Stalked barnacle (*Pollicipes pollicipes*) harvesting in the Berlengas Nature Reserve, Portugal: temporal variation and validation of logbook data

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Stalked barnacle (*Pollicipes pollicipes*) exploitation at the Berlengas Nature Reserve, Portugal, by professional harvesters has been subject to specific regulation since 2000. The only available information on barnacle exploitation there comes from catch reports (logbooks) provided by the harvesters. We evaluated the quality of the logbook information, described the temporal patterns of *P. pollicipes* fishing effort from 2000 to 2006 based on the logbook data, and modelled the daily fishing effort in relation to variability in oceanographic conditions. Results suggest different levels of reliability for the information contained in the logbooks: (i) information on the date of harvest seems to be reliable because 83% of the observed harvest dates were also declared; (ii) information on the quantity harvested shows a large discrepancy (mean = 31.8%) between declared and observed amounts, but we believe it can be used to analyse temporal patterns of exploitation, because there was no systematic bias (under- and overreporting was to the same extent). The total quantity of barnacles harvested between 2000 and 2006 ($\sim$16 t year^{-1}) was closely related to the effort applied. Daily harvesting effort was considered a function of two predictive variables (significant wave height and tidal range) and of their interaction. Neither the harvesting activity nor the resource itself seems to be at risk of collapse if such levels of pressure are maintained, but efforts should be made to increase surveillance and monitoring within the marine protected area.

Keywords: Berlengas, fishery, harvesting, marine reserve, *Pollicipes*, Portugal, stalked barnacle.

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Introduction

In the Iberian Peninsula, the stalked barnacle *Pollicipes pollicipes* is considered a delicacy and is heavily exploited for human consumption wherever it is abundant (Cruz, 2000; Molares and Freire, 2003; Bald *et al.*, 2006; Borja *et al.*, 2006b; Jesus, 2006). Owing to a strong market demand (Bernard, 1988; Lessard *et al.*, 2003), its distribution limited to very exposed shores (Barnes, 1996; Borja *et al.*, 2006a), and the difficulty and risk associated with the fishery (Molares and Freire, 2003), *P. pollicipes* ("percebes") price can be >€50 kg^{-1} at first sale. Its commercial fishery is an important or exclusive income for local fishers in northwest Spain and western Portugal.

In Galicia, northwest Spain (Figure 1), barnacle harvesting is a very important activity, involving around 1650 persons from local communities, yielding $\sim$409 t and €11 million annually (average 2001–2005; source: www.pescadegalicia.com). Since 1992, *P. pollicipes* exploitation in Galicia has been managed by a community-based cooperative system, responsibility for the exploitation of the resource being shared between fisher guilds ("cofradías") and fishery authorities (Molares and Freire, 2003). According to those authors, such a management system is yielding excellent results in some cofradías at an organizational, social, and economic level, whereas in other cofradías there are still problems to solve.

In the Basque Country (northern Spain), the Gaztelugatxe Marine Reserve was created in 1998 with the aim, *inter alia*, of protecting the stalked barnacle populations and repair the subsequent damage of the associated species communities caused by barnacle harvesting (Borja *et al.*, 2006b). Since 1998, barnacle harvesting has been forbidden there. According to the system dynamic model proposed by Bald *et al.* (2006), the harvesting prohibition in the reserve permits not only its own conservation, but also the maintenance of other exploited adjacent areas, because the protected populations may act as a spawning pool of larvae to nourish and sustain the exploited areas.

To our knowledge, no information has been published on exploitation of *P. pollicipes* in other areas of its distribution (e.g. France, Morocco). Published information on the exploitation and conservation of other species of *Pollicipes* is restricted to the situation in British Columbia, Canada (Jamieson *et al.*, 1999; Lauzier, 1999a, b; Lessard *et al.*, 2003). There, the fishery for *P. polymerus* was closed in 1999 because of concerns about the lack of biological and stock-assessment information on barnacles, information on the ecological impacts of harvesting to the rocky

Figure 1. Site of the Berlengas Nature Reserve (RNB) and other areas, e.g. Natural Park of Sudoeste Alentejano and Costa Vicentina (PNSACV) with management plans for *Pollicipes pollicipes* exploitation in the Iberian Peninsula (see text). The position of the Leixões oceanographic buoy relative to the study area is shown as a black star.

intertidal community, and consistent catch reporting by harvesters (Lessard *et al.*, 2003). A plan to develop a directed fishery on stalked barnacles off the west coast of Canada was proposed (Jamieson *et al.*, 1999; Lauzier, 1999a, b), and ecosystem-based management and a precautionary, phased approach to data collection and fishery development are seemingly required before the fishery can be reopened (Lessard *et al.*, 2003).

