REPORT

Assessing the sustainability and adaptive capacity of the gooseneck barnacle co-management system in Asturias, N. Spain

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Abstract The gooseneck barnacle fishery in Asturias (N. Spain) has undergone three important changes: (1) the early implementation of a co-management system based on Territorial User Rights for Fishing, (2) a change in management measures (due to a decrease in landings), and (3) an economic crisis. This has allowed us to analyze the systems' sustainability in time through examining five critical variables: landings, effort, catch per unit effort (CPUE), mean market prices, and annual revenue. Additionally, we used focus groups and questionnaires to determine the response of the system to these three changes. Co-management has succeeded in maintaining or increasing CPUE throughout all management areas and produced stable mean market prices. This was achieved through flexible management policies and adaptive strategies adopted by the fishers, such as increased selectivity and diversification. The analysis of this fishery provides important lessons regarding the need to understand the evolutionary dynamics of co-management and the importance of embracing adaptive capacity.

Keywords Adaptive capacity · Sustainability · Social–ecological system · Change · Gooseneck barnacle

INTRODUCTION

Fisheries are faced with unpredictable social, economic, and ecological changes (Folke 2006). To achieve resilience they must incorporate learning processes that tackle uncertainty and change (Berkes et al. 2003; Armitage et al.

2009). Nonetheless, despite growing awareness on fishing stock vulnerability to global drivers (Tuler et al. 2008), the mechanisms underlying adaptive capacity within management frameworks have not received sufficient attention (Folke 2006; Fulton et al. 2011).

Co-management is the collaboration between governments and users in the exercise of resource management (Pinkerton 1989). It has been proposed as a useful approach to generate adaptive capacity (Berkes 2009) and sustainable fisheries (Costanza et al. 1998). During the past decades, successful examples of co-management systems have emerged worldwide (Gutiérrez et al. 2011), with some salient examples from fisheries (Cinner et al. 2012). These systems generally rely on a learning-by-doing approach, where problems are solved using knowledge generated from experience (Berkes 2009). Analysis of their adaptability can help unravel the processes that promote the resilience of social–ecological systems (Folke et al. 2002).

Co-management systems are generally regarded as successful if they are long-enduring (Ostrom 1990). However, ascertaining that a long-enduring system is actually sustainable requires long-term, empirical verification (Gardner et al. 1990). This may prove difficult to conduct in social–ecological settings where the livelihood and welfare of a community is at stake. However, when possible, such verification not only increases our understanding of the co-management process but may also help identify basic principles that are relevant to other contexts (Garcia and Staples 2000; Gelcich 2014).

The gooseneck barnacle (*Pollicipes pollicipes*) inhabits rocky shores from France to Senegal (Barnes 1996). It is considered a delicacy in the Iberian Peninsula, where it reaches prices up to 200 euros kg^{−1} (Rivera et al. 2014). The Asturian gooseneck barnacle fishery (Fig. 1c) has been co-managed for the past 20 years, providing a wealth of

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Fig. 1 **a** Image of a gooseneck barnacle (*Pollicipes pollicipes*). **b** Group harvesting on an exposed fishing site. **c** Map of the Asturian coast showing the locations of the gooseneck barnacle management areas (*squares*), and the subdivision of these units into fishing sites (*circles*)

empirical information on a complex social–ecological system in Europe (Rivera et al. 2014). Despite its economic importance in the region, the resource was not commercialized in Asturias until the establishment of the co-management system in 1994. Currently, 189 Asturian fishers harvest nearly 45 000 kg year⁻¹ of gooseneck barnacles (Rivera et al. 2014), which represents an important share of the total fishery activity in Asturias (INDUROT et al. 2010). This long-standing fishery has survived through three important changes: (1) the early implementation of the co-management system from 1994 to 2004, (2) a change in management practices after the 2004–2005 fishing season, prompted by a general perception of decreased resource abundance and a reduction in landings, and (3) an economic crisis which began impacting Spanish markets in 2008 (Fernandez-Villaverde and Ohanian 2010). To determine the long-term sustainability of the fishery, we have analyzed a 10-year time-series of landings, effort, catch per unit effort (CPUE), mean weekly prices, and mean annual revenue. Furthermore, we used fishers' perception to systematically address five key factors that may contribute to the adaptability of the system—effort, addition of new members, new technologies, selectivity, and diversification—through the three episodes of change. Last, we integrated these results to assess and

discuss the effect of co-management on the sustainability and adaptive capacity of the gooseneck barnacle fishery.

