and PNSACV management is practised on a significantly larger spatial scale (> 100 km). Although the number of licences for professional harvesters is limited in all regions, in Morbihan and PNSACV recreational harvesting is allowed. When the surveys for this study were conducted, management of the fishery in Asturias-East was basically top-down (implemented since 1992), with minimal exchange of information between the regional government and users. But in February 2023, two TURFs were created, reducing the spatial scale and allowing for a more participatory co-management. The current management in PNSACV 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). 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.

Implemented management strategies

In our study, we focused on ten management strategies that are considered the primary strategies implemented in various regions (Table 4.1). 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 4.1 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 5-8kg/person/day, whereas RNB and PNSACV have higher quotas of 10 and 15kg/person/day, respectively. In stark contrast, Morbihan allows a remarkably high quota of 120kg/person/day. 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.

Survey

The survey questions were originally developed in 2019 for the stalked barnacle fishery in Asturias, where we had extensive discussions with experts in fishery, including scientists, government officials, and professional harvesters. We then amplified the study range, 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 minutes). 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' perceived knowledge of management tools, their 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. To evaluate harvesters' 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.

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, 1976), 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 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.

Data treatment, statistical analysis and modelling

Prior to conducting data analysis and modelling, we checked for the most common statistical assumptions. We assessed the association between categorical variables using Fisher's exact tests (Table C1 see appendix C). Furthermore, we performed Kruskal-Wallis tests on data from the two regions in Asturias 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 C1).

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. 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 (Table 4.1). 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 (Fig. C2 see appendix C). To determine the model that best described the association between the independent variables (region, age, main income source, educational 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).

4.3. Results

The statistical tests confirmed that there were no significant differences in responses among data collection methods used before and during the pandemic (Table C1). Significant associations between the dependent variable (most important management strategy) and the independent variables (region, main income source, and educational level) were detected (Table C1).

General information and socio-economic characterization of the fisheries

Additionally to important differences in the management, study regions also differ considerably in size and length of coast (Fig. 1.1 see introduction), as well as in number of licences and active harvesters (Table 4.1). The fishery is dominated by men and only in Galicia a small percentage (16.7%) of women participated in the survey (Table 4.1). Harvesters in Asturias (East and West) were found to be younger and presented a higher educational level than those in other regions, particularly than in the Portuguese regions (RNB and PNSACV; Table 4.1). 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 4.1).

Table 4.1. List of the stalked barnacle fishery management strategies implemented in the six regions, with √ indicating management strategies that are generally present and X indicating those that are present as an exception in the region, while empty spaces indicate that management strategies are not present in the region; General information of the study regions: numbers of professional licences, active harvesters, and surveys (from 2020) and average stalked barnacle price taken from Aguión et al. 2022 ; Demographic variables (gender, age, educational level and main income source), presented in percentages, of the participating harvesters.

		Morbihan	Asturias-East	Asturias-West	Galicia	RNB	PNSACV
Co-management	Co-management	√	√	√ in law	√ in law	√ in law [a]	√
Spatial restrictions	Harvest Ban	√		√	√	√	√
	Marine Reserve	√				√	√
	TURF		[b]	√	√		
Temporal restrictions	Restricted Harvest Time	√	√	√	√		
	Harvest Season	√	√	√[c]	X[d]	√	√
	Harvest Area Rotation			X[c]	√[e]		
Output restrictions	Minimum Barnacle Size (rotro-carinal length in mm)		√	√	√	√	√
	Individual Quota (kg/person/day)	√	√	√	√	√	√
	Community Quota (kg/rock/year)			√[d]	X[f]		
Nº of surveys (total = 184)		6	24	54	48	25	27
Nº of active harvesters		10	54	216	1250	40	80
Nº of professional licences		21	100	220	1341	40	80
Stalked barnacle price (Euros/kg)		5-8	15-18	23-32.5	23.5	23	14
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
References		pers. Communication M. Barbier CRPMEM (Comité régional des Pêches Maritimes et des Élevages Marins de Bretagne) 3. March 2020; Aguión et al. 2022	pers. Communication P. Péon (Centro de Experimento Pesquero) 1. December 2021; Aguión et al. 2022	pers. Communication P. Péon (Centro de Experimentación Pesquera, Dirección General de Pesca Marítima) 1. December 2021; Aguión et al. 2022	pers. Communication P. Péon (Centro de Experimentación Pesquera, Dirección General de Pesca Marítima) 1. December 2021; Aguión et al. 2022	Cruz et al. 2022; Aguión et al. 2022	Cruz et al. 2022; Aguión et al. 2022

[a] Included into the fisheries legislation in 2021 - 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.

Harvesters' perceived knowledge of management strategies

Harvesters' perceived knowledge of management strategies was assessed by asking them to indicate which strategies they knew well enough to describe in their own words. Overall, harvesters expressed to have a relatively good knowledge of the management strategies currently implemented in their region, with some notable exceptions. Surprisingly, harvesters in regions with a long tradition and high level of co-management implementation, such as Galicia and Asturias-West, indicated to have a low level of knowledge of co-management (around 35% and 37% of responses, respectively; Fig. 4.2). In Asturias-West, only 50% of respondents reported knowing about the harvest season strategy, which is a basic strategy implemented along the entire Asturian coast (Fig. 4.2). Only 18% of respondents in Asturias-West indicated to know about community quotas, a strategy currently implemented only in some Asturian and Galician TURFs, whereas in Galicia 60% of respondents reported knowing this strategy. In Morbihan 17% of respondents claimed to know about the implemented maximum harvest time strategy (Fig. 4.2). In both RNB and PNSACV, perceived knowledge of all implemented strategies was high (> 75% of responses), except for the harvest ban, which slightly less harvesters indicated to know (68% and 63%, respectively; Fig. 4.2). The perceived knowledge of management strategies that are not currently implemented in the regions was generally lower than that of implemented strategies, with the community quota being the strategy least harvesters claimed to know, followed by the rotation of harvest areas (Fig. 4.2).

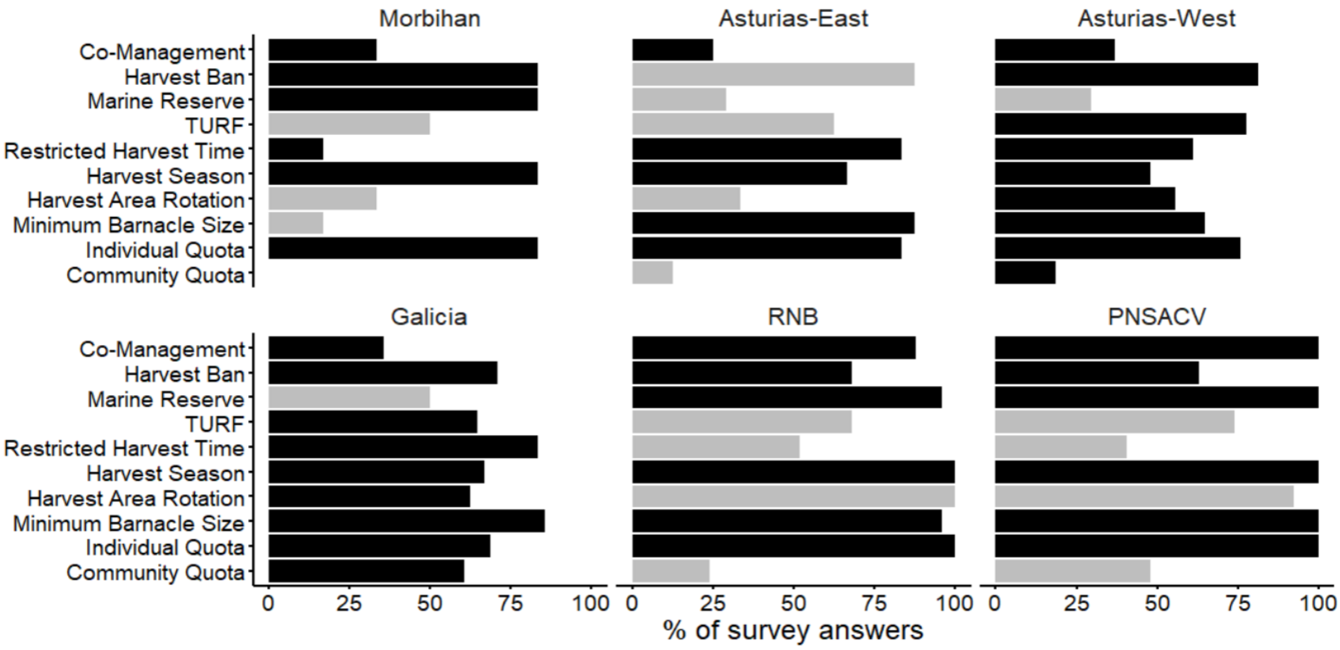


Figure 4.2. Percentage of survey answers indicating the perceived knowledge harvesters have regarding management strategies. Black bars represent management strategies that are implemented in the regions, whereas grey bars represent strategies that are not implemented.

Most effective management strategies in place

The perceptions of the most effective management strategies in place for a sustainable fishery varied among regions. 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. 4.3). 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. 4.3). 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. 4.3). 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. 4.3). 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).

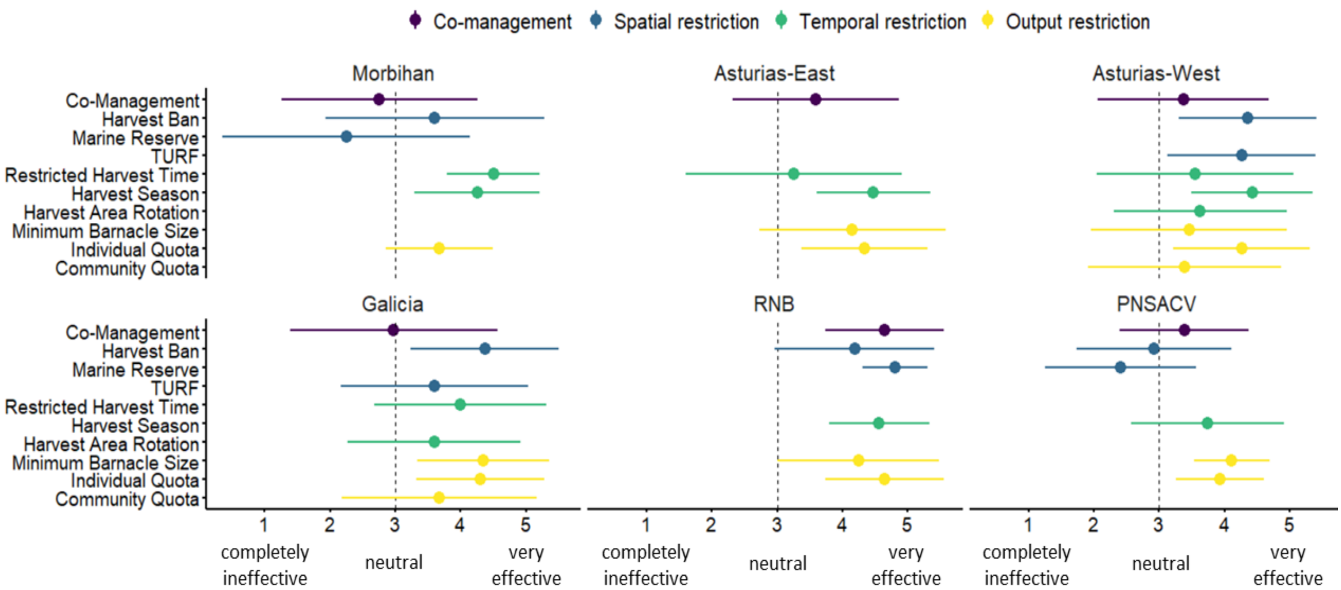


Figure 4.3. Mean Likert scale values with standard deviations for the perception of effectiveness of the regionally implemented management strategies. Note: blank means that the management strategy is not in place in the fishery.

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. 4.4). In Galicia and Asturias-West only 42% and 32% of harvesters, respectively, were willing to change the management strategies, while 23% and 6%, respectively, were opposed to it (Fig. 4.4). 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).

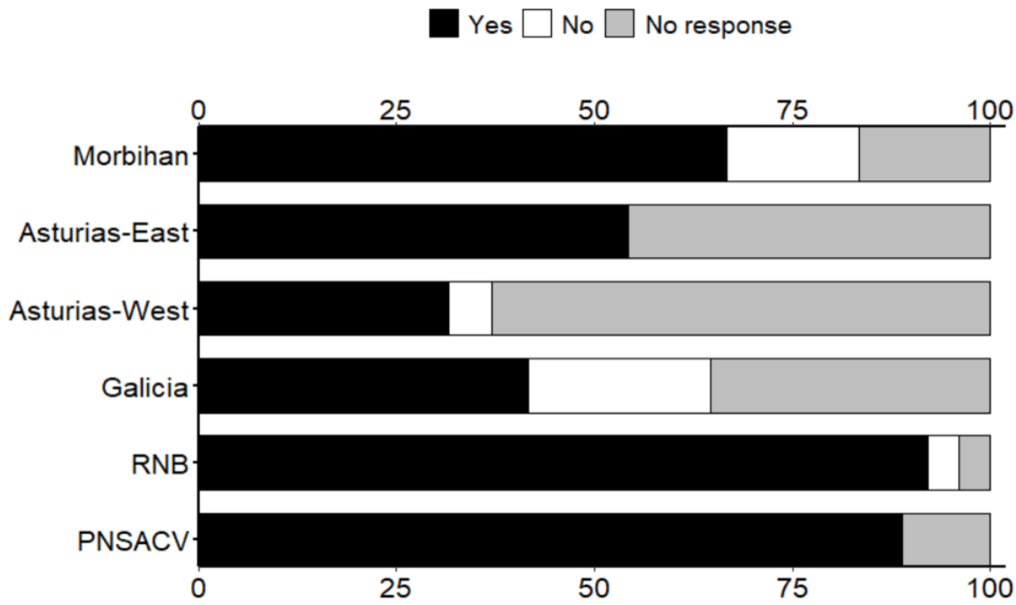


Figure 4.4. Relative frequency (%) of harvesters willingness for changing the management strategies in each region.

Modelled harvesters preference for management

Based on the AIC model selection analysis results (Table 4.2), 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.

Table 4.2. 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 leve	42	396.70	48.16	0.00	1.00	-135.59

Harvesters preferred future management choice

In Asturias-West (71.5%), Asturias-East (44.4%), and Galicia (64.3%) harvesters considered spatial restrictions 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 (Table 4.3). 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 (Table 4.3).

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 4.3). 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 4.3).

Table 4.3. Percentage of harvesters who chose the most important management strategy to ensure sustainability of the stalked barnacle fishery in their region. The darkness of the colour and number in each cell represents the percentage of harvesters who selected the corresponding management strategy as the most effective in that region.