Along the Portuguese coast, despite its socio-economic interest, professional barnacle harvesting is not subject to specific regulations except in the Berlengas Nature Reserve, since 2000, and in the Natural Park of Sudoeste Alentejano and Costa Vicentina (Figure 1), since 2006. Moreover, most of the catch is sold directly to intermediaries or to the final consumer (at an average price of ~€20 kg^{-1}), without regulation. Consequently, in Portugal, official fishery data are scarce and hardly reflect the real harvesting pressure applied to local barnacle populations (Cruz, 2000; Jesus, 2006).

A management plan for barnacle exploitation at the Berlengas Nature Reserve by professional harvesters was implemented in 2000, and it includes spatial and temporal closures (harvesting is not allowed in August and September, on Mondays, Fridays, weekends, and holidays, before the delivery of the annual licences, usually in March, or at night), rotational harvesting, a limited number of harvest licences (the number is determined each year by legislation), size and bag limits for the catches (a maximum of 20 kg d^{-1} per harvester, and at least 50% of the harvest volume to contain animals with a rostro-carinal length >25 mm), and catch reporting in biannual logbooks.

There are no studies or monitoring programmes to evaluate this management plan or the sustainability of harvesting in the area protected. The only information available on barnacle exploitation at Berlengas comes from the biannual logbooks provided by the harvesters. Each logbook includes information on the number of days of harvesting, the area exploited, and the weight harvested.

A first goal of the present study was to evaluate the quality of the logbook information (catch and harvesting effort data). Second, because the logbook information was considered to be reliable for our purposes, a second objective was to describe the temporal patterns of *P. pollicipes* harvesting effort, harvested amounts, and catch rates at Berlengas from 2000 to 2006, based on the logbook data. Finally, we modelled the daily harvesting effort in relation to daily oceanographic conditions to understand better the drivers for the variability observed in harvesting effort.

Methods

Harvest-logbook validation

To validate the logbook information, we observed harvesting and compared the information with corresponding logbook data.

Barnacle harvesting was observed on 51 days between June 2005 and December 2006 ($n = 24$ d in 2005; $n = 27$ d in 2006). Most observations were at the port of Peniche, where most of the catches are landed ($n = 21$ d in 2005; $n = 26$ d in 2006), and a few at Berlengas by accompanying the harvesters, in their boats, to the harvesting sites ($n = 3$ d in 2005; $n = 1$ d in 2006). Observations consisted of the identification of boats and harvesters that went harvesting during these days and on weighing the total harvest landed per boat from boats selected randomly ($n = 65$). The harvest was weighed using a portable spring balance with a precision of ± 0.1 kg.

Harvest observations (harvest dates and amount harvested per day and boat) were compared with the corresponding information extracted from the biannual individual harvest logbooks for 2005 and 2006. Validation was based on the relative number of coincident data between observed and declared.

Temporal patterns of barnacle exploitation

As the logbook information was considered reliable for the purposes of our study (see below), we analysed for each year between 2000 and 2006 the patterns of (i) total harvesting effort (one unit of effort is one harvesting person per day), (ii) total harvest (in kg year^{-1}), (iii) the total number of harvest days per harvester, and (iv) the total harvest (in kg year^{-1}) per harvester. As the number of licences and the number of allowed days for the harvest varied annually, we also considered annual variability, as well as the percentage of harvest days (days with at least one harvester) in relation to the number of allowed harvest days. Further, because there is a daily bag limit per harvester, we also calculated the percentages of harvest in relation to this limit of 20 kg per bag. Finally, we described the monthly variation in the harvest and the number of harvest days (of at least one harvester per day).

Modelling harvesting effort as a function of oceanographic conditions

The aim of this part of our study was to find a relationship between daily harvesting effort and daily oceanographic conditions, using logbook information and physical data recorded between 2000 and 2005. The response variable was the proportion of licensed harvesters per day (rounded to integer). Several predictive variables were considered (continuous, physical data; nominal, month).