MATERIALS AND METHODS

The gooseneck barnacle fishery

Gooseneck barnacles (*Pollicipes pollicipes*) are pedunculate cirripedes, with larvae adapted for dispersal and a sessile adult stage. They inhabit highly exposed rocky intertidal areas (De La Hoz and García 1993) and are harvested on foot using a helmet, wet suit, mesh bag to store the barnacles, and a sharp metal tool known as *bistranza*, to manually remove the resource (Fig. 1b). The fishery operates exclusively under the jurisdiction of the regional council (*comunidad autónoma del Principado de Asturias*).

The Asturian gooseneck barnacle co-management system is located in the Cantabrian coast (Spain; Fig. 1c). The system is being co-managed by the government agency *Dirección General de Pesca Marítima del Principado de Asturias* (DGPM) and the local fishers' associations. Seven management areas, known as plans, comprise the co-management system: *Tapia de Casariego-Figueras*,

Viavélez, Ortiguera, Puerto de Vega, Luarca, Cudillero-Oviñana and Cabo Peñas (Rivera et al. 2014). Currently, Tapia de Casariego-Figueras, Viavélez, Ortiguera, Puerto de Vega, Luarca and Cudillero-Oviñana (i.e., seasonal plans) have a fishing season length of 7 months. A perceived decline of the resource in 2004 led to a reduction of the individual daily TAC from 8 to 6 kg. This decline was not perceived in the Cabo Peñas plan, therefore their daily individual TAC remained at 8 kg and their fishing season was extended to a year-round harvest. In view of the different management strategies, we analyzed the sustainability of Cabo Peñas (yearly plan) and the seasonal plans (7-month harvest) separately.

Sustainability of the fishery

For the past 20 years, fishers and surveillance officers have recorded daily landings and effort as part of the co-management agreement. We used this data to assess the sustainability of the co-management system by analyzing total yearly landings (kg), effort (days), and CPUE (kg day⁻¹) from the 1998–1999 to the 2010–2011 fishing seasons. The different management plans were sequentially incorporated into the co-management system, until the present size of seven management plans was reached in 1998. Therefore, data from 1994 to 1998 were not included in the analyses because not all the management plans were in place and a comparison of years with an unequal number of plans could lead to spurious trends. Data for the Luarca management plan were incomplete and had to be excluded from the analyses.

Landings, effort, and CPUE data were first modeled by linear regression to extract the long-term trend and the noise component as

$$y_t = a + \beta t + \varepsilon_t$$

where y represents landings, effort or CPUE, t is time in years, ε is the noise component, α the intercept and β the slope of the long-term trend.

We then performed a multiple linear regression of the long-term trend, the changes that affected the fishery using a factorial variable with two levels (i.e., early implementation from 1998 to 2004 and new management measures from 2004 to 2011) as an independent regressor and the noise component, it can be written as

$$y_t = a + \beta t + \text{Management}_t + \varepsilon_t$$

where y represents landings, effort or CPUE, t is time in years, Management indicates the effect of the early implementation of co-management and new management policies on the time-series, ε is the noise component, α the intercept, and β the slope of the long-term trend. The effect of the economic crisis was not accounted for due to limited data.

We used the Akaike Information Criterion (AIC) to determine which of the two models best explains the long-term trends in landings, effort, and CPUE separately for the yearly plan and for the seasonal plans.

We analyzed gooseneck barnacle sales from 2002 to 2011 in the Puerto de Vega fish market, which sells a major share of the catch from the co-management plans. Sales prices were adjusted for inflation using the price index for mollusks and crustaceans in the Spanish market (source: www.ine.es). To determine long-term trends in weekly price per kilogram data and its seasonality we used Generalized Additive Modeling (GAM; Wood 2006). The variability in the time-series was divided into three components: long-term trend, seasonal component, and noise component (Chatfield 2013). Our model assumes a linear long-term trend incorporated through a sequence of time and a flexible seasonal pattern. The model can be written as

where Variable is price per kilogram, t is time in weeks, ε is the noise component, α the intercept, β the slope of the linear long-term trend, and f is the smooth function of the week of the year w . We estimated $f(w)$ using cyclic cubic regression spline smoothing (Wood 2003) and the effective degrees of freedom were selected by the generalized cross-validation score (GCV). All GAM calculations were analyzed using the *mgcv* package. To obtain a general picture of the long-term trend in sales prices, mean yearly price per kilogram was also analyzed through linear regression analysis.

We used landings data—part of which are sold in the black market—and mean yearly price obtained from sales data in Puerto de Vega to analyze mean annual revenue per fisher in the seasonal plans for 2001–2011. Annual revenue per fisher for the yearly, Cabo Peñas plan was not analyzed because most of their sales occur in black markets and cannot be accounted for.