		Morbihan	Asturias-East	Asturias-West	Galicia	RNB	PNSACV	
Co-management	Co-management	0	5.5	11.9	4.8	48	34.6	
	TURFs	0	33.3	11.9	14.3	0	7.7	
Spatial restrictions	Harvest Ban	0	0	54.8	23.8	0	0	
	Marine Reserve	0	11.1	4.8	26.2	4	3.8	0
	Harvest Area Rotation	0	5.5	2.4	9.5	4	23.1	1-10%
Temporal restrictions	Harvest Season	0	5.5	0	0	12	11.5	11-20%
	Restricted Harvest Time	33.3	5.5	2.4	0	4	0	21-30%
	Community Quota	33.3	5.5	0	0	0	0	31-40%
Output restrictions	Individual Quota	33.3	16.7	7.1	11.9	16	11.5	41-50%
	Minimum Barnacle Size	0	11.1	4.8	9.5	12	7.7	> 50%

4.4. Discussion

Our study aimed to investigate the preferences of harvesters in different management regions for fisheries management strategies, in order to identify key insights that can be used to improve the sustainability of the stalked barnacle fishery. Our findings indicate that the majority of harvesters from regions with co-management systems that present lower decision-making power and participation of harvesters, such as Asturias-East, Morbihan, PNSACV and RNB (see Aguión et al., 2022), demonstrated willingness to make changes in the fisheries management (Fig. 4.4). The willingness to make changes 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). The stalked barnacle fisheries in Galicia and Asturias-West generally exhibit higher scores in terms of governance and sustainability attributes (Aguión et al. 2021). Harvesters here, furthermore, demonstrated lower willingness to make changes (Fig. 4.4), suggesting that they may have a higher level of contentment with the current management (e.g. Rivera et al., 2017). The high market prices attained by harvesters in these two regions (Rivera et al., 2014; Ruiz-Díaz et al., 2020; Table 4.1) could also contribute to their positive satisfaction levels. While harvesters generally appeared to have a good understanding of the strategies currently implemented in their region, some gaps in the perceived knowledge were identified. Certain discrepancies arose between the strategies identified as the most important for ensuring the sustainability of the fishery in the future and their rated effectiveness under current implementation. Furthermore, no clear trend emerged regarding a single "optimal" management strategy preferred by harvesters across regions. This finding was not unexpected, due to the substantial differences in fisheries management practices and cultural and socio-economic characteristics among regions (Table 4.1). 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. Furthermore, the diversity of preferred management strategies highlights the importance of considering a combination of multiple management strategies to achieve sustainable fisheries management, rather than relying on a single approach.

We identified some challenges associated with the knowledge of management strategies. For example, perceived knowledge of co-management seemed low among harvesters (with the exception of the two Portuguese regions; Fig. 4.2). This result was surprising in Galicia and Asturias-West, where participatory co-management was already implemented in 1992 and thus has a long tradition (Macho et al. 2013; Rivera et al. 2014). It is noteworthy, however, that we only assessed harvesters' own perception of knowledge regarding the management strategies and did not test their actual knowledge. While co-management has been extensively implemented in Galicia and Asturias-West (Macho et al. 2013; Rivera et al. 2014), it is worth considering that harvesters may not be familiar with the official term "co-management." As a result, they may not explicitly associate their involvement in decision-making processes and shared responsibilities with the government under the specific label of co-management. This limited familiarity with the term could also have influenced the results of their perceptions of its effectiveness (Fig. 4.3). However, harvesters may also 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 fully be aware of its effects or appreciate its significance. In contrast, in RNB, where co-management was being implemented legally during the time of the survey and harvesters thus are familiar with this term, it was rated as highly efficient (Fig. 4.3) and voted as the most important management strategy to ensure fishery sustainability (Table 4.3). Harvesters here were experiencing a positive change through the implementation of co-management, allowing for more participation. In PNSACV, where harvesters are also familiar with the official term of co-management, respondents perceived it to be implemented less effectively than desired, with a rating slightly above neutral (Fig. 4.3). Nevertheless, 34.6% of respondents still believed it to be the most important management strategy for a sustainable fishery (Table 4.3). Our findings highlight the need for education and awareness-raising efforts regarding co-management and its importance for sustainable fisheries management. By fostering a deeper understanding and appreciation of the co-management system, it can be further strengthened and effectively maintained in all regions.

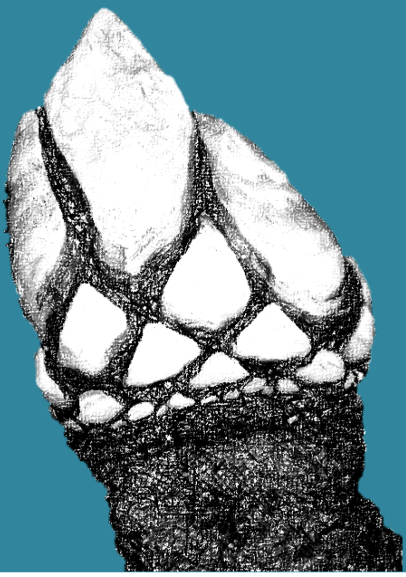
Harvesters of Galicia and Asturias-West rated spatial restrictions as the best management approach for ensuring a sustainable fishery, which corresponds with the implemented highly detailed spatial management strategies in these regions (Aguión et al., 2022; Rivera et al., 2014; Fig. 4.3; Table 4.3). 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. 2017a). However, Galician harvesters rated marine reserves as the most important management strategy for ensuring a sustainable fishery. According to Afflerbach et al. (2014), resource users who possess territorial user rights, such as Galician harvesters, have a greater motivation to manage their resources sustainably and undertake conservation efforts, including the establishment of marine reserves (permanent no-take areas). Their preference could also be attributed to a misconception of the strategy, as the Parque Nacional das Illas Atlánticas in Galicia is not a no-take zone for stalked barnacles and harvesters in this area enjoy a privileged situation due to the controlled access provided by its geographical setting as islands and increased surveillance by National Park guards, which effectively minimises poaching (Geiger et al. 2022). However, in Morbihan, where permanent no-take zones are established, and in RNB and PNSACV, where no-take marine reserves are in place, only a small percentage of harvesters perceived this as the most effective approach to achieve a sustainable fishery. In fact, in Morbihan and PNSACV, most harvesters considered marine reserves an ineffective management strategy (Fig. 4.3). The economic benefits of marine reserves, though, 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). 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. (2013) 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 temporary small-scale marine 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 (Fig. 4.3). This was the case in Asturias-East, where harvesters perceived TURFs as the key strategy to improve their fishery (Table 4.3), likely influenced by the success of the fishery management in Asturias-West. 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. These examples suggest a "grass is greener" effect, where harvesters perceive management strategies in other areas as more effective or desirable than their own, even with limited knowledge or experience of those strategies. This mind-set can potentially lead to unrealistic expectations regarding the universal applicability of specific management strategies and it is important to keep in mind that the success of a strategy in one region does not guarantee its effectiveness in others. As fisheries management is a complex and ever-evolving process, there is no one-size-fits-all solution for a sustainable management (Degnbol et al. 2006; Bianchi et al. 2009; Jentoft and Bavinck 2014). The interest of harvesters in management strategies implemented in other regions, however, also 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 (Trimble and Plummer 2019; Geiger et al. 2022). 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 highlighted by de la Torre-Castro and Lindström (2010), fisheries management should be an open-ended and dynamic process rather than a fixed condition. By acknowledging the preferences and aspirations of harvesters for specific management strategies, policymakers and stakeholders can work towards aligning management practices with the expectations and needs of the fishing communities, promoting more effective and region-specific approaches to sustainable fishery management.

Moving forward, it is important to investigate whether harvesters continue to strive for improvement, regardless of the level of fisheries management. Alternatively, it could be the case that harvesters reach a point where they are satisfied with the level of management and may no longer aspire for even better management. An interesting case study for this purpose is the implementation of the "all for all" (from the Spanish 'todos para todos') strategy by the *cofradía* of Cangas (Geiger et al. 2022). Here, harvesters have created a cohesive and highly organised system, where the entire harvest is negotiated in advance with the buyers to avoid overexploitation and harvesters work as a team, dividing up all necessary activities and sharing the profit equally among them (Geiger et al. 2022). This system, despite some minor difficulties during the initial implementation period, is now appreciated by its members and is starting to be acknowledged as a successful management of the stalked barnacle fishery by other *cofradías* and regions, where it might serve as an inspiration to follow (pers. Communication B. Barreiro, Technical Assistant *Cofradía* Baiona, 15. June 2023).

4.5. Conclusions

This study contributes to our understanding of the effectiveness of management strategies in European stalked barnacle fisheries by examining the perceptions of harvesters. We found that harvesters from fisheries with lower levels of governance and overall sustainability are considerably more willing to make changes to current management strategies, reflecting their awareness of the need for improvement. Harvesters prioritise distinct strategies for sustainable fishery management, which can vary depending on factors such as regulatory frameworks, geographical settings, and cultural aspects specific to each region. Therefore, tailored management strategies that consider the unique needs and characteristics of each fishery are crucial for effective and sustainable management. Additionally, the "grass is greener" effect may influence harvesters' perception of the effectiveness of management in their area, highlighting the importance of taking a holistic and multi-faceted approach to sustainable fisheries management. Overall, ongoing efforts to promote trans-regional management through joint workshops and research, such as this study, can facilitate mutual learning and knowledge exchange, leading to innovative and effective management solutions for the common challenges faced by fisheries. By prioritising the unique needs and characteristics of each fishery and fostering cooperation across jurisdictional boundaries, we can work towards achieving sustainable management of our oceans' resources.



CHAPTER 5

An inter-regional challenge: poaching in European Stalked Barnacle Fisheries

5.1. Introduction

The Common Fisheries Policy Reform in 2013 aimed to improve fisheries management in the European Union, including the promotion of coastal fishing activities (Reg EU 1379/2013 in CFP, 2013; (European Union 2013c). One practical approach to achieve these goals is the identification of successful practices that could be adapted to different cultural or socioeconomic contexts. The international PERCEBES project (http://www.unioviedo.es/percebes/) identified the potential of the stalked barnacle fishery in SW and W Europe as a model for the exchange of management practices among regions (Fig. 5.1). Harvesters in these small-scale fisheries collect stalked barnacles, which grow on very exposed rocky shores. Cultural differences among the regions have led to large differences in the socio-economic relevance of these fisheries (Table 5.1).

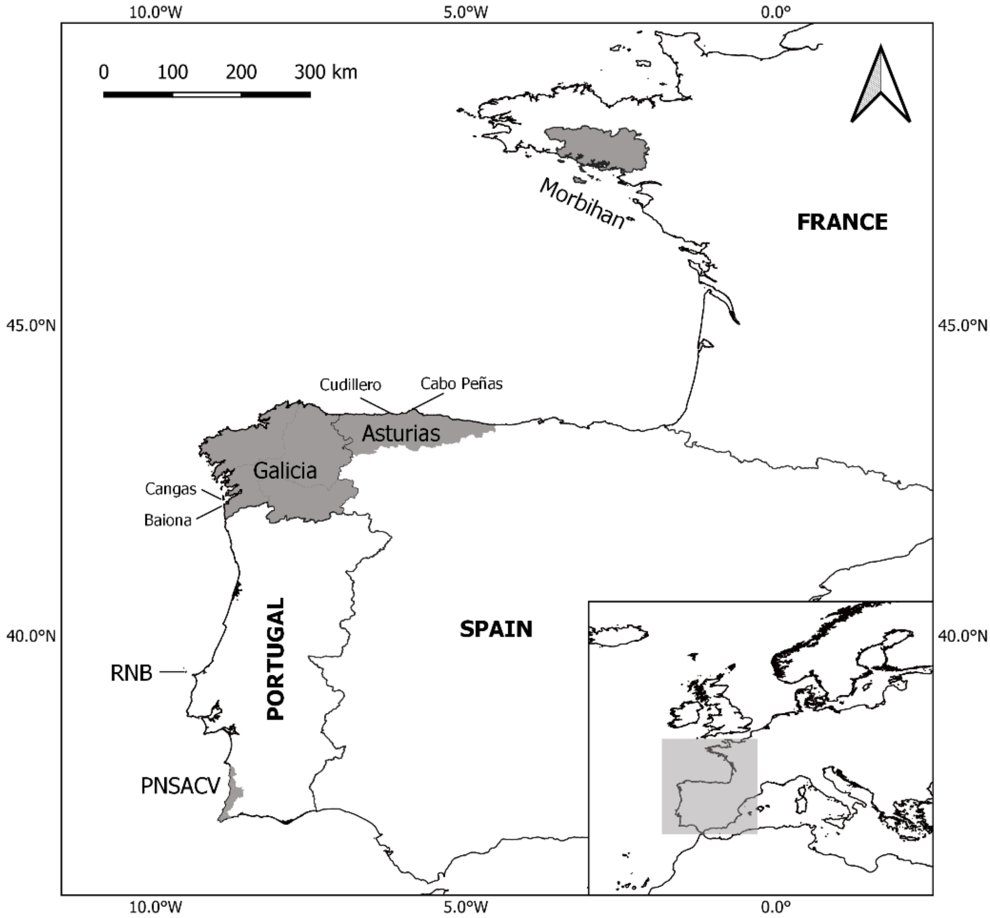


Figure 5.1. Map of the regions represented in the workshop. This includes the Morbihan region in Brittany, individual Territorial Use Rights for Fishing (TURF) areas in the Spanish regions of Galicia and Asturias (Baiona, Cangas, Cudillero and Cabo Peñas), the Reserva Natural das Berlengas (RNB, Portugal) and the Parque Natural do Sudoeste Alentejano e Costa Vicentina (PNSACV, Portugal). Locations (Cabo Peñas, Cudillero, Cangas and Baiona) indicate the *cofradías* represented by participating professional harvesters.

Table 5.1. Socio-economic characteristics and management tools of the participating stalked barnacle fisheries. Figures are representative for recent years. Adapted from Aguión et al. 2021.

Region	Socio-economic characteristics				Management tools				
	Number of professional harvesters	Landing volume (t year^{-1})	Landing value (10^3 € year^{-1})	Price (€ kg^{-1})	Recreational fishery	Daily quota recreational (kg day^{-1})	Professional licenses	Daily quota professionals (kg day^{-1})	Minimum size* (mm)
Morbihan	30	50	325	5 to 8	Yes, without license	3	Yes, unlimited	120	No minimum size
Asturias-West	204	44	1408	32	No	-	Yes, limited	5-8	18.0 on 60% of the harvest
Galicia	1308	325	7640	23.5	No	-	Yes, limited	3-10	18.3 on 60% of the harvest
RNB	40	12	275	23	No	-	Yes, limited	20	23.0 on 50% of the harvest
PNSACV	80	-	-	14	Yes, with license	2	Yes, limited	10-15	20.0 on 75% of the harvest

*Rostro-carinal length (Cruz 1993)

The Atlantic regions also differ in the spatial scale of management, the participation of harvesters in monitoring and surveillance, the level of responsibilities of harvesters and administration in the decision-making process (e.g. co-management) and the access regime (e.g. Territorial Use Rights for Fishing - TURFs(Aguión et al. 2021). However, harvesters, administrations, NGOs and scientists frequently remain unaware of many successful management practices applied outside of their regions. In January 2020, the PERCEBES project organized a workshop with the participation of a diverse group of stakeholders from Portugal, Spain and France to facilitate the exchange of knowledge and experience among regions. During the discussions, poaching surfaced as the main issue common to all regions, with systemic effects on all aspects of the fishery. Despite its relevance, poaching in the stalked barnacle fishery has only been investigated in Galicia (Ballesteros et al. 2017; Ballesteros and Rodríguez-Rodríguez 2018b; Ballesteros and Rodríguez-Rodríguez 2018a; Ballesteros and Rodríguez-Rodríguez 2019; Ballesteros et al. 2021), where this complex phenomenon causes significant economic losses (Ruiz-Díaz et al. 2020). In Asturias and in Portugal, poaching of *P. pollicipes* has only been indirectly addressed (Jacinto et al. 2010; Rivera et al. 2014), whereas in France poaching is only mentioned in the news. The present work is a summary of the information extracted during the workshop, with particular emphasis on the problem of poaching and on potential solutions.