Physical data consisted of mean daily values of significant wave height (SWH; cm), wave period (s), and daily tidal range (TR; m) collected between February 2000 and July 2005 (we only included allowed harvesting days for which we had a complete dataset of all variables; $n = 353$). Data on SWH and wave period were recorded by the Instituto Hidrográfico oceanographic buoy at Leixões (41°11′N 8°42′W; Figure 1). Predicted tidal heights (above Chart Datum) for Peniche were obtained from the tide tables of the

Instituto Hidrográfico. Daily TR was defined as the difference between the daily maximum and minimum tide height.

Data exploration and generalized linear models (GLM) applying a Poisson distribution and a log-link function were performed using Brodgar software (Highland Statistics Ltd) linked with R software (www.r-project.com). Overdispersion was detected, and the standard errors were corrected using a quasi-GLM model where the variance is given by $\varphi \times \mu$, where μ is the mean and φ the dispersion parameter. Comparisons of deviances of nested models (using an *F*-test) were carried out to identify the optimal model (Zuur *et al*., 2007).

Results

Harvest-logbook validation

Comparisons between the logbook information and our observations suggest different degrees of reliability of the declared information, depending on whether the information was the harvest date or the harvested quantity. Of the 189 observed date/harvester combinations, 17% were not declared in the logbooks. In contrast, when comparing the observed and declared harvest ($n = 65$; allowing for a $\pm 5\%$ divergence between them), the proportion of incorrect information was 77%. The (unsigned) discrepancy between the declared and observed quantities ranged from 0 to 418% (mean = 31.8%, s.d. = 56.2) of the observed quantity. However, the information was not systematically biased: there was under- and overreporting, equally often, as indicated by the average ratio of declared to observed quantities being unity (Figure 2). As there was no bias in one direction, for the further purpose of this study (inter- and intra-annual comparisons), we used the means of the declared quantities by year or month (pooled over years) as estimates of what was taken by each harvester in the reserve in each year or month, respectively.

Patterns of barnacle harvesting at Berlengas based on logbook information

Total harvest and harvesting effort from 2000 to 2006 are presented in Figure 3. The two variables were significantly correlated

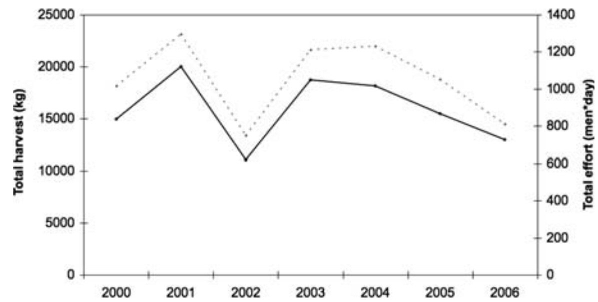

Figure 3. Annual variation, 2000–2006, of the total harvest of *P. pollicipes* at Berlengas Nature Reserve (kg; solid line) and the total harvesting effort (men*day; dotted line), based on logbook information.

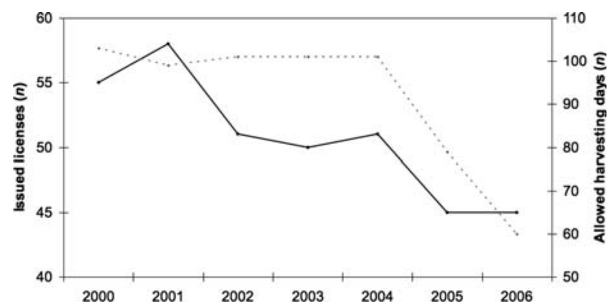

Figure 4. Annual variation, 2000–2006, in the total number of licenses issued to harvest *P. pollicipes* in the Berlengas Nature Reserve (solid line) and the total number of harvesting days allowed (dotted line).

(Spearman's $r = 0.95$, $p < 0.05$), suggesting that variability in the annual catches is attributable to harvesting effort. The total quantity of barnacles harvested per year at Berlengas varied between 11 039 kg in 2002 and 19 979 kg in 2001 (15 898 kg on average for 2000–2006).

The maximum effort allowed, a function of the number of licenses issued and days of harvesting permitted, varied between years, as shown in Figure 4. In 2000 (the first year of the management plan), 55 licenses were delivered. After 2001 (58 licenses delivered), the number of licenses gradually declined, and in 2005 and 2006, just 45 licenses were issued annually. The number of allowed harvesting days per year is normally ~100 days (3 days per week, over 8 months), but in 2005 and 2006, there were considerably fewer days because of delays in the issuing of licenses (in 2005 licenses were delivered only in late April, and in 2006 in early June).