Adaptive capacity of the resource users

We assessed the adaptive capacity of the resource users when confronted with the three main changes in the fishery: early implementation of the co-management system, change in management measures and economic crisis. For this, we first carried out focus groups in the seven co-management plans from October to December 2012, each focus group included resource users and government officers. Using the information provided by the focus groups, we developed a questionnaire to evaluate the fishers' level of agreement with 15 statements ranked in a 5-point Likert scale, using “strongly disagree” and “strongly agree” as anchor points. The questionnaire assessed adaptive capacity according to five aspects: effort, addition of new

members, new technologies, selectivity, and diversification. The use of new technologies mainly refers to wet suits and high-speed inflatable boats. Selectivity is defined as the harvest of high quality individuals whose market value is on average 51.95 euros kg^{-1} greater than low quality individuals (Rivera et al. 2014). Diversification could be focused toward other species (marine-based) or toward work on land (land-based). A total of 73 questionnaires were conducted, which covered 16–87 % of fishers per plan. Differences among plans and time periods (based on the three changes) were analyzed using a non-parametric Kruskal–Wallis one-way analysis of variance by ranks. If significant differences were detected, we used proportional odds logistic regression for ordered dependent factors using the MASS package (Venables and Ripley 2002). The effects of the proportional odds logit model were assessed using the effects package (Fox 2009). All analyses were done using R computing software version 2.15.3 (R Development Core Team 2012).

RESULTS

Sustainability of the system

Trends in fishery data for the seasonal management plans

According to AIC, the model that best describes the long-term trends in landings and CPUE is the multiple linear regression, which accounts for the change in management measures (Fig. 2a, c). A steady decrease in landings is observed after the early implementation of the co-management system. However, after the change in management measures in 2004, landings stabilized at ca. 30 000 kg year^{-1} (multiple linear regression; $R^2 = 0.78$, $p = 0.06$; Fig. 2a). The best model to describe the trends in total effort for the seasonal plans is the linear regression, which reveals a continuous decrease of 111 days year^{-1} ($R^2 = 0.45$, $p = 0.01$; Fig. 2b). This indicates that the 2004 change in management policies had no significant effect on the fishing effort. Therefore, the establishment of co-management had a negative effect on effort and landings during the early implementation period, and generated a decreasing trend of CPUE between 1998 and 2004. Nonetheless, a reduction of the individual, daily TAC in the 2004–2005 fishing season was successful in generating positive trends in CPUE for the seasonal plans.

Trends in fishery data for the Cabo Peñas plan

Results in the Cabo Peñas plan differ from those observed in the other six management plans (see preceding section). There are no significant long-term trends in landings, effort,

or CPUE in the yearly plan (Fig. 2d–f, $p = 0.68$, 0.45 , and 0.9 , respectively). However, declining trends in landings and effort occur after the implementation of the co-management system and the incorporation of year-round harvest in 2004 (Fig. 2d, e). There is a distinct decrease in effort and landings in the 2002–2003 campaign in Cabo Peñas, which corresponds with a temporal closure in the plan after the Prestige oil spill (Rivera et al. 2014). The model that best describes the trends in CPUE in the yearly plan is the linear regression, indicating that year-round harvest does not affect CPUE. Nonetheless, CPUE decreases during the first year of the economic crisis (2008–2009 fishing season; Fig. 2f) but recovers the following fishing seasons.

Trends in sales data

Gooseneck barnacle sales have a distinct seasonal component. The highest sales prices are achieved during the holidays, toward the third week of December (GAM; $p < 0.0001$, $EDF = 15.72$; Adjusted $R^2 = 0.33$; Fig. 3a). Mean sales prices for gooseneck barnacles in Asturias peaked the year before the economic crisis (2007). Nonetheless, there is no significant long-term trend in mean weekly and yearly price kg^{-1} from 2002 to 2011 (Fig. 3a, b). Therefore, the economic crisis does not appear to have a significant impact on gooseneck barnacle sales prices. However, it might affect the mean annual revenue per fisher, which decreases to 53.89 euros $\text{fisher}^{-1} \text{year}^{-1}$ throughout the time-series. However, this trend is not statistically significant (linear regression; $p = 0.33$).