5.2. Methods

The workshop took place in Cudillero (Asturias) on January 24, 2020. Among the stakeholders there were harvesters (n = 8), fisheries managers (n =7), fisheries surveillance personnel (n = 4), NGO advocates (n = 4) and scientists (n = 27). Participants came from Spain (n = 33), Portugal (n = 10) and France (n = 6), specifically from the following 5 regions: Morbihan (Brittany, France), Asturias and Galicia (Spain), Reserva Natural das Berlengas (RNB, Portugal) and Parque Natural do Sudoeste Alentejano e Costa Vicentina (PNSACV, Portugal). The stakeholders received a summary of the project's findings and were introduced to the different management practices of each of the five participating regions. We followed a roundtable discussion approach (Bridgeman 2010) to explore the opinions of a diverse group of stakeholders from different regions. All discussions were aided by 3-language simultaneous translation, recorded and transcribed for analysis. The quantitative method we employed, renders bottom-up solutions that are more likely to be accepted and help garner higher compliance by the users.

Table 5.2. Topics voted for discussion and topics discussed in the regional roundtables.

Region	Topics voted in the regional tables	Topics discussed
Morbihan	Differences of the management between France and Galicia	Yes
(France)	Scientific knowledge and monitoring	Yes
	Poaching	Yes
	Market and price issues	Yes
	Marine Reserve	Yes
Asturias-West	Collaboration between science and fishing sector	No
(Spain)	Marine Reserves	No
	Poaching	No
	Reasons for stock decrease	No
	Raising education and awareness of harvesters	No
	Surveillance	No
		Improving co-management
Galicia	Rotation and harvest bans	Yes
(Spain)	Current state of resource	Yes
	Marine Reserve	Yes
	Larval fixation	No
	External scientific counseling	No
	External figure in co-management	No
		Poaching
RNB/PNSACV	Co-management vs centralized management	Yes
(Portugal)	Poaching	Yes

Facilitators steered the discussions to ensure equal input opportunities for all participants. In a first session of roundtable discussions participants from each sector separately -harvesters, fisheries managers, fisheries surveillance personnel, NGOs and scientists- shared experiences and perceptions regarding the exploitation and management of stalked barnacles in their respective regions. In a second session, participants from each region gathered to identify the most relevant topics for the sector and discuss the potential of importing successful management practices from other regions (Table 5.2). A concluding, general session allowed summarizing the most important topics for each region and sector. The final recommendations were not discussed among all stakeholders during the workshop, but were extracted during the analysis of the recordings from the roundtable discussions. Therefore, consensus on them was not tested, neither were they ranked by importance or efficiency. Images and further information on the workshop can be viewed at: https://www.youtube.com/watch?v=Y3CQqsu5O2w&feature=youtu.be.

5.3. Results and discussion

Poaching was a central theme during the meeting. It dominated the discussions on the harvesters' roundtable, and was addressed in the scientists and managers/NGOs tables. Furthermore, it was voted a key discussion topic and further discussed in the regional roundtables. Nonetheless, we aim to convey all main results of the workshop.

Management strategies within the participating region

This summary is based on the detailed regional account in Aguión et al. 2021 and on information acquired during the workshop. In general, management differs among countries, but only slightly between regions within the same country (for example, Galicia and Asturias in Spain vs RNB and PNSACV in Portugal; Table 5.1). Common to all regions are the need for a professional license and the enforcement of daily harvest quotas, both for professional and recreational harvesters (Table 5.1). In addition, in all regions, except for Morbihan, there is a legal minimum size for the stalked barnacles (Table 5.1). However, there are important differences among regions in the level of implementation of the four governance elements (Spatial scale of management, level of co-management, fisher's participation and access regime; (Aguión et al. 2021).

Implementation is higher in Galicia and West Asturias, with an exclusive access regime, high levels of co-management and fisher's participation, small (10s to 1000s Km) spatial scales of management and no recreational harvesting allowed. In these regions, the harvesters belong to *cofradías*, which are geographically based fishers associations located in coastal villages. Additionally, in Galicia stalked barnacle harvesters form resource-specific associations within the *cofradías*. TURFs are granted to the *cofradias*, giving exclusive access over an area and its resource to a limited number of harvesters (Christy 1982). The resource is co-managed between the *cofradía* or association and the regional fisheries authorities, who share decision-making power and responsibilities (Macho et al. 2013; Rivera et al. 2014). The harvesters propose a yearly management plan, providing detailed indications for the temporal and spatial allocation of harvesting effort (*e.g.* rotational harvesting schemes or temporal ban areas) at scales ranging from kilometers to barely a few meters. The management plans must then be approved by the regional fisheries administration and made publicly available for consultation. Surveillance is done by TURF and regional coast guards, and in some cases by harvesters and National Park guards.

Lowest implementation levels characterize Morbihan and PNSACV, where management is done at regional scales, recreational harvesting is allowed and surveillance is conducted by reduced police patrols along vast swaths of coast. The quota for recreational harvesters is lower than for professionals, particularly in Morbihan. Recreational licenses though, are only needed in PNSACV, where they are obtained on a daily basis.

RNB takes on an intermediate or transitional position. Inspired by the TURF system applied in Spain, harvesters in RNB are involved in a pilot-project (CO-PESCA 2) since 2018 to transition towards co-management (Sousa et al. 2020). The project has already resulted in an increased level of participation of the harvesters in management and better monitoring of the resource. Recreational harvesting is forbidden and because RNB is an archipelago of islands, it functions similarly to a TURF.

Poaching in the stalked barnacle fisheries

During the workshop, poaching was identified as a major problem in all regions, with the potential to jeopardize the sustainability of the resource. In the context of this fishery, poaching is the illegal harvest of stalked barnacles. It is a complex phenomenon, that has been classified in detail by (Ballesteros and Rodríguez-Rodríguez 2018b). During the workshop, certain types of poaching, likely those perceived as the most common and/or harmful, were mentioned by the participants. According to these outcomes, poaching can be done by:

- ***Licensed professional harvesters*** who are allowed to harvest stalked barnacles for sale but do not comply with the rules, by exceeding the daily permitted quota (referred to as *overquota*), harvesting at prohibited places or times inside or outside of their own region or selling on the black market. Hereafter we will refer to these as *insider poachers* and the rest as *external poachers*.

- ***Recreational harvesters*** who are allowed to catch barnacles for self-consumption but do not comply with the rules through *overquota*, by selling their catch on the black market, by harvesting in forbidden areas or at forbidden dates, or without a license where a license is required (e.g. (Carvalho et al. 2017).

- ***Unlicensed harvesters:*** Anyone who extracts stalked barnacles without a permit in areas where licenses are required. Some of them form highly organized groups with carefully planned logistics and use rental cars, shared boats and SCUBA-diving equipment. The typically small fines are often factored into their budgets, leading to a significant accumulation of legal charges. Violent behavior and clashes with local harvesters are frequent, because these poachers operate on the best harvest sites, or in areas which have been banned in collaboration with the licensed harvesters to allow recovery of the stock. In Spain they sometimes bypass legal SCUBA-diving prohibitions and harvest at illegal sites or times (*i.e.* during high tides or at night) while relying on public disclosures of TURF regulations to locate the best harvest areas.

- ***Trans-national harvesters*** extract stalked barnacles illegally in both Brittany and Portugal to sell them in Spain where the market price is higher. They include unlicensed harvesters, professionals licensed to operate in other regions, and traders who buy stalked barnacles and use their legal invoices to hide a barnacle load larger than declared, usually involving a handful of local collaborators as harvesters.

Individual motives for the conscious breaking of fishery regulations may be manifold (Ballesteros and Rodríguez-Rodríguez 2018a; Ballesteros and Rodríguez-Rodríguez 2019). During the workshop stakeholders only discussed market and profit-based motivations (value, differences in markets, commercialization, distribution and the role of restaurants in the black market) and control (traceability and surveillance), leaving out drivers like recreational pleasure, use and habit, self-consumption, drug addiction or necessity (Ballesteros and Rodríguez-Rodríguez 2018a; Ballesteros and Rodríguez-Rodríguez 2019). This is a natural bias, since their interest is on physically deterring the illegal harvest of stalked barnacles and not on addressing the underlying causes, which are in any case problems of a much broader nature.

Professional harvesters at the workshop considered external poachers as the core of the problem. They expressed their dissatisfaction with the existing surveillance, whose main focus is on controlling professional harvesters and not external poachers. They requested more severe punishments for poachers that cause serious harm to the resource, act repeatedly, or form highly organized criminal groups. In contrast, the fisheries surveillance group identified the constant and very common practice of small-scale overharvesting by professionals as more harmful for the resource than the occasional large losses due to external poachers. This may reflect the widespread acceptance of small-scale overharvesting by the professionals (Ballesteros and Rodríguez-Rodríguez 2018a).

Last, underfunding causes inefficient surveillance in all regions, with limited personnel covering vast territories and having numerous responsibilities. In addition, coast guards in Spain depend on the Police and *Guardia Civil* (a military body) for the enforcement of sanctions (Ballesteros et al. 2017), adding yet another layer of bureaucratic complexity. Fines on poaching are negligible according to the harvesters in the workshop and frequently members of highly organized poaching groups plead insolvency to avoid payment of the sanction. This is a common legal gap known to be used by shellfish poachers in Galicia (Ballesteros et al. 2017).

The adaptive nature of poaching

According to the discussions, poaching seems to evolve in response to the level of management. In PNSACV and Morbihan, where the recreational harvest of stalked barnacles is still allowed and strongly integrated in the local culture and co-management and TURFS have not yet been implemented, poaching by non-professionals represents the main problem. In Morbihan anyone can harvest stalked barnacles recreationally without a license and in Portugal recreational licenses are unlimited and easily obtained, making poaching harder to control. Stakeholders from Portugal, though, hope for a positive development in the fight against poaching, given the recent legal initiatives that facilitate co-management initiatives in future. Co-management, however does not automatically assure less poaching (Pomeroy and Williams, Meryl J. 1994). Moreover, this transition will take time, and will likely face the resistance of different stakeholders through intense trial/error processes before arriving to locally tailored solutions (Ostrom 1990).

In the other end of management complexity, regions with co-management, TURFs, restricted access and significant social capital have to deal with technically sophisticated and organized poachers. For their success in the fight against poaching, these systems need to promote a strong sense of ownership and responsibility for the resource among harvesters, promoting their participation in the governance and enforcement of the resource (Ballesteros et al. 2021). For example, members of the *Cofradía* of Baiona (Galicia) first had to overcome severe cases of corruption and intense internal poaching before reaching solid social capital driven by strong leadership, which allowed for the introduction of useful internal agreements. Members now pay a monthly fee to hire additional surveillance that supplements the co-paid internal surveillance common to all

Galician TURFs. Failure to comply with fees or regulations (i.e. overquota) is treated with a graduated sanctions scheme. This strategy has successfully addressed both internal and external poaching.

The TURF managed by the *Cofradía* of Cangas (Galicia) has the highest level of organization represented in the workshop and is an excellent example for successful management of the resource. Here, harvesters have adopted the so-called "all for all" (from Spanish "todos para todos") strategy, where they work as a team with specific roles for harvesting, selecting, sorting, transporting and selling, mimicking the women's associations in Galicia dedicated to clam harvesting (Marguán, Pintos 2004). They focus their daily harvesting activity in one particular area of the TURF, and both roles and areas are rotated in subsequent harvesting bouts. Total harvest is negotiated in advance with buyers to avoid superfluous exploitation, and the benefits are shared equally among the harvesters. In such a highly cohesive system, internal poaching is very difficult. Given that most of the TURF is located within the *Illas Atlánticas* National Park, the level of surveillance is higher than in other TURFs and the harvesters themselves conduct surveillance in groups of 10 with one guard from the *cofradía*. The success of this system partly stems from strong leadership in the harvesters association, which has also been identified as a key aspect of successful Asturian *cofradias* (Rivera et al. 2019). All these circumstances lead to virtually no poaching activity, as acknowledged by members of the Cangas harvesters association in the workshop. Although not all fishers associations have the necessary social capital to achieve this high degree of cohesion, it may inspire fisheries where co-management is already in place, such as in Galicia and Asturias.

Trans-national poaching predates on the marked contrast in the level of governance and social structure of the fishery and in the difference in demand and market prices between France, Portugal and Spain. Spanish poachers are experienced in the highly surveyed and spatially organized TURFs and garner precise knowledge of black market channels in Spain. This gives them an advantage in less organized, surveyed, and therefore undefended fisheries.

Last, it is worth noting that poaching thrives in a consolidated black market, capable of absorbing large quantities of national and international illegal shellfish, and uses sophisticated distribution networks supported by the legal shellfish market (Ballesteros et al. 2017). However, prosecution is strongly biased towards poachers and not the supporting market and commercialization structures (Mosquera 2019).

5.4. Recommendations

Increasing social capital:

All stakeholders at the workshop showed great interest in the graduated sanctions scheme from Baiona, the "all for all" strategy from Cangas and their practice of holding preliminary contacts with the buyers. However, to implement this in other regions would require strong leadership, adaptation to the local context and support from the administration. Incremental steps towards this ideal may be highly beneficial at all levels of governance. For example, in Brittany, a minimum level of association among harvesters may allow them to bypass intermediaries, i.e. through online markets or by investment in a distribution infrastructure. Direct sale at Spanish markets would lead to higher profits, allowing for more professionalization of the fishery and laying the grounds for further improvement. Co-management is gaining momentum in Portugal, with RNB at the forefront. Nevertheless in PNSACV the problem of competition with recreational harvesters remains. Conflict mitigation might be achieved with the implementation of professional TURFs interspersed with zones for recreational harvesting (Carvalho et al. 2017), leading to partial exclusion of recreational harvesters. Stricter access rules, the introduction of limited licenses and enhanced control of the recreational harvesting would be important in the fight against poaching in both, Portugal and Morbihan.

Cooperative co-management requires that government and users work together as equal partners in decision-making (Sen and Raakjaer Nielsen 1996). Although decisions are adopted under some degree of consensus between the fisheries administration and the harvesters, the government can always impose its decision if they consider it necessary. To increase equity in decision making, co-management should first be incorporated into the legal framework (Pomeroy and Williams, Meryl J. 1994; Rivera et al. 2021). An example is Portugal or the Spanish Autonomous Region of Catalonia, where co-management has been recently included into the core of their fisheries legislations (Portuguese Decreto-Lei n.º 73/2020 (Portugal 2020), September 2020 and Catalonian Decreto 18/2018 (Cataluña 2018), June 2018).

Improve enforcement-compliance:

With the recent change in the Spanish law (Article 335 of the Penal Code of the Organic Law 1/2015 (España 2015), of 30 March), illegal harvest of stalked barnacles has changed from an administrative to a criminal offense. The law now involves higher fines and the possibility of penal charges, of up to two years in prison. Whether this change, long-claimed by the fishing sector, actually achieves an effective deterrence of poaching in the future is not certain, as long as the underlying systemic factors that lead to the illegal harvest stay unresolved (Mosquera 2019). For example, stricter sanctions may not be as effective when addressing poaching driven by poverty, drug addiction or unemployment, and may in fact lead to a vicious poaching circle (Ballesteros and Rodríguez-Rodríguez 2019). In this regard, anti-poaching measures should allow for a distinction among different types and motives for poaching (Ballesteros and Rodríguez-Rodríguez 2018b; Ballesteros and Rodríguez-Rodríguez 2018a).