The number of licenses issued, allowed harvesting days, and bag limits all influence the amount of effort that can be applied. However, there are other constraints (mostly concerned with oceanographic conditions), and harvesting is normally much less than what is allowed (Figure 5). Overall, ~72% of total allowed harvesting days are actually used by at least one harvester, and ~20% of the maximum allowed quantities are harvested.

Individual effort, in terms of total number of days operating (Figure 6a), is variable. Median number of days per harvester varied between 14.5 (in 2002) and 25.5 (in 2004). The total harvest per harvester per year was also variable (Figure 6b). The median quantity harvested *per capita* varied between 224 kg

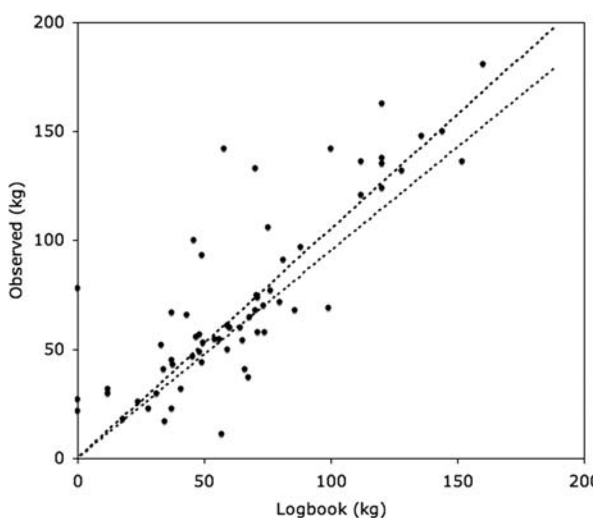

Figure 2. Declared quantities of *P. pollicipes* in the Berlengas Nature Reserve logbooks plotted against observed quantities. Dotted lines bound the coincidence band where the declared quantity equals the observed quantity $\pm 5\%$.

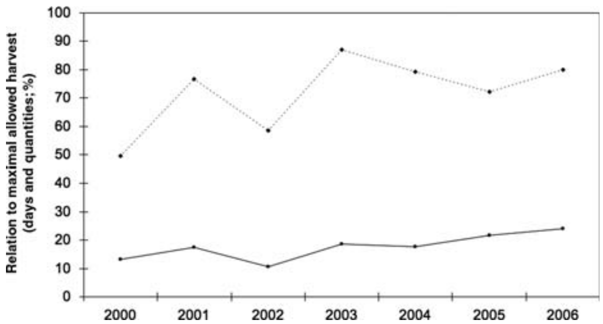

Figure 5. Annual variation, 2000–2006, of the percentage of harvest days (with at least one harvester) in relation to the maximum number of harvesting days allowed (dotted line) and of the percentage of the harvest in relation to the maximum allowed harvest (solid line), for *P. pollicipes* harvesting in the Berlengas Nature Reserve.

(in 2002) and 414 kg (in 2003), and the average harvest of barnacles per day (for the years 2000–2006) was 15 kg per harvester.

The monthly variation in barnacle harvesting (again averaged over the years 2000–2006) is shown in Figure 7. The quantity harvested between May and June is some 56.2% of the total annual take and is related to an increase in the number of harvesting days during those months.

Modelling daily harvesting effort as a function of oceanographic conditions

Our analyses suggested linear relationships between the response variable and each predictive continuous variable, and a possible interaction between the variables SWH and TR (Figure 8).

The model that described the relationship between harvesting effort (proportion of harvesters per day) and oceanographic variables best was a GLM using a Poisson distribution (corrected for overdispersion) and log-link function (Table 1; Figure 9), and the selected predictive variables were SWH, TR, and their interaction effect (TR × SWH). The GLM model explained 52.5% of the deviance and was of the form

$$\log(\text{Effort}) = 5.697 - 0.286\,\text{TR} - 0.021\,\text{SWH} + 0.004\,\text{TR} \times \text{SWH}.$$

According to the model predictions (Figure 10), most (60–90%) harvesters will work when waves are low (<1 m wave height), regardless of TR. As wave height increases (>1 m), the