Adaptability of the system

Fishers perceived that effort was reduced after the change in management measures and the economic crisis (Fig. 4). This is consistent with our effort time-series data (Fig. 2b, e). Early implementation of co-management was not taken into account because management guidelines explicitly control effort. Additionally, an increase in new members and new technologies was only perceived after initial implementation of the co-management system (Fig. 4; Kruskal–Wallis, $p < 0.01$). We did not consider an increase in new technologies after the change in management measures because we deemed it unlikely that new technologies would emerge in the time gap between the change in management period and the economic crisis period.

Fishers became more selective after each of the three changes. Nonetheless, after the change in management measures and the economic crisis, the responses differed among management plans (Kruskal–Wallis; $p = 0.06$ and 0.01 , respectively; Fig. 5). This perceived increase in selectivity is greater in the three smallest co-management plans (Viavélez, Ortiguera, and Puerto de Vega; Fig. 5).

Fig. 2 Optimal model for the long-term trends on landings, effort, and catch per unit effort in the seasonal plans (i.e., *Tapia de Casariego-Figueras*, *Viavélez*, *Ortiguera*, *Puerto de Vega*, *Luarca*, and *Cudillero-Oviñana* management areas) and the yearly plan (i.e., *Cabo Peñas* management area). **a** Landings for the seasonal plans. **b** Effort for the seasonal plans. **c** CPUE for the seasonal plans. **d** Landings for the yearly plan. **e** Effort for the yearly plan. **f** CPUE for the yearly plan. The solid line indicates the long-term trend for each variable and the dotted line the standard error. Shapes represent the different time periods: Early implementation (circles), change in management measures (squares and triangles), and economic crisis (triangles). The R^2 and p value for the best model are represented in the upper left corner of each graph

After the economic crisis, most plans perceived a need to diversify (Fig. 6). This diversification is, in general, directed towards other species and less towards work on land (Kruskal–Wallis, $p < 0.001$; Fig. 6). The *Tapia-Figueras* plan was the only exception, with nearly 75 % of fishers not perceiving a diversification of their income (Kruskal–Wallis; $p = 0.01$). The adaptive strategies employed by the plans after each change are summarized in Table 1.

DISCUSSION

We have assessed the sustainability and resilience of the gooseneck barnacle fishery in Asturias after three important changes: the early implementation of a co-management system, a change in management measures, and a

global economic crisis. Throughout the 20-year history of the gooseneck barnacle fishery, fishers have self-organized and developed adaptive strategies to cope with these changes. Social learning and continuous rounds of learning-by-doing were included in management policies that adapted to the changing environment and the individual needs of the resource users, triggering sustainable CPUE and stable prices. The implementation of the gooseneck barnacle co-management system in 1994 generated the commercialization of the resource in Asturias (Rivera et al. 2014). From 1994 to 1998, the system grew markedly in number of users and in management areas (Fig. S1). The addition of new members (Fig. 4b) may have produced a decrease in landings during the early implementation period (1998–2004; Fig. 3a, d). According to the fishers, this trend was counteracted with an increase in the use of new technologies such as speedboats to reach more fishing sites

Fig. 3 Trends in gooseneck barnacle sales and revenue from January 2002 to December 2011. **a** Long-term changes in weekly mean price per kg, predicted values from the Generalized Additive Models (GAM, *black curve*) are plotted with their standard error (*dotted line*). Long-term linear component of the model is represented by a *solid black line*. **b** Long-term linear trend in yearly mean price per kg (*solid line*) and its standard error (*dotted line*). **c** Long-term linear trend for mean annual revenue per fisher for the seasonal plans (i.e., *Tapia de Casariego-Figueras*, *Viavélez*, *Ortiguera*, *Puerto de Vega*, *Luarca*, and *Cudillero-Oviñana* management areas; *solid line*) and its confidence intervals (*dotted line*). The different time periods are represented by *arrows*

Fig. 4 Adaptive response of the users to the three changes in the fishery (early implementation of co-management, change in management measures, and economic crisis) based on **a** effort, **b** new members, **c** new technologies, and **d** selectivity. The *box* represents the inter-quartile range, *bold line within the box* represents the median, the *whiskers* represent the data range, and the *dots* the outliers. Kruskal–Wallis analysis showed significant difference in new members and new technologies, p values are indicated

Fig. 5 Differences in selectivity among plans after the change in management measures and the economic crisis

Fig. 6 Difference in diversification strategies after the economic crisis for **a** management plans and **b** livelihood options. The *box* represents the inter-quartile range, the *bold line within the box* represents the median, *whiskers* represent the data range, and the *dots* the outliers

in a single day (Fig. 4c), a strategy that commonly leads to stock depletion (Pauly et al. 2002). However, the perceived decline in landings led to a change in management measures, which succeeded in stabilizing or increasing CPUE (Fig. 3). Additionally, management measures were adapted to the individual needs of each plan. For example, instead of reducing TAC in the *Cabo Peñas* plan, effort was controlled through the restriction of the total fishing days per year and the number of new members (Rivera et al. 2014). This kind of collaborative trial and error process through which new management measures are tested confers greater resilience to fisheries, increasing their social and ecological sustainability (Berkas 2006; Armitage et al. 2009). In addition, the collaborative nature of co-management systems typically facilitates the empowerment of the resource users and increases social awareness and self-reliance (Pomeroy et al. 2001).