Landings monitoring:

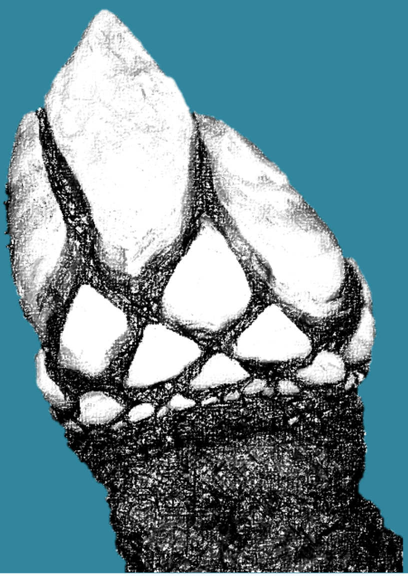
In Spain, all barnacles sold must be labelled with the total weight, cost and harvesters name, which is possible because catches can only be landed in authorized points. Spanish *cofradías* are usually in charge of these landing points and run the first market sales, allowing for the initial traceability of the product. In Portugal, harvesters can legally sell the barnacles in auction points, but also "outside the auctions", thus turning the monitoring of the landings more difficult (Jacinto et al. 2010). However, professional barnacle harvesters are striving to adopt an official label and to channel the first sale through the harvesters associations (Carvalho et al. 2017). Although the Common Market Organisation (CMO, Reg EU No 1379/2013; (European Union 2013a) adopted in the European Union incentivizes the use of certifications, this practice has not been implemented in all regions yet. A clear recommendation that came from the workshop is to have a comprehensive monitoring of all catches in the fishery and to centralize sales in auction points under the control of the fishers associations.

Increase in surveillance and traceability:

Surveillance needs to be intensified and novel strategies need to be adopted to cope with the reality of each region. Active participation of professional harvesters in the surveillance is required. Furthermore, surveillance drones are currently being tested in Asturias, with promising results. Randomized flight schedules and infrared, night-vision may effectively deter poaching. Moreover, there are emerging methodologies to detect fraud in markets and restaurants. Genetic methods, such as microsatellites and additional DNA fingerprints (Manel et al. 2002), which are currently being developed for stalked barnacles, may help trace the origin of confiscated barnacles in the future. Another applicable method is the analysis of trace elements in the calcareous shells of the barnacles that identifies their geographic origin in a scale of 10’s of kilometers with confidence levels of up to 98% (Albuquerque et al. 2016). In spite of their promising results, the tracing of large amounts of illegally harvested stalked barnacles in restaurants (Ballesteros et al. 2017), however, might not render cost nor time-beneficial with these methods.

Implementation of market-based solutions:

EU No 1379/2013 (European Union 2013a) regulation prompts for the adoption of quality and sustainability labels. Compliance with certification standards, linked to awareness-raising campaigns among the consumers may increase transparency and facilitate fraud detection. In a post-COVID context where online seafood markets are gaining momentum (Love et al. 2021), labels may play an important role. The adoption of co-management may facilitate the development of sustainability labels, thus increasing the profitability of the fishery (as in the MSC-certified Octopus fishery in Western Asturias; Fernández Sánchez et al. 2020).



CHAPTER 6

Discussion & Conclusions

The stalked barnacle fishery is a complex social-ecological system where the ecological and social realms are interconnected and interdependent. To withstand the future challenges, small scale fisheries will need to enhance their resilience, referring to their capacity to absorb environmental and economic perturbations, self-organise, learn and adapt (Berkes 2003). Consequently, it is imperative for management strategies to prioritise the preservation of the productive capacity and resilience of the interconnected social-ecological system (Berkes 2003). Therefore, to comprehensively understand the stalked barnacle fishery, we employed both ecological and social science methodologies. Firstly, in Chapter 2, we assessed the impact of the stalked barnacle harvest on the intertidal community structure and *P. pollicipes* recovery potential. In Chapter 3 we evaluated responses from Asturian harvesters to hypothetical bio-economic fluctuations. Chapter 4 focused on analysing harvesters' perceptions of the implemented strategies across various European regions. Finally, in Chapter 5, we identified the problem of poaching as a common challenge faced by stalked barnacle fisheries across different European regions. By integrating ecological and social science perspectives, our study provides a comprehensive understanding of the stalked barnacle fishery and lays the groundwork for effective and sustainable management approaches.

6.1. Ecosystem-based science to ensure resilience of stalked barnacle fisheries

Our stalked barnacle harvest experiments demonstrated that although the harvest is a highly selective collection method (Álvarez-Fernández et al. 2010) it generates changes in the intertidal community (Chapter 2). Harvest led to an increase in *Chthamalus* spp. and *Corallina* spp. and a decrease in *P. pollicipes* and *Mytilus* spp. in the intertidal community present on the Asturian coast within the Bay of Biscay. These findings provide insights into the expected dynamics for communities with similar species compositions. However, it is important to note that the composition of intertidal communities varies across the geographical distribution of *P. pollicipes* (Cruz et al. 2022), a fact that was also evident from the differences observed among the study locations. Depending on the initial composition of the community, the stalked barnacle harvest could lead to different outcomes. The co-existence and a direct interaction between stalked barnacles and mussel species, however, seems to be a general pattern shared among different intertidal communities. Mussels (*Mytilus californianus*) along the East Pacific coast have been observed to outcompete *Pollicipes polymerus* and establish dominance in the intertidal community (Wootton 1993; Wootton 2001), whereas in the intertidal community investigated in this study it remains uncertain whether one of the species, *Mytilus* spp. or *P. pollicipes*, would prevail. Our study demonstrated that reduced harvest intensity of *P. pollicipes*, combined with the presence of cages, results in higher coverages of both *P. pollicipes* and *Mytilus* spp. (Chapter 2). Although *P. pollicipes* larvae mostly recruit on conspecific adults (Cruz et al. 2010), recruits have also been observed on and between other marine organisms, including mussels (Cruz et al. 2022). Hence, the results of our experiment may indicate that the presence of adult individuals from both *P. pollicipes* and *Mytilus* spp. facilitates the recruitment of both species through favourable physical structures for larval settlement, leading to mutual enhancement of the species coverages (Chapter 2).

Our findings suggest that the stalked barnacle fisheries would benefit from an integrated ecosystem-based management that takes in account interdependencies between species, as well as the direct and indirect impacts of human activities (Meyer et al. 2020). The necessity for adopting such an approach is furthermore illustrated by the strong conflict observed in Galicia between stalked barnacle harvesters and mussel producers in aquaculture. This conflict arises due to the collection of mussel spat by aquaculture operations in areas where stalked barnacle harvesters operate and is known as the "mussel spat war" (from the Spanish "guerra de la mejilla") (Gaspar et al. 2021). Since mussel spat harvest involves complete clearing of the substrate to bare rock (Decreto 406/1996 37-4; Xunta de Galicia 1996), and stalked barnacles rarely recruit directly on rock substrate (Barnes and Reese 1960), this activity has a strong negative impact on the settlement of *P. pollicipes* recruits. Solutions to this conflict must take into account the direct and indirect ecological impacts of the mussel spat collection to adequately address the needs of both sectors and to ensure long-lasting sustainability of the ecosystem.

To develop ecologically sustainable management strategies for the stalked barnacle fishery it is crucial to assess the potential for *P. pollicipes* recovery from exploitation. The results of our human-exclusion experiment have demonstrated that *P. pollicipes* aggregations can recover within two years when undisturbed, but the recovery potential among harvested plots varied (Chapter 2). Therefore, factors such as availability of conspecifics for recruitment, individual stalked barnacle growth, and environmental factors that affect recruitment and growth, such as sea surface temperature, chlorophyll-a concentration, and upwelling (Aguión et al. 2022) are also likely to play a significant role in the potential for recovery. As mentioned previously, *P. pollicipes* larvae recruit heavily on conspecific adults (Cruz et al. 2010) and the estimated time between settlement and commercial size in *P. pollicipes* (21.50 mm rostro-carinal length) ranges between 1 (Cruz et al. 2010) and 5 years (Cruz 2000). It is important to note that our analysis involved quantifying coverage through image analysis rather than measuring individual sizes. The observed increase in coverage is most likely attributed primarily to the growth of individuals and larvae that were already attached to adults at the commencement of the experiment, rather than stemming from the settlement of new individuals on bare rock. According to Edwards (2020), recruitment of *P. polymerus*, a close relative of *P. pollicipes* from the East Pacific Ocean, mainly occurred along the edges of the cleared plots. Another study confirmed that the larvae predominantly attach on individuals located at the edges of *P. polymerus* clusters and on solitary adult individuals (Helms 2004). Location within the cluster was found to be more important in determining the abundance of recruits than cluster size and solitary adult barnacles served as nuclei for future clusters (Helms 2004). The larvae of *P. pollicipes* may exhibit similar habitat selection patterns (Aguión et al. 2022), in which case the harvesting method employed on adult barnacles would exert an important effect on the potential for the recovery of the stock. Growth rates of individuals also vary according to their location, with those located lower on the intertidal horizon generally presenting higher growth rates than the ones located higher up (Cruz et al. 2010). Moreover, juvenile barnacles grow slower when situated inside of clusters, as opposed to when located on the edges (Helms 2004). Therefore, the recovery of stalked barnacle stocks is not a straightforward process, and multiple factors need to be considered. Nonetheless, our findings suggest that extended harvest bans of at least 2 years can prove to be a useful measure for the recovery of exploited stalked barnacle stocks, contributing to the sustainability of the fishery. To enhance our understanding of stock recovery, future studies should focus on determining the minimum coverage percentage of *P. pollicipes* necessary to initiate and sustain the process. Additionally, these studies should integrate factors that influence individual growth and recruitment, while covering larger experimental areas preferably in no-take zones and a longer study duration to enable more accurate predictions of the recovery potential of stalked barnacle stocks.

6.2. Benefits for the stalked barnacle fishery from enhanced collaboration among stakeholders in the co-management

The ecosystem-based approach is useful but lacks the critical social aspect necessary for a truly sustainable fisheries management (Prellezo and Curtin 2015). In a co-management system, social capital is one of the most important strengths (Pretty 2003; Gutiérrez et al. 2011) and enables stakeholders to create innovative solutions to emerging problems (Fischer et al. 2004). The stalked barnacle fishery in Europe presents a great variety of co-management models, with varying degrees of involvement from resource users (Aguión et al. 2021). Highest participation of harvesters was observed in the adaptable co-management systems in Galicia and Asturias-West (Aguión et al. 2021). A crucial prerequisite for a successful development of the co-management is the openness of stakeholders towards change (Cinner et al. 2009). The majority of harvesters in the regions in Portugal and France were willing to make changes to current management strategies, reflecting their awareness of the need for improvement (Chapter 4). In fisheries with higher levels of governance and management success (Galicia and Asturias-West), this willingness is considerably smaller (Chapter 4). Particularly noteworthy is the high level of interest in management reforms among harvesters from regions where fewer opportunities to participate in the decision-making process existed at the time of the survey. This was observed in Portugal (RNB and PNSACV), Morbihan, and Asturias-East, in contrast to harvesters from Galicia and Asturias-West. In the case of RNB, this interest can be understood as their support for the ongoing management changes and the transition towards a legally supported co-management system that occurred during the survey period (personal com. Teresa Cruz), because these changes instilled hope for an improvement of the management including increased participation among harvesters. However, in the other regions, it is likely that the expressed interest in management reforms reflected harvesters' dissatisfaction with the current management practices. In contrast, a previous study identified that harvesters in Asturias-West held positive perceptions of the performance of their management system and the resource users additionally presented a strong conservation ethic (Rivera et al. 2017a). This disparity in perceptions and satisfaction levels is likely attributed to higher levels of harvester participation in well-established co-management systems, as exemplified by the fishery in Asturias-West. The approach of learning-by-doing, in particular, fosters social learning (Berkes 2009), and as harvesters gain awareness of the consequences of their actions and embrace a responsible ethic for resource conservation, authentic stewardship can develop (Gelcich et al. 2008; Cooke et al. 2013). For this to occur, however, it is essential to provide resource users with opportunities for active participation that motivate them to engage in the problem solving process (Fischer et al. 2004).

Despite the lower level of governance of the fishery in Asturias-East, however, our findings highlight a strong commitment for the conservation of the resource among harvesters in both Asturias-West and Asturias-East (Chapter 3). They displayed a willingness to prioritise the long-term sustainability of stalked barnacle stocks over short-term gains by choosing restrictive management tools when necessary, indicating a stewardship mentality (Chapter 3). Resource users in Galicia and Asturias-West furthermore have demonstrated a strong commitment to conservation, evidenced by their preference for particularly restrictive management strategies, such as the establishment of marine reserves and implementation of harvest bans to ensure the sustainability of the fishery (Chapter 4). By engaging in practical hands-on experiences and directly witnessing the positive outcomes of conservation efforts, resource users in Galicia and Asturias have understood the effects of their actions, helping to develop a sense of responsibility for preserving the resource (Frangoudes et al. 2008; Rivera et al. 2017a). This suggests that experiential learning through the active participation in decision-making processes can increase resource users' awareness of the importance of resource conservation and lead to the adoption of a stewardship mentality (Sutton and Tobin 2009; Silva et al. 2019; Mason et al. 2020). Good examples for this are the *cofradía* of Baiona (Galicia), where harvesters have adopted an internal graduated sanctions scheme to address internal poaching and the *cofradía* in Cangas (Galicia), where members created the sophisticated “all for all” group strategy (Chapter 5; Geiger et al. 2022). This strongly cohesive team approach combats poaching and overharvesting successfully through concrete division of labour among all members, direct negotiation of the total harvest with the buyers in advance, and equal sharing of the benefits among all harvesters (Chapter 5; Geiger et al. 2022).

To improve sustainability of stalked barnacle fisheries in Europe, it is crucial to increase active participation and collaboration among different stakeholder groups within existing co-management systems (Aguión et al. 2021). The inclusion of resource users in scientific research can be highly beneficial because it provides valuable insights into the underlying problems of the fishery and helps direct research efforts (Heyman and Granados-Dieseldorff 2012; Nenadovic et al. 2012). However, in some cases, a shift in attitudes is first needed from both scientists and resource users to maximise the contributions of users to fisheries management, as they are often sceptical of scientific findings that exclude their input or understanding (Gray 2005). If scientists actively reach out to engage with resource users, the quality of scientific advice can improve, and a better understanding of the science behind fisheries management decisions can be promoted (Trimble and Plummer 2019). A trusting relationship between resource users and scientists, in which scientists are perceived as partners for achieving the sustainability of the fishery rather than enemies preventing users from fishing as they please, is necessary for good collaboration (Ebel et al. 2018). In our study surveys harvesters were open and showed interest in participating, which could be attributed to their positive experiences with previous surveys. To build the necessary long-lasting collaboration between scientists and the fishing sector, it should be integrated into a permanent framework (Daw and Gray 2005; Gray 2005). A first initiative in this direction is the “REDEPESCA”, founded in 2018 in Asturias as a collaboration network between the regional government, fishermen, scientists, and members of environmental NGOs, in which the stalked barnacle fishery is included. The main objective of REDEPESCA is to achieve sustainable management of fishing resources in the Principality of Asturias by encouraging participation of all stakeholders, facilitating mutual understanding and transfer of knowledge, and identifying necessary research lines. Specific objectives include promoting participation of the fishing sector in research, providing scientific monitoring, promoting pilot studies and research projects, disseminating knowledge, and carrying out scientific outreach and training (Principado de Asturias 2018).