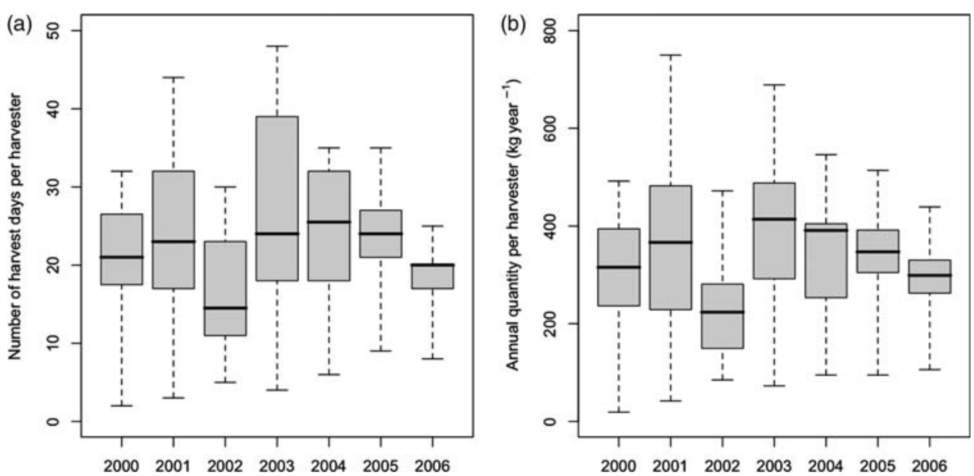

Figure 6. Boxplots (quartiles and extreme datapoints) of (a) the number of days used per harvester and (b) the annual quantities declared per harvester, 2000–2006, based on logbook information for *P. pollicipes* harvesting in the Berlengas Nature Reserve.

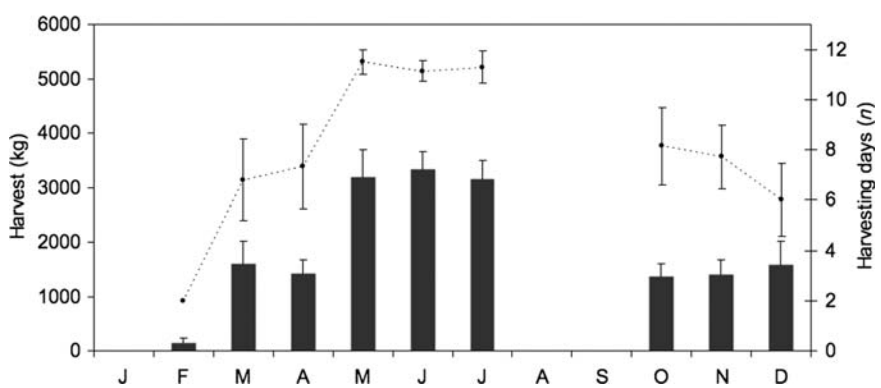

Figure 7. Monthly variation (averaged over the years 2000–2006) of the quantities of *P. pollicipes* harvested in the Berlengas Nature Reserve (bars, mean ± s.e.) and days of harvest (dots, mean ± s.e.), based on logbook information.

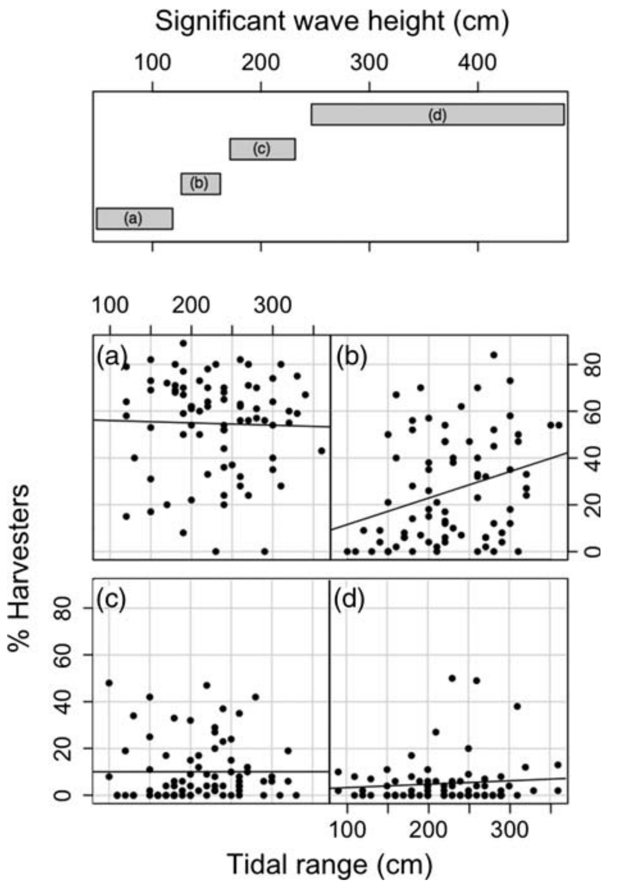

Figure 8. Linear regressions between the percentage of harvesters operating and TR, conditional on SWH, (a) for SWH < 110 cm; (b) for 120 cm < SWH < 160 cm; (c) for 170 cm < SWH < 240 cm, and (d) for SWH > 250 cm.