Co-management systems can also increase the economic and ecological awareness of resource users (Schumann 2007; Gelcich et al. 2008). The co-management system in

Asturias generated social learning, which drove the fishers to adopt adaptive strategies such as diversification and selectivity. The fishery is embedded in the global economy and must therefore be able to cope with its unpredictabilities. From 1994 to 2008, Spain experienced a real state boom, which propelled the national economy. This *real state bubble* (as is commonly called in the media) collapsed in 2008, leading to an acute recession (Fernandez-Villaverde and Ohanian 2010). Such crises can potentially assist in the collapse of inflexible fisheries, as was the case of Canada's northern cod fishery (Schrank 1995). This was not the case in the Asturian gooseneck barnacle fishery, where the management plans adapted and diversified (Fig. 6) instead of increasing effort (Fig. 2a, e). This strategy generated stable sales prices and reduced mean annual revenue (Fig. 3). These type of responses are known to lead to the long-term sustainability of a fishery (Cinner et al. 2011). Moreover, fishers chose to expand their activities both on land and, to a greater degree, to fishing for other species (Fig. 6). This is consistent with research

Table 1 Summary of adaptive strategies employed by each co-management plan during the three changes. Gray indicates that the strategy was implemented and NA means that this information is not available

Adaptive strategies	Cudillero-Oviñana	Luarca	Tapia-Figueras	Cabo Peñas	Ortiguera	Viavelez	Puerto de Vega
Early implementation of the co-management system							
Reduction in effort	NA						
Increase in new members							
Use of new technologies							
Increase in selectivity							
Increase in marine-based diversification							
Change in management measures							
Reduction in effort							
Increase in new members							
Use of new technologies	NA						
Increase in selectivity							
Increase in marine-based diversification							
Economic crisis							
Reduction in effort							
Increase in new members							
Use of new technologies							
Increase in selectivity							
Increase in marine-based diversification							

on the Asturian artisanal fleet, showing that fishers diversify their harvest but do not expand to other *métiers* (García-De-La-Fuente et al. 2013). Diversification to a wider range of target species is not only ecologically sound, but also helps reduce economic risks by addressing investor's needs (according to Portfolio Theory in economics; Markowitz 1970). It confers greater resilience to artisanal fisheries, by providing a source of income to the community while moving towards an ecosystem-based approach. Furthermore, Asturian fishers in the smaller plans adapted to changes in management and the economic crisis by increasing their selectivity towards higher quality barnacles to maximize profits (Figs. 3a, 5; Rivera et al. 2014). This strategy also helps reduce by-catch (Worm et al. 2009), which is important in this fishery, particularly for juvenile barnacles (Macho et al. 2013). Thus, selectivity in the Asturian gooseneck barnacle fishery preserves the smaller individuals, potentially improving subsequent harvests.

Co-management, like any other management approach, is not a panacea and might not be able to meet every small-scale fishery's needs. Due to their unpredictable nature, adaptive management of complex social-ecological

systems requires monitoring to constantly steer change in the appropriate direction (Mahon et al. 2008). Very recently, fishers in the seasonal plans requested that some of the zones were open to harvest during the summer. This new harvest strategy of the co-management system is being closely monitored and the information generated will surely feed back into the adaptive management cycle (sensu Fulton et al. 2011). In addition, the results presented here are currently being disseminated among the resource users so they can evaluate the effectiveness of previous decisions. This information may prove crucial in future rounds of decision-making and experimentation to confront more complex problems, such as those expected from climate change drivers.

An analysis of the evolutionary dynamics of co-management in Asturias has allowed us to understand the role of adaptive capacity, particularly the effect of fishery diversification, and increased selectivity in gooseneck barnacle quality, in sustaining the gooseneck barnacle fishery during the last 20 years. Social learning, adaptability towards unpredictability, and the role of repeated rounds of learning-by-doing must be included as critical elements in the design and implementation of co-

management systems. Co-management confers adaptive capacity to fisheries, thus promoting their resilience in an uncertain world.

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