Our study demonstrated the utility of surveys for acquiring important information regarding harvesters' preferences in various scenarios. The results indicated that, as the market values of stalked barnacles decline, harvesters tend to opt for less sustainable management strategies (Chapter 3). This underscores the significance of market fluctuations in making appropriate choices for management strategies. As market dynamics become more important, the coordination between market performance and fisheries management measures are increasingly significant (Raakjaer Nielsen 1996). In the case of the stalked barnacle fishery, initiatives to stabilise the price, will be crucial for acquiring long-term sustainability (Chapter 3). This might be obtained by integrating buyers as recognised stakeholders with rights and responsibilities within the co-management system (Raakjaer Nielsen 1996). An example to put this into practice is the “all for all” strategy, practised in the Cangas *cofradía* (Galicia), where harvesters and buyers reach an agreement on the overall yield and price before the harvesters head out to collect the stalked barnacles. This approach ensures fair and equitable market prices for both parties. Moreover, it promotes the long-term sustainable use of the resource by preventing overexploitation and fostering a high level of perceived fairness through the equitable distribution of earnings among group members (Geiger et al. 2022; Chapter 5). The success of this approach, however, will depend on the establishment of long-lasting and trusting relationships between harvesters and buyers.

It is an opportune moment to introduce management innovations and incentivize the participation of more stakeholders in the existing co-management systems in Europe's stalked barnacle fisheries. This is because there is a growing recognition of the significant potential of SSFs to contribute to sustainable development goals, as evidenced by recent initiatives to ensure the sustainability of SSFs worldwide (FAO 2023). Additionally, the European Common Fisheries Policy (CFP, 2016; European Commission) has prioritised the promotion of efficient management in small-scale fisheries since 2016. Important progress for integrating co-management principles into fisheries legislation in Spain and Portugal has been made through the Catalonian Decreto 18/2018 (June 2018) and the Portuguese Decreto-Lei n.º 73/2020 (September 2020), demanding greater equity in decision-making among stakeholders. Furthermore, we observed that harvesters demonstrated a notable interest in the management practices of other regions, potentially influenced by a "grass is greener" effect (Chapter 4). This tendency indicates an exchange among harvesters across regions, as well as an openness and desire for exploring alternative management strategies. This highlights the potential for collaborative efforts and knowledge sharing among stakeholders to drive positive transformations in fisheries management.

6.3. Potential benefits of an interconnected European-wide multi-scale polycentric governance for the stalked barnacle fisheries

Our findings revealed that poaching is a serious and wide-spread problem on the international scale that threatens the sustainability of the stalked barnacle fisheries across Europe (Chapter 5). In cases where poaching has become an organised and international criminal activity, it will require international collaboration among police and justice systems to be effectively dealt with (Mitchell 2016; Tretyakov et al. 2021). Currently, the European stalked barnacle fisheries represent a consortium of independent and distinct complex socio-ecological systems, with different levels of governance implementation and highly variable management scales, ranging from large scales (>100 km, Morbihan, Asturias-East, PNSACV and Portugal, except for RNB) to very small spatial scales (10s km Asturias and Galicia; Aguión et al. 2021). In ecological terms, it has been estimated that larvae of *P. pollicipes* have a wide dispersal range of approximately 200 to 300 km, allowing for the interconnection of distant populations around the Iberian Peninsula through both direct recruitment and transgenerational steppingstone processes (Nolasco et al. 2022). Hence, the average scale of larval dispersal exceeds the sizes of Asturian and Galician TURFs. However, there is some level of cooperation among TURF units within each region through co-management with the regional governments (Nolasco et al. 2022). To incorporate the effects of the high exchange of larvae along the Iberian Peninsula, though, cooperative management on spatial scales of approximately 200 km is required (Nolasco et al. 2022). Therefore, to effectively address the complex issue of international poaching, prevent gaps between institutional boundaries and the life history traits of the species (Berkes 2003), and ensure more resilient and sustainable stalked barnacle fisheries throughout the Atlantic Arc a multi-scale, polycentric governance system* (Fig. 6.1; Ostrom 2009) might be necessary (Nolasco et al. 2022).

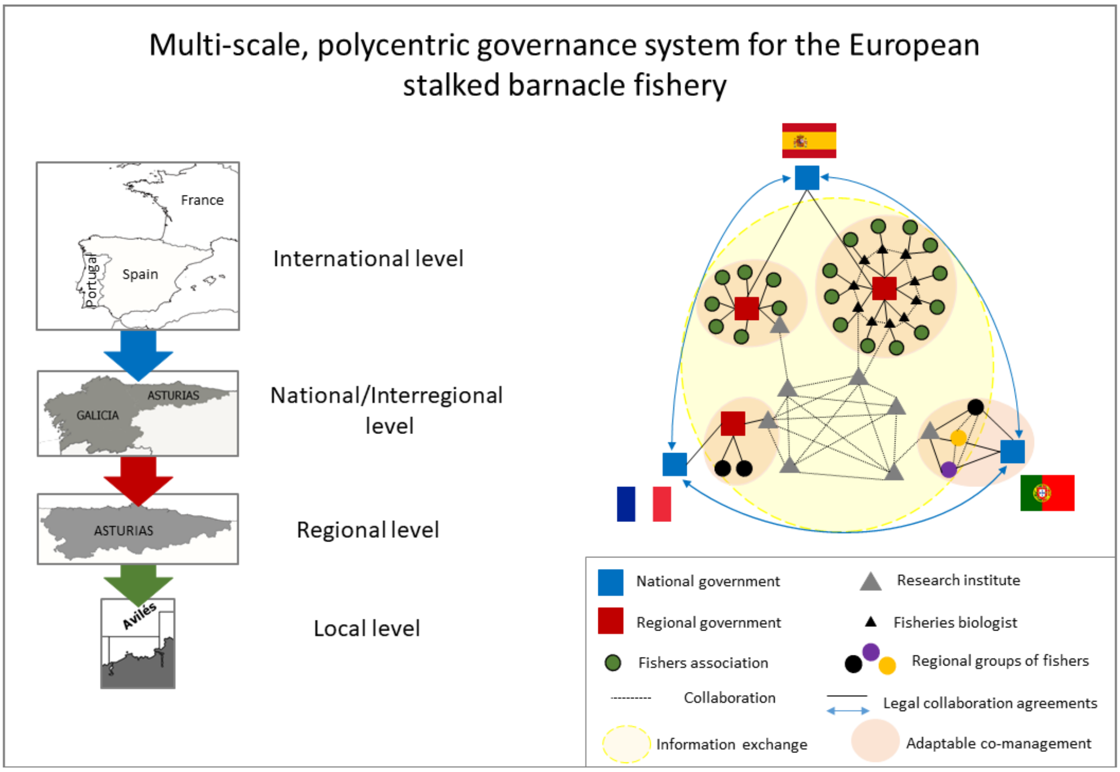


Figure 6.1. Scheme of a multi-scale, polycentric governance system adapted to the example of the stalked barnacle fishery in Europe, representing the multiple levels and diverse centres of authority for the decision-making.

* Multi-scale, polycentric governance systems refer to governance structures that involve multiple levels of decision-making and multiple centres of authority.

Multi-scale governance systems are designed to address complex issues that require collaboration and coordination among different levels of government, organisations, and communities. They operate at multiple levels, from local to regional, national, and even international levels. Each level within the system may have its own governing bodies, rules, and decision-making processes. Polycentric governance systems have multiple centres of authority that share power and distribute decision-making among various actors instead of being centralised in a single authority. In such systems, different actors and institutions may have varying levels of authority and decision-making power, depending on the specific issue or context at hand.
The integration of multiscale and polycentric governance concepts suggests that governance systems can be more effective and resilient when the decision-making is distributed across multiple levels and centres of authority. This distributed governance approach enables greater flexibility and adaptability in responding to complex challenges, while also fostering increased participation and engagement from a diverse range of stakeholders. By embracing multi-scale and polycentric governance, societies can build greater resilience and enhance their ability to address and overcome the multifaceted issues they face (Ostrom 2009).

How could a transition from the current, independent regional management systems towards an interconnected multiscale polycentric governance look like?

The great variability in management systems among European stalked barnacle fisheries, the cultural and socio-economic differences among regions, as well as the limited communication and exchange of experiences between stakeholders across regions (Fig. 6.2.A) pose potential difficulties for a common governance framework. The objective of a multi-scale, polycentric governance system, however, is not to create a one-size fit all system that should be equal for the stalked barnacle fisheries in all regions, but rather facilitate collaboration between the multiple levels of authorities and diverse groups of stakeholders among regions (Fig. 6.2.C; Ostrom 2009). The PERCEBES project has laid the foundation for multi-sectoral knowledge exchange on an international scale, by providing a platform for dialogue through scientific studies and stakeholder workshops (Fig. 6.2.B). It is essential to continue the exchange of valuable socio-ecological information among the fisheries, to develop shared future goals and enhance the sustainability of European stalked barnacle fisheries at a regional and international level. A common governance framework essentially could serve for the implementation of international and interregional legal agreements, facilitating a unified enforcement of effective measures. In this regard, the recommendations discussed in Chapter 5 to improve the stalked barnacle fisheries and decrease poaching, would benefit from this.

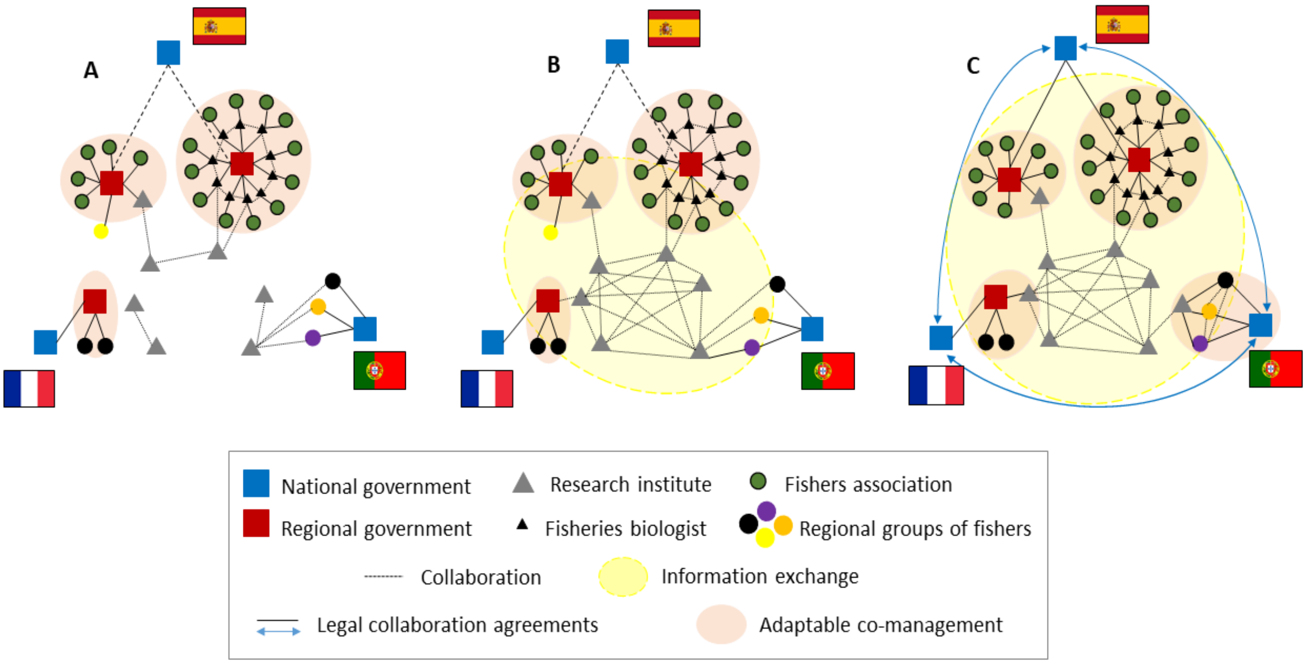


Figure 6.2. Schematic representation of a hypothetical transition towards an interconnected multiscale polycentric governance system for the stalked barnacle fisheries in Europe. A) Independent regional management systems, without official international interactions (Situation before the PERCEBES Project in 2017-2019). B) Independent regional management systems, with inter-regional and international collaboration among different stakeholder groups connected through the scientific institutions involved in the PERCEBES Project (Situation during the PERCEBES Project in 2017-2019). Information exchange between all stakeholder groups from all regions in PERCEBES Project workshop, held in Cudillero in February 2020. C) Interconnected polycentric governance system, with inter-regional and international collaboration with and without legal agreements at multiple levels among stakeholder groups, including regular information exchange at multiple levels (Hypothesised optimal future situation).

An interconnected multiscale polycentric governance system could also facilitate the incorporation of co-management into the legal framework of all European stalked barnacle fisheries, following Portugal's example (Portuguese Decreto-Lei n.º 73/2020, September 2020). To enhance enforcement and compliance of rules common penalization standards and international legal agreements could be implemented, penalising all forms of non-compliance and poaching activities. In Spain, the illegal harvest of stalked barnacles is considered a criminal offence, and fines and imprisonment of up to two years can be imposed as penal charges (Article 335 of the Penal Code of the Organic Law 1/2015, of 30 March). If consistent penalization standards were applied across the united governance system, similar to the Spanish example, it would likely result in reduced poaching at all levels, from local to international. An interconnected multi-scale, polycentric governance scheme could furthermore help to adopt cross-regional surveillance efforts. International cooperation among governmental surveillance and police bodies could be facilitated through this governance system. Additionally, poaching could be reduced through active participation of professional harvesters in the surveillance, the introduction of new technologies to detect poachers using drones (Jiménez López and Mulero-Pázmány 2019; Kandrot et al. 2022), or through fraud detection in markets and restaurants using genetic and trace-element methods (Manel et al. 2002; Albuquerque et al. 2016; Duarte et al. 2022). Successful enforcement of these strategies in one region, could then serve as incentives for their adoption in other regions (Chapter 5; Geiger et al. 2022). Adapting traceability and landing monitoring in Portugal and Brittany to meet Spanish standards could also lead to improvements, because in Spain catches are only allowed to be landed at authorised points and are then sold at auction points under the control of fishers' associations (Chapter 5; Geiger et al. 2022). Apart from the minimum requirements for catch labelling set by the European Parliament regulations (CMO, Reg EU No 1379/2013 European Union 2013), Spanish labels used for barnacles sold on markets include additional useful information, such as the total weight, price, and the harvester's name, allowing for more transparency (Chapter 5; Geiger et al. 2022). This demonstrates that regions with advanced implementation and high standards could serve as examples for implementing or improving standards in other regions.

To promote ecological sustainability on a metapopulation scale, networks of no-take zones for stalked barnacles (Rivera et al. 2013), serving as refuges and larvae sources, could be distributed along the entire Atlantic Arc. Even if these no-take zones were temporary and integrated into a rotation scheme, they could enhance the sustainability of the fisheries, by fostering the recovery of the stocks on a regular basis, as shown by the experience in some Galician and Asturian TURFs (Rivera et al. 2014; Ruiz-Díaz et al. 2020). Sharing information regarding stock levels, yields, and control measures associated with the sustainable exploitation of stalked barnacles, especially among neighbouring management units, including transregional units, would aid in monitoring and identifying trends in metapopulation dynamics. For a correct evaluation of the state of a fishery, high quality long-term data are critical (Chen 2003; Carrick and Ostendorf 2007) and a standardised methodology for databases would increase comparability and facilitate the analysis of metapopulation studies, which could contribute to the development and continuous improvement of transregional management strategies. In this regard, the implementation of co-management with TURFs in the early 1990s generated valuable, detailed long-term harvest and first-sales market databases for the stalked barnacle fisheries in Galicia and Asturias (Macho et al. 2013; Rivera et al. 2014). These databases have been instrumental for exploring the economic and ecological functioning of the fisheries (see Rivera et al. 2014) and assessing their vulnerability facing climate change (Ruiz-Díaz et al. 2020). The lessons learned in these two regions for establishing high-quality, long-term databases (Macho et al. 2013) could be applied to other regions to aid in the implementation of effective tools and systems for future database creation. Another factor that promotes social capital in the case of the stalked barnacle fisheries in Europe is the existence of scientific institutions with expertise. Particularly the Marine and Environmental Sciences Centre (MARE) associated with the University of Évora has dedicated decades to the investigation of *P. pollicipes* and its fishery in Portugal (see e.g. Cruz 1993; Cruz and Hawkins 1998; Cruz and Araújo 1999; Cruz 2000; Cruz et al. 2010; Jacinto et al. 2010; Sousa et al. 2013; Cruz et al. 2015; Cruz et al. 2022; etc.). Similarly, ongoing efforts have been made in Spain to study *P. pollicipes* biology, ecology, and fishery management (see e.g. Pavón Iturmendi 2003; Macho et al. 2013; Rivera et al. 2014; Rivera et al. 2016; Rivera et al. 2017a; Rivera et al. 2017b; Pita et al. 2019; Rivera et al. 2019; Ruiz-Díaz et al. 2020; etc.). In contrast, studies on *P. pollicipes* in France are notably less in number (De Kergariou 1971; Girard 1982; Joncourt 2005). The PERCEBES project was the first large scale collaborative study initiative focussing on the ecology and management of *P. pollicipes* in Europe. The project included universities and research institutes from Spain (Asturias and Galicia), Portugal and France (Brittany) and was coordinated by the University of Oviedo (Asturias). Additionally, it has been a good opportunity for strengthening cooperation among stakeholders in various regions through a multiregional research approach and the PERCEBES workshop.

Implementing a multiscale, polycentric governance system in the European stalked barnacle fisheries may foster collaboration among diverse stakeholder groups and authorities at various levels across different regions. This approach could play a pivotal role in effectively addressing the complex international challenges that arise within the context of this fishery.

6.4. Conclusions

1. The stalked barnacle harvest leads to community changes of space-occupying species by creating openings for other species to settle, thus initiating a succession process that impacts ecological diversity. The regular disturbance caused by this harvest leads to a net increase of the diversity of space occupying species.
2. Although stalked barnacle aggregations have the capacity to recover within two years when undisturbed, the recovery of exploited stocks will ultimately require a combination of time and availability of conspecific adults. Total harvest bans of at least two years can benefit the recovery of stalked barnacle stocks and promote ecological sustainability of the fishery.
3. Harvesters of the Asturian stalked barnacle fishery accept restrictive measures (i.e. harvest bans) to protect their resource under reduced abundance scenarios. Market fluctuations, though, can prompt unsustainable responses indicating that economic profitability is critical for the future of the fishery. Adaptable management measures, responding to both economic and ecological fluctuations, are necessary to ensure the long-term sustainability of this valuable resource.
4. Stalked barnacle harvesters from fisheries with lower governance levels and overall sustainability are more willing to make changes in the implemented management, than harvesters from highly participatory and more successfully managed fisheries.
5. There is no clear trend regarding a single "optimal" strategy across regions, which highlights the importance of considering multiple management strategies for sustainable fisheries management. To achieve sustainability in stalked barnacle fisheries throughout Europe, it is crucial to adapt management strategies to the unique needs and characteristics of each region, while simultaneously fostering transregional cooperation and knowledge exchange.
6. Knowledge exchange and mutual learning can be promoted through joint cross-regional workshops and research, as demonstrated by the project PERCEBES, serving to stimulate trans-regional collaboration among stakeholders and inspire endeavours to enhance fisheries management.
7. Poaching presents a common and serious problem affecting the stalked barnacle fisheries across Europe. How fisheries respond to this challenge depends on the types of poachers involved, and the level of governance a fishery has developed.
8. Trans-national poaching is facilitated by the contrast in the level of governance and social structure of the fishery, as well as due to differences in demand and market prices between countries. Poaching is also enabled by a consolidated black market and sophisticated distribution networks.
9. The stalked barnacle fisheries in Europe could benefit from a multiscale, polycentric governance system that facilitates collaboration between the multiple levels of authorities and diverse stakeholder groups among regions to address complex international challenges.

General summary and conclusions (In Spanish)

Resumen general

Desafíos para las pesquerías artesanales de recursos bentónicos sedentarios marinos

Hoy en día las pesquerías enfrentan múltiples y complejos desafíos debido a los impactos del cambio climático, las fluctuaciones socioeconómicas y las incertidumbres socio-políticas, entre otros (ver ejemplos en: Barange et al. 2018; Ricke et al. 2018; Bennett et al. 2020; Knight et al. 2020). Adicionalmente, los humanos actúan como depredadores selectivos clave que pueden alterar significativamente los ecosistemas con sus actividades de explotación (Castilla 1999) al punto de que la sobreexplotación amenaza actualmente la supervivencia de muchas pesquerías (Pauly 2009; Pomeroy 2012; Muallil et al. 2014). La resiliencia y adaptabilidad de las especies marinas en respuesta al cambio climático y a la explotación son altamente variables y, en muchos casos, desconocidas (Jones and Cheung 2018). Sin embargo, los organismos bentónicos sésiles marinos son especialmente vulnerables a los efectos del cambio climático y a una alta presión de explotación debido a su baja movilidad espacial (Hiddink et al. 2015) y su dependencia de las condiciones hidrodinámicas y los factores climáticos que regulan el suministro de larvas y su asentamiento (Bertness et al. 1996; Crimaldi et al. 2002; Hiscock et al. 2004).

La evaluación de los impactos de la explotación en la especie objetivo y en las interacciones entre especies es fundamental para desarrollar estrategias de gestión basadas en los ecosistemas, con el objetivo de mejorar la sostenibilidad ecológica de las pesquerías (Crowder et al. 2008). Sin embargo, como las pesquerías son sistemas socioecológicos complejos, los factores ecológicos y sociales son interdependientes entre sí (Ostrom 2009). Por lo tanto, se requiere un enfoque de gestión integral que considere la relación entre la condición ecológica de los recursos y la vulnerabilidad social (Ruiz-Díaz et al. 2020). Las pesquerías artesanales de recursos bentónicos sedentarios marinos son particularmente vulnerables debido a las limitaciones ecológicas del recurso para escapar de los impactos del cambio climático y de la alta presión de explotación. Así mismo, la fuerte dependencia de los pescadores en los recursos locales y la necesidad de mercados estables para su sustento exacerba el riesgo de estas pesquerías (Ruiz-Díaz et al. 2020). La resiliencia de las pesquerías, incluyendo sus dimensiones ecológicas, socioeconómicas y de gobernanza, jugará un papel crucial en determinar si pueden resistir los desafíos futuros (Mason et al. 2022).

Las pesquerías de percebe en Europa

Pollicipes pollicipes (Gmelin, 1791 [en Gmelin, 1788-1792]) es un cirrípedo pedunculado sésil, comúnmente conocido como percebes, que crece en costas rocosas muy expuestas desde la zona submareal poco profunda hasta la zona intermareal media (Cruz et al. 2022). Su distribución geográfica se extiende desde la costa suroeste del Reino Unido hasta Senegal en África Occidental (Cruz et al. 2022). Los percebes pasan por 6 estados de nauplio y una etapa de cirrípedo antes de asentar y fijarse preferentemente encima de adultos de la misma especie (Kugele and Yule 1996; Cruz et al. 2022). Las poblaciones están interconectadas a través de un amplio intercambio larval impulsado principalmente por fenómenos oceanográficos como corrientes, sistemas de afloramiento y remolinos (Nolasco et al. 2022). Además, se espera que la conectividad transgeneracional a través de poblaciones situadas a distancias medianas conecte poblaciones a distancias mayores (Nolasco et al. 2022).

En Europa, los percebes han sido explotados desde el Mesolítico (Álvarez-Fernández et al. 2010), y la pesquería moderna tiene un alto valor cultural y económico, especialmente en la Península Ibérica (Aguión et al. 2021; Cruz et al. 2022). En España, los percebes están considerados un producto de lujo y los precios en las subastas del mercado pueden alcanzar los 200-266€/kg (Rivera et al. 2014; Ruiz-Díaz et al. 2020). A pesar de la importancia cultural y socioeconómica de la pesquería, aún no se conocen los impactos ecológicos del marisqueo de percebe en la comunidad intermareal. El alto valor en el mercado de esta especie también plantea desafíos, ya que fomenta la sobrepesca y la pesca ilegal, poniendo en peligro la sostenibilidad socioecológica de la pesquería (Geiger et al. 2022).

Considerando la relación interconectada e interdependiente entre los aspectos ecológicos y sociales de la pesquería de percebes, hemos empleado metodologías de ambos ámbitos para llenar brechas de conocimiento. El objetivo general de esta tesis es alcanzar una comprensión integral e identificar posibles mejoras en la gestión para contribuir a superar los desafíos que enfrentan las pesquerías de percebe en Asturias y otras regiones europeas.

La gestión de las pesquerías de percebe varía significativamente entre regiones europeas, con diferencias en regulaciones, monitoreo y prácticas de cumplimiento (Aguión et al. 2021). En el ámbito de esta tesis, incluimos las pesquerías del percebe de las siguientes regiones europeas: España (Asturias y Galicia), Portugal (Reserva de Berlengas - RNB y Parque Natural do Sudoeste Alentejano e Costa Vicentina - PNSACV) y Francia (Morbihan).

En Galicia y a lo largo de la costa oeste de Asturias, las pesquerías de percebe tienen el mayor nivel de implementación entre todas las regiones y se gestionan a una escala espacial detallada a través de una estructura de acceso exclusivo proporcionada por los derechos de uso territorial en las pesquerías (DUTP; Aguión et al. 2021). La cogestión es consultiva-cooperativa, con responsabilidades y poder de toma de decisiones compartidos entre las cofradías y el organismo gubernamental local (Molares and Freire 2003; Rivera et al. 2014). Los perceberos proponen planes de gestión anuales con indicaciones temporales y espaciales detalladas sobre el esfuerzo de pesca, que deben ser aprobados por la administración pesquera regional y puestos a disposición del público para su consulta (Geiger et al. 2022). La vigilancia se lleva a cabo por guardias regionales y guardapescas exclusivos de los DUTPs, así como en algunos casos por los propios pescadores y guardias del Parque Nacional Marítimo-Terrestre de las Islas Atlánticas de Galicia.

A lo largo de la costa este de Asturias, la pesquería se gestiona como una unidad única, implementando sólo estrategias de gestión generales hasta febrero de 2023, cuando se implementaron dos DUTPs que cubren toda el área. Antes de la implementación de los DUTPs, la co-gestión estaba en el nivel instructivo, lo que representa el nivel más bajo de co-gestión entre las regiones estudiadas (Aguión et al. 2021).

La gestión de la pesquería de percebe en Portugal varía según la ubicación. En la Reserva Natural de Berlengas, un pequeño archipiélago cerca de la costa portuguesa, la pesquería opera de manera similar a un DUTP debido a su geografía y al número limitado de licencias para perceberos profesionales. En 2021, la pesquería de percebe de RNB pasó a la co-gestión por ley, lo que representa el primer caso de co-gestión acordada legalmente en Portugal. Esto ha llevado a un mayor nivel de co-gestión, una mayor participación de los perceberos y una mejora en el monitoreo del recurso, con la expectativa de que el nivel de co-gestión continúe aumentando en el futuro (Cruz et al. 2022). En PNSACV se permite el marisqueo recreativo de percebe y la vigilancia se realiza a través de patrullas reducidas a lo largo de extensas áreas de costa (Aguión et al. 2021).

La co-gestión en Morbihan se acuerda de manera informal, con representantes no oficiales de los perceberos proponiendo diversas regulaciones que luego deben ser aprobadas por el comité pesquero regional y validadas por las autoridades francesas. Se permite la pesca recreativa y, al igual que en PNSACV, la vigilancia es escasa.

Fundamentos para una gestión pesquera de percebe basada en los ecosistemas

Con el fin de generar conocimiento científico fundamental que facilite una transición hacia una gestión pesquera basada en los ecosistemas, llevamos a cabo experimentos ecológicos para evaluar el impacto del marisqueo de percebe en la estructura de la comunidad intermareal y el potencial de recuperación de *P. pollicipes*. A pesar de la importancia socio-económica de este recurso en la Península Ibérica, éste es el primer estudio que evalúa la respuesta de la comunidad intermareal al marisqueo de percebe. Se realizó un experimento de dos años que se llevó a cabo en tres sitios a lo largo de la costa oeste de Asturias desde julio del 2017 hasta julio del 2019.

La explotación regular de *P. pollicipes* condujo naturalmente a una disminución en la cobertura de percebes y un aumento de áreas de roca. Además, observamos cambios en la composición de especies de la comunidad intermareal, con una mayor cobertura de *Chthamalus* spp. y *Corallina* spp. al final de los dos años del experimento. La extracción de *P. pollicipes* disminuyó la diversidad ecológica al principio, hasta que la roca fue nuevamente cubierta por especies en el transcurso de la sucesión, lo que condujo a un aumento neto en la diversidad. Por lo tanto, la extracción creó espacio para que otras especies se establecieran durante el proceso de sucesión. Al contrario, bajo condiciones no explotadas, la comunidad estaba dominada por *P. pollicipes* y *Mytilus* spp. después de un período de dos años. La recuperación de las agregaciones de percebes explotadas fue lenta, pero en condiciones de no extracción bajo jaula, la cobertura inicial de la especie aumentó hasta un 80%. Estos cambios dinámicos en la comunidad intermareal ocurren comúnmente durante el proceso de sucesión ecológica después de una perturbación como es la explotación por humanos (Duran and Castilla 1989; Dye 1992). Según se conoce en otros estudios, un nivel intermedio de perturbación puede conducir a una mayor diversidad ecológica dentro de la comunidad rocosa intermareal (Levin and Paine 1974; Paine and Levin 1981). En toda la Península Ibérica, los seres humanos son indudablemente los depredadores más importantes de *P. pollicipes* y se pueden considerar como depredadores selectivos clave (Castilla 1999) que promueven la diversidad ecológica a través de la perturbación regular resultante del marisqueo de percebe. Sin embargo, no está claro si esta aparente mayor diversidad ecológica realmente es un indicio de una comunidad más diversa, ya que nos centramos únicamente en los ocupantes primarios del espacio y no incluimos especies altamente móviles y crípticas. Queremos señalar que existe una brecha actual en el conocimiento con respecto a la diversidad de especies crípticas asociadas con la estructura tridimensional creada por los arrecifes de *Pollicipes* y *Mytilus*.

Basándonos en nuestros resultados, sugerimos que las vedas prolongadas de una duración mínima de dos años pueden ser una medida de recuperación útil para las poblaciones de percebes explotadas y pueden ayudar a promover la sostenibilidad de esta pesquería. Sin embargo, se necesitan estudios adicionales para determinar el porcentaje mínimo de cobertura de *P. pollicipes* necesario para asegurar una recuperación completa de la población dentro de un marco de dos años. Es de esperar que por debajo de un umbral mínimo de cobertura de *P. pollicipes*, se requeriría un período mucho más largo para la recuperación de la población. Además, es necesario investigar otros factores que podrían influir en el potencial o la rapidez de recuperación de los percebes, como por ejemplo el efecto de la distribución espacial de las agrupaciones de *P. pollicipes* y la temporada en la que se realiza la explotación. También sería beneficial ampliar las áreas experimentales, preferiblemente en zonas vedadas o reservas marinas donde no exista ningún tipo de explotación de percebes, y prolongar la duración de los estudios para permitir predicciones más precisas del potencial de recuperación de las poblaciones de percebe. Asimismo, se necesitan estudios a largo plazo para comprender el proceso completo de sucesión, descubrir la composición final de especies estables de esta comunidad intermareal y determinar el marco temporal de este proceso.

Integrar la percepción de los perceberos en la gestión pesquera:

Respuestas de perceberos asturianos ante cambios biológicos y económicos del percebe

La resiliencia de una pesquería está condicionada por las interacciones dinámicas de variables que cambian gradualmente, por ejemplo, el clima o las tradiciones culturales, y variables que cambian rápidamente, por ejemplo las variaciones climáticas, o el mercado local (Chapin et al. 2009). Dado que los impactos externos son inevitables en la pesca, los gestores deben centrarse en aspectos que puedan controlar, específicamente en la dimensión humana. Como ya señalaron Miller y Van Maanen (1979), gestionar una pesquería implica gestionar principalmente el comportamiento de los pescadores. En consecuencia, la dimensión humana es un componente clave para una gestión pesquera efectiva (Jentoft and McCay 1995; Kaplan and McCay 2004) y debe abordarse para ayudar a diseñar políticas que no sólo protejan el recurso, sino que también generen menos conflictos, inspiren un mayor cumplimiento y minimicen los costos asociados con la protección del recurso (Marshall 2007; Perez de Oliveira 2013). El conocimiento sobre las reacciones de los pescadores frente a las fluctuaciones ecológicas y económicas del recurso puede ayudar a diseñar estrategias de gestión sostenible (Béné and Tewfik 2001; Daw et al. 2012) que conduzcan a una pesquería resiliente (Yletyinen et al. 2018). En este estudio, utilizamos el análisis de elección discreta para determinar las preferencias de los perceberos por las estrategias de gestión en diferentes escenarios hipotéticos de abundancia biológica de percebe y de su precio en el mercado.

Los perceberos respondieron de manera similar en ambas regiones de gestión (Asturias-Oeste y Asturias-Este), siendo la duración del escenario (una temporada o dos temporadas) un factor que afectó sus respuestas. La mayoría de los perceberos mostraron preocupación por la sostenibilidad del recurso en escenarios de reducción de la abundancia, lo que indica una disposición para sacrificar temporalmente sus beneficios económicos por la sostenibilidad de la pesquería a largo plazo. Esto es especialmente importante cuando la sobreexplotación de un recurso requiere medidas de gestión a largo plazo para su recuperación (Jamieson 1993). Las herramientas de gestión elegidas para proteger el recurso en escenarios de reducción de abundancia de percebe fueron herramientas restrictivas comúnmente utilizadas en la gestión implementada en Asturias, como la veda, lo que demuestra la efectividad de estas estrategias. Además, solicitaron un aumento en la ejecución y vigilancia en condiciones de baja abundancia del recurso, lo que confirma su preocupación por el recurso. En cambio, escenarios de fluctuaciones en el valor de mercado generaron una mayor variabilidad en las respuestas. Por ejemplo, los perceberos en Asturias-Este sugirieron reducir la cuota individual y el tiempo de marisqueo para aumentar el precio de mercado mediante una oferta limitada. Las tendencias económicas negativas, especialmente si persistían en el tiempo, aumentaron la probabilidad de que los perceberos abandonaran la pesquería. Por lo tanto, promover valores estables en el mercado es crucial para garantizar la sostenibilidad de la pesquería a largo plazo. En un escenario mixto con menor abundancia y mayores valores de percebe, los perceberos se dividieron entre aquellos que optaron por proteger el recurso reduciendo el esfuerzo y aquellos que aceptaron el riesgo de sobreexplotación para obtener ganancias. Esto destaca la necesidad de un monitoreo regular del mercado y medidas de gestión adaptables, para que la pesquería de percebe en Asturias pueda continuar prosperando a la vez que se garantiza la sostenibilidad a largo plazo de este valioso recurso.

Estrategias de gestión pesquera preferidas por los perceberos europeos

Involucrar a los usuarios de los recursos en la toma de decisiones ayuda a fomentar la confianza, aumentar su sentido de responsabilidad y rendición de cuentas, promover la legitimidad y aceptación de las prácticas y decisiones de gestión, y contribuir a una aplicación más efectiva de las normas y regulaciones al incrementar la probabilidad de cumplimiento (Pita et al. 2010; Perez de Oliveira 2013). Específicamente, el cumplimiento de los usuarios desempeña un papel fundamental en la efectividad de la gestión implementada (Hatcher and Pascoe 2006; Oyanedel et al. 2020). Comprender la percepción de los usuarios de los recursos sobre la legitimidad de las estrategias de gestión y su disposición para adoptar nuevas estrategias a nivel local ayuda a predecir los niveles de cumplimiento (Groves 2011; Oyanedel et al. 2020). Por lo tanto, incluir la experiencia, el conocimiento y las percepciones de los usuarios sobre las estrategias de gestión puede ser de gran valor para evaluar su efectividad (Bennett 2016).

Garantizar la sostenibilidad de las pesquerías europeas de percebe requiere estrategias de gestión efectivas. Realizamos campañas de encuestas en seis regiones europeas, en España, Portugal y Francia, para investigar las percepciones de los perceberos sobre su conocimiento y la eficacia de las estrategias de gestión pesquera implementadas y su interés en cambiar las estrategias actuales. Utilizamos análisis de elección discreta para determinar las estrategias consideradas más eficaces. Además, recopilamos información de los perceberos sobre su estrategia de gestión preferida para lograr la sostenibilidad en la pesquería. Por último, utilizamos la selección de modelos multinomiales para identificar los patrones que impulsan las percepciones que tienen los perceberos sobre la gestión.

En general, los perceberos indicaron una buena comprensión de las estrategias implementadas, sin embargo, se identificaron algunas brechas que podrían haber surgido debido a desconocimiento de los términos oficiales de las estrategias. La mayoría de los perceberos en las regiones de Portugal y Francia, donde los sistemas de co-gestión presentan un menor poder de toma de decisiones y participación de los perceberos, estaban dispuestos a realizar cambios en las estrategias actuales de gestión pesquera, mientras que en las pesquerías con mayores niveles de gobernanza y éxito en la gestión (Galicia y Asturias-Oeste), la disposición de cambiar las estrategias fue considerablemente menor. El reconocimiento de deficiencias en la gestión actual por parte de los perceberos en Portugal y Francia, es un paso crucial hacia la mejora de la gestión pesquera (Cinner et al. 2009) en estas regiones. Los perceberos de Galicia y Asturias-

Oeste calificaron las restricciones espaciales, específicamente el uso de vedas, como el enfoque de gestión más efectivo para garantizar una pesquería sostenible, lo cual se corresponde con las estrategias de gestión espacial altamente detalladas implementadas en estas regiones. En Asturias-Este y las regiones de Portugal, sin embargo, los perceberos dieron prioridad a estrategias de gestión no implementadas localmente, lo que sugiere un efecto de "la hierba es más verde al otro lado", donde los perceberos perciben las estrategias de gestión en otras áreas como más efectivas o deseables que las propias, incluso con un conocimiento o experiencia limitada de esas estrategias. Esta mentalidad puede llevar a expectativas poco realistas sobre la aplicabilidad universal de estrategias de gestión específicas, y es importante tener en cuenta que el éxito de una estrategia en una región no garantiza su efectividad en otras, ya que no existe una solución única para una gestión sostenible (Bianchi et al. 2009; Jentoft and Bavinck 2014). Sin embargo, el interés de los perceberos en las estrategias de gestión implementadas en otras regiones también resalta el potencial de intercambio de conocimientos y aprendizaje entre regiones, donde los perceberos de diferentes áreas se inspiran en estrategias exitosas implementadas en otros lugares (Geiger et al. 2022).

No se observó una tendencia clara en cuanto a una única estrategia de gestión "óptima" preferida por los perceberos en todas las regiones. Este hallazgo no fue sorprendente debido a las considerables diferencias en las prácticas de gestión pesquera y en las características culturales y socioeconómicas entre las distintas regiones. De hecho, nuestro análisis de selección de modelos multinomiales confirmó que la región fue la variable más significativa para explicar los patrones en la selección de la estrategia de gestión más importante para lograr la sostenibilidad en la pesquería. Nuestros resultados, enfatizan la necesidad de considerar múltiples estrategias de gestión para lograr una gestión pesquera sostenible y la importancia de adaptar las estrategias de gestión a las prácticas, necesidades y características específicas de cada región.

Enfrentando al furtivismo en las pesquerías europeas de percebe

En enero del 2020, el proyecto PERCEBES organizó un taller internacional con la participación de múltiples partes interesadas de Portugal, España y Francia para facilitar el intercambio de conocimientos y experiencias sobre buenas prácticas de gestión entre las regiones. Durante las discusiones, el furtivismo emergió como el principal problema común en todas las regiones, con efectos sistemáticos en todos los aspectos de la pesquería. A pesar de su relevancia en todas las regiones, el furtivismo en la pesquería de percebe sólo ha sido abordado en Galicia (Ballesteros et al. 2017; Ballesteros and Rodríguez-Rodríguez 2018a; Ballesteros and Rodríguez-Rodríguez 2018b; Ballesteros and Rodríguez-Rodríguez 2019; Ballesteros et al. 2021), donde se ha encontrado que este fenómeno complejo causa pérdidas económicas significativas (Ruiz-Díaz et al. 2020). En Asturias, Portugal y Francia, el furtivismo del percebe sólo ha sido mencionado indirectamente (Jacinto et al. 2010; Rivera et al. 2014). El taller nos permitió caracterizar los factores impulsores del furtivismo e identificar medidas de gestión para abordar este problema, con relevancia potencial para otras pesquerías artesanales.

Los furtivos en la pesca de percebe pueden ser tanto perceberos profesionales como recreativos, así como aquellos que operan sin licencia, y pueden operar a diferentes escalas, desde local hasta transnacional. Están motivados por los altos precios de mercado y se benefician de la existencia de un mercado negro bien establecido. Además, la falta de trazabilidad y una vigilancia ineficiente fomentan la práctica del marisqueo ilegal. Cómo las pesquerías responden a este desafío depende de los tipos de furtivos involucrados y del nivel de gobernanza que haya desarrollado una pesquería.

La falta de restricciones del marisqueo recreativo de percebes en Francia y Portugal conlleva un alto riesgo de ocurrencias de furtivismo en dichos países. Mientras que en España el marisqueo comercial de percebes reemplazó hace mucho tiempo el marisqueo recreativo, en Francia y Portugal, el marisqueo recreativo de percebes todavía está fuertemente integrado en la cultura local. En Francia, cualquier persona puede recolectar percebes recreativamente sin licencia, mientras que en Portugal las licencias recreativas son ilimitadas y se obtienen fácilmente, lo que dificulta el control del furtivismo. La exclusión parcial de los perceberos recreativos, o normas de acceso más estrictas y un mayor control del marisqueo recreativo, serían pasos importantes en la lucha contra el furtivismo tanto en Portugal como en Francia.

Según los resultados del taller, el furtivismo transnacional es una consecuencia de las grandes diferencias en la gobernanza y estructura social de la pesquería, así como en la demanda y los precios de mercado entre Francia, Portugal y España. Los furtivos españoles tienen experiencia en los DTUPs altamente vigilados y espacialmente organizados, y tienen un conocimiento preciso de los canales del mercado negro en España. Esto les otorga una ventaja en pesquerías menos organizadas, vigiladas y, por lo tanto, menos defendidas. Los participantes del taller coincidieron en que el furtivismo sólo puede ser combatido mediante un alto nivel de co-gestión, específicamente a través de derechos de acceso muy restrictivos y un mayor capital social, aunque los furtivos superan el obstáculo de la co-gestión altamente desarrollada al aumentar su nivel de tecnificación y organización. Por lo tanto, es necesario intensificar la vigilancia y adoptar estrategias novedosas para hacer frente a este problema. El empleo de drones de vigilancia y la participación activa de los perceberos profesionales en la vigilancia, junto con el uso de metodologías emergentes para detectar fraudes en mercados y restaurantes, fueron identificados como potenciales partes de una solución. Los participantes del taller concluyeron que una fuerte cohesión entre los perceberos y altos niveles de cooperación entre las partes interesadas, ofrecen las mejores condiciones para reducir el furtivismo.

Eventos como este taller internacional y multisectorial son fundamentales para fomentar el intercambio de conocimientos y el aprendizaje mutuo, lo cual puede resultar en la creación de soluciones de gestión efectivas e innovadoras para abordar los desafíos comunes en las pesquerías de percebe en Europa.

El potencial de un sistema de gobernanza policéntrico y de múltiples escalas para las pesquerías de percebe en Europa

Actualmente, las pesquerías europeas de percebe representan un consorcio de sistemas socioecológicos complejos, independientes y distintos, con diferentes niveles de implementación de gobernanza y escalas de gestión altamente variables. La implementación de un sistema de gobernanza policéntrico y de múltiples escalas (Ostrom 2009) podría ayudar a abordar problemas complejas, como por ejemplo el furtivismo internacional y podría facilitar la incorporación de la co-gestión en el marco legal de todas las pesquerías europeas de percebes, siguiendo el ejemplo de Portugal (Decreto-Lei n.º 73/2020, septiembre de 2020). El objetivo de un sistema de gobernanza policéntrico y de múltiples escalas no es crear un sistema único que se adapte a las pesquerías de percebe en todas las regiones, sino facilitar la colaboración entre los múltiples niveles de autoridades y diversos grupos de interesados entre las regiones

(Ostrom 2009). Un marco de gobernanza común podría servir para la implementación de acuerdos legales internacionales e interregionales entre los sistemas de policía y justicia, facilitando una implementación unificada de medidas efectivas (Mitchell 2016; Tretyakov et al. 2021). Para mejorar el cumplimiento y la aplicación de las normas, se podrían implementar estándares de penalización comunes y acuerdos legales internacionales que sancionen todas las formas de incumplimiento y actividades de furtivismo. En España, la recolección ilegal de percebes se considera un delito penal, y se pueden imponer multas y penas de prisión de hasta dos años (artículo 335 del Código Penal de la Ley Orgánica 1/2015, de 30 de marzo). Si se aplicaran estándares de penalización consistentes en todo el sistema de gobernanza unificado, de manera similar al ejemplo español, es probable que se reduzca el furtivismo en todos los niveles, desde el local hasta el internacional. Además, un marco de gobernanza común podría ayudar a adoptar esfuerzos de vigilancia transregionales. La cooperación internacional entre los organismos gubernamentales de vigilancia y la policía podría facilitarse a través de este tipo de gobernanza. Las regiones con una implementación avanzada y altos estándares podrían servir como ejemplos para implementar o mejorar los estándares en otras regiones (Geiger et al. 2022).

El proyecto PERCEBES ha sentado las bases para el intercambio de conocimientos multisectoriales a nivel internacional, al proporcionar una plataforma de diálogo a través de estudios científicos y talleres con los interesados. Es esencial continuar el intercambio de valiosa información socioecológica entre las pesquerías, desarrollar metas futuras compartidas y mejorar la sostenibilidad de las pesquerías europeas de percebe a nivel regional e internacional.

Conclusiones

1. El marisqueo de percebe genera cambios en la comunidad biológica, ya que la apertura de espacio en el intermareal permite que otras especies se establezcan, lo que da inicio a un proceso de sucesión que afecta la diversidad ecológica. La perturbación regular causada por esta actividad conduce a un aumento neto en la diversidad de las especies que ocupan dicho espacio.

2. Aunque las agregaciones de percebe tienen la capacidad de recuperarse en un plazo de dos años en condiciones de veda, la recuperación de las poblaciones explotadas requerirá en última instancia una combinación de tiempo y disponibilidad de percebes adultos. Vedas prolongadas de al menos dos años pueden favorecer la recuperación de los stocks de percebe y promover la sostenibilidad ecológica de este marisqueo.

3. Los perceberos de Asturias aceptan medidas restrictivas, como las vedas, para proteger su recurso en escenarios de disminución de abundancia biológica. Sin embargo, las fluctuaciones del mercado pueden generar respuestas insostenibles, lo que indica que la rentabilidad económica es crucial para el futuro de la pesquería. Se necesitan medidas de gestión adaptables, que respondan tanto a las fluctuaciones

económicas como ecológicas, para garantizar la sostenibilidad a largo plazo de este valioso recurso.

4. Perceberos de pesquerías con niveles de gobernanza y sostenibilidad más bajos muestran una mayor disposición a efectuar cambios en la gestión implementada, en comparación con aquellos en pesquerías altamente participativas y sostenibles.

5. No existe una tendencia clara en cuanto a una única estrategia "óptima" en todas las regiones, lo cual resalta la importancia de considerar múltiples estrategias de gestión para lograr una gestión pesquera sostenible. Para alcanzar la sostenibilidad en las pesquerías de percebe en toda Europa, es crucial adaptar las estrategias de gestión a las necesidades y características únicas de cada región, al mismo tiempo de fomentar la cooperación transregional y el intercambio de conocimientos.

6. El intercambio de conocimientos y el aprendizaje mutuo pueden promoverse a través de talleres y estudios conjuntos entre regiones, mostrado por el proyecto PERCEBES, lo que contribuye a estimular la colaboración transregional entre las partes interesadas e inspirar esfuerzos para mejorar la gestión pesquera.

7. El furtivismo presenta un problema común y grave que afecta a las pesquerías de percebe en toda Europa. La forma en que las pesquerías responden a este desafío depende de los tipos de furtivos involucrados y del nivel de gobernanza que haya desarrollado la pesquería.

8. El furtivismo transnacional se facilita debido a las diferencias en el nivel de gobernanza y estructura social de la pesquería, así como a las disparidades en la demanda y los precios de mercado entre países. Además, el marisqueo ilegal se ve favorecido por la existencia de un mercado negro consolidado y redes de distribución sofisticadas.

9. Las pesquerías de percebe en Europa podrían beneficiarse de un sistema de gobernanza multinivel y policéntrico que facilite la colaboración entre los múltiples niveles de autoridades y diversos grupos de partes interesadas entre regiones para abordar desafíos internacionales complejos.

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Appendices

Appendix A (Chapter 2)

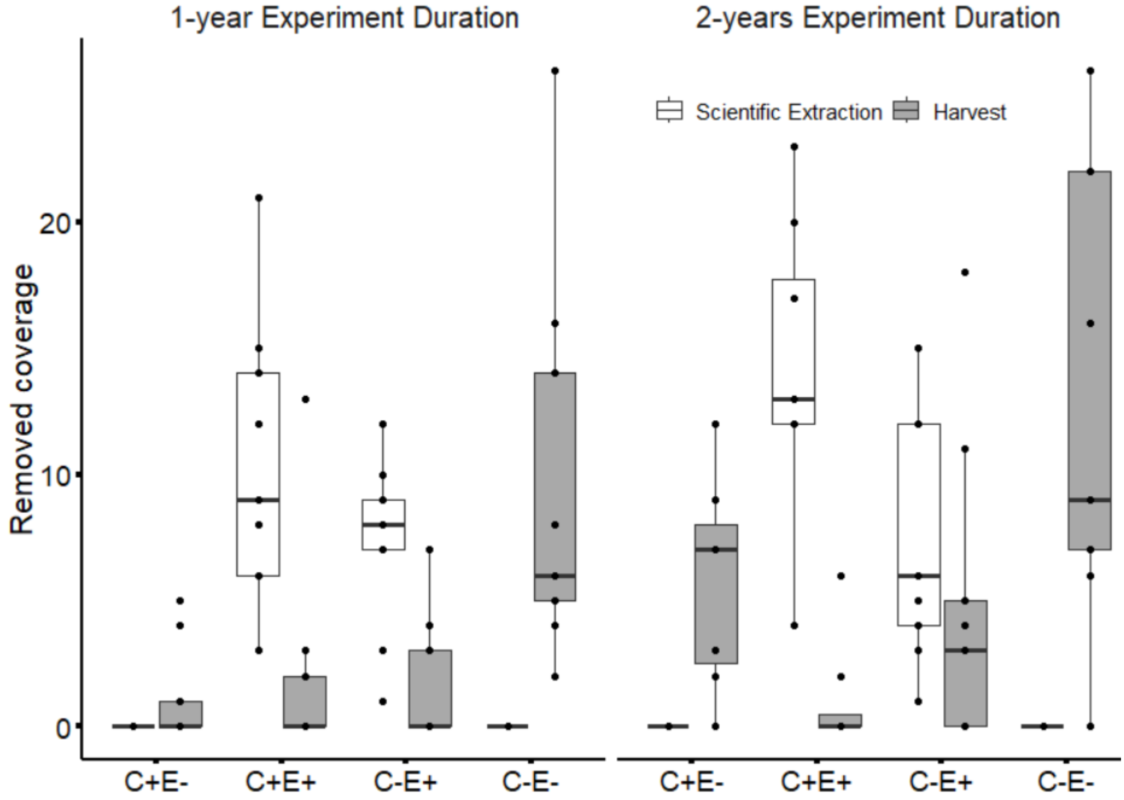

Figure A1. Removed coverages of *P. pollicipes* (dots represent replicates and boxplots represent average coverages of all three locations with standard errors) through scientific extraction (white boxplots) and through harvesters, predators, and storms (dark grey boxplots) of the experiment in the 1-year experiment duration (July 2018 to July 2019) and 2-years experiment duration (July 2017 to July 2019).

Table A1. Species list comprising the intertidal community accompanying *P. pollicipes.* This is not an exhaustive list, but describes species or genus found in the experimental plots of this study in the three study locations (*La Cruz*, *Las Salsinas* and *Las Llanas*) between July 2017 and July 2019.

		Mean coverage (%) ± standard deviation		
		La Cruz	Las Salsinas	Las Llanas
ANIMALS	**Cnidaria, Anthozoa (Anemones):**			
	Actinia equina (Linnaeus, 1758)	✓	0.09 ± 0.06	0.17 ± 0.10
	Mollusca, Gastropoda (Periwinkles, Dogwhelks, Limpets):			
	Phorcus lineatus (Da Costa, 1778)			✓
	genus *Patella* (*P. depressa* Pennant, 1777, *P. ulyssiponensis* Gmelin, 1791, *P. rustica* Linnaeus, 1758, *P. vulgata* Linnaeus, 1758)	3.42 ± 0.45	5.95 ± 0.64	5.04 ± 0.42
	Mollusca, Bivalvia (Mussels):			
	Mytilus spp.	7.13 ± 1.67	5.95 ± 0.74	6.22 ± 0.88
	Annelida, Polychaeta (Worms):			
	Eulalia viridis (Linnaeus, 1767)	✓		
	Echinodermata, Echinoidea (Urchins):			
	Paracentrotus lividus (Lamarck, 1816)	✓		✓
	Arthropoda, Cirripedia (Barnacles):			
	genus *Chthamalus* (*C. montagui* Southward, 1976, *C. stellatus* (Poli, 1791))	23.08 ± 3.51	24.41 ± 2.27	21.70 ± 2.24
	Pollicipes pollicipes (Gmelin, 1791 [in Gmelin, 1788-1792])	19.58 ± 2.21	17.18 ± 1.40	15.61 ± 1.03
ALGAE	**Rhodophyta (Red algae):**			
	Asparagopsis armata Harvey, 1855			✓
	Callithamnion spp.		✓	✓
	Ceramium spp.	0.46 ± 0.21	0.09 ± 0.09	0.04 ± 0.04
	Gelidium spp.			✓
	Laurencia obtusa (Hudson) J.V.Lamouroux, 1813	✓		✓
	Lomentaria articulata (Hudson) Lyngbye, 1819	✓		✓
	Mastocarpus stellatus (Stackhouse) Guiry, 1984	✓	0.46 ± 0.46	✓
	Nemalion helminthoides (Velley) Batters, 1902	0.63 ± 0.15	2.23 ± 0.71	0.91 ± 0.43
	Osmundea pinnatifida (Hudson) Stackhouse, 1809	0.88 ± 0.35	1.00 ± 0.46	✓
	Plocamium cartilagineum (Linnaeus) P.S.Dixon, 1967			✓
	Polysiphonia spp.		✓	✓
	Porphyra sp. (in *Conchocelis* phase)		✓	
	Rhodothamniella floridula (Dillwyn) Feldmann, 1978			✓
	Calcareous:			
	Corallina spp. and Ellisolandia elongata (J.Ellis & Solander) K.R.Hind & G.W.Saunders, 2013	12.21 ± 2.96	13.27 ± 1.77	4.00 ± 1.30
	Lithophyllum incrustans Philippi, 1837	3.42 ± 0.86	1.45 ± 0.46	1.00 ± 0.37
	Tenarea tortuosa (Esper) Me.Lemoine, 1910	4.54 ± 0.94	1.68 ± 0.46	6.22 ± 1.06
	Ochrophyta (Brown algae):		±	
	Caulacanthus ustulatus (Mertens ex Turner) Kützing, 1843	0.21 ± 0.09	0.46 ± 0.41	0.04 ± 0.04
	Colpomenia peregrina Sauvageau, 1927		✓	
	Ectocarpus siliculosus (Dillwyn) Lyngbye, 1819			✓
	Leathesia marina (Lyngbye) Decaisne, 1842		✓	
	Petrospongium berkleyi (Greville) Nägeli ex Kützing, 1858	✓	0.46 ± 0.46	0.09 ± 0.06
	Ralfsia verrucosa (Areschoug) Areschoug, 1845	6.71 ± 0.70	5.73 ± 0.92	11.09 ± 1.27
	Sphacelaria fusca (Hudson) S.F.Gray, 1821		✓	✓
	Chlorophyta (Green algae):			
	Bryopsis plumosa (Hudson) C.Agardh, 1823	✓	0.14 ± 0.14	
	Chaetomorpha linum (O.F.Müller) Kützing, 1845		✓	✓
	Lychaete pellucida (Hudson) M.J.Wynne, 2017			✓
	Ulva spp.	✓	✓	✓
	Cianobacteria			
	genus *Microcoleus* Desmazières ex Gomont, 1892			✓

Appendix B (Chapter 3)

Table B1: Results of Kruskal Wallis tests for determining possible bias due to sampling time (before and during the Covid-19 pandemic) and data collection methods (in person or by phone).

	Scenario	Chi-squared	df	p-value
Covid-19 pandemic	Reduced Abundance 1 Season	0.168	1	0.682
	Reduced Abundance 2 Seasons	0.516	1	0.473
	Reduced Price 1 Season	0.0005	1	0.982
	Reduced Price 2 Seasons	0.590	1	0.442
	Reduced Abundance with Increased Price	0.204	1	0.652
Data collection method	Reduced Abundance 1 Season	2.446	3	0.485
	Reduced Abundance 2 Seasons	1.297	3	0.730
	Reduced Price 1 Season	2.805	3	0.423
	Reduced Price 2 Seasons	2.195	3	0.533
	Reduced Abundance with Increased Price	3.550	3	0.314

Appendix C (Chapter 4)

Table C1: Results from statistical tests to examining data bias in survey answers due to the COVID-19 pandemic using Kruskal-Wallis and determining the association between categorical variables using Fisher's exact tests.

Test	Independent variable		Dependent variable	P-value
Kruskal-Wallis	Covid-19 pandemic	Asturias-East	Most important management strategy	0.629
		Asturias-West		0.8484
Fisher's exact	Region			0.0005***
	Income source			0.0209*
	Educational level			0.0299*

* p<0.05 ** p<0.01 *** p<0.001

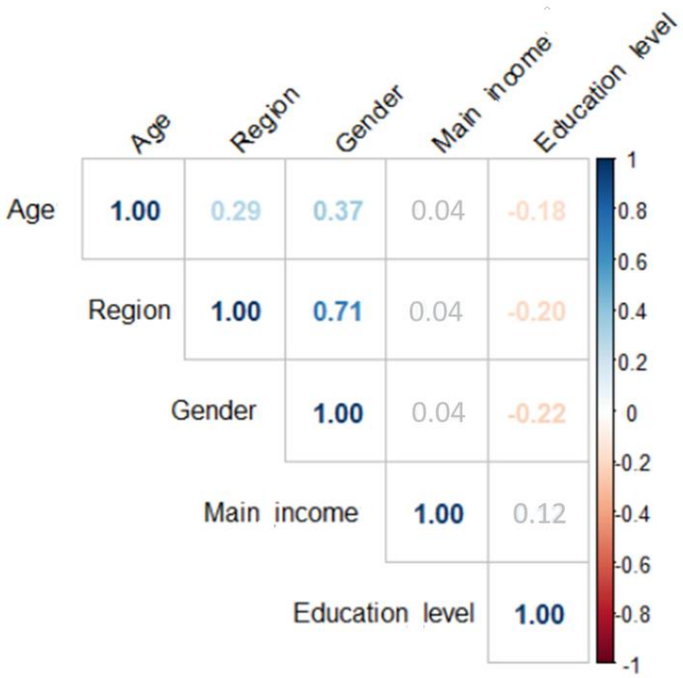

Figure C2. Kendall rank correlation test results. The coefficient indicates the degree of relatedness among independent variables to be used in the multinomial model.