Table 1. Estimated parameters obtained by the GLM model containing TR, SWH, and their interaction effect (TR × SWH).

Parameter	Estimate	Std. Error	*t* -value	*p*-value
Intercept	5.697	0.490	11.627	**<0.001**
TR	−0.286	0.203	−1.407	0.160
SWH	−0.021	0.003	−6.049	**<0.001**
TR:SWH	0.004	0.001	2.609	**0.009**

Dispersion parameter for quasi-Poisson family taken to be 15.92. Null deviance: 10 292.9 on 352 degrees of freedom. Residual deviance: 4886.8 on 349 degrees of freedom. Emboldened values indicate significance ($p < 0.05$).

predicted proportion of harvesters decreases (more or less gradually, depending on TR), and a larger proportion of harvesters is expected when the TR is larger (spring tides). During the periods of large swell (>3 m wave height), the proportion of harvesters is small (<10% of those allowed), and harvesting is almost totally restricted to spring tides.

Discussion

Since the implementation of the management plan for barnacle harvesting at Berlengas Nature Reserve in 2000, the only source of information on the activity is from logbooks. Each licensed harvester has to complete and submit two logbooks each year (one for each semester) and deliver them to the nature reserve to allow license renewal. Until now, this information has not been validated nor used for any other purposes than license renewal. Logbook information is used to monitor many fisheries throughout the world (Walsh *et al.*, 2005; Williams *et al.*, 2008), but in terms of *P. pollicipes* exploitation in Portugal, logbook information is potentially even more important than elsewhere because there are no representative data on the fishery in official statistics.

We compared our own harvesting observations with logbook information to validate the logbook data. The results suggest different levels of reliability for the different types of information contained in the logbooks: (i) information on the date of harvest seems to be reliable because 83% of the observed harvest dates were also declared; (ii) information on the quantity harvested shows a large discrepancy (mean = 31.8%) between declared and observed quantities, but we believe nevertheless that it can be used to analyse temporal patterns of exploitation, because there is no systematic bias (under- and overreporting is to the same extent).

Logbooks also contain information on exploited area, quantities sorted, and destination, which we did not validate. Exploited area is difficult to validate because it would require intensive on-ground monitoring with identification of harvesters and boats. Sorted quantities and destination information are also difficult to validate because there is no control in the commercial circuit.

Inconsistency in fishery data and low compliance with catch reporting has also been identified in the barnacle (*P. polymerus*) commercial fishery in British Columbia, Canada (Lauzier, 1999a). Concerns over the ecological impact on mussel beds and on stalked barnacle stocks, and a lack of confidence in the fishery data, dictated the closure of that commercial activity in 1999 (Lessard *et al.*, 2003).

In Galicia, the cofradías have the capacity to commercialize the catch because they generally manage the first-sale markets (Molares and Freire, 2003). Additionally, according to those authors, in many cofradías, the catch and effort data are cross-validated with data derived from control points, located strategically close to the fishing grounds.

We suggest that serious consideration be given to establishing a monitoring programme on harvesting activity at the Berlengas Nature Reserve, including on-ground monitoring and a formal landing site (control point) at the port of Peniche, which could be used for monitoring, complementing data from logbooks, improving the quality of the data, and making its validation easier. Such a control point would also be important for managing the fishery through improving control and enforcement. As in Galicia, where each cofradía (or group of cofradías) has its own first-sale place for better control of harvest, sizes, and stabilization of prices, such a control point would also be important for managers and harvesters if it becomes the only place where the *P. pollicipes* harvested in the Berlengas Nature Reserve are first sold.

Graphical analysis of logbook information suggests that between 2000 and 2006, the total harvest of barnacles at Berlengas varied in relation to the effort applied. Effort variation throughout the years has been attributable to a gradual decline in the number of licenses issued, but also to delays in delivering the licenses, so reducing the number of harvesting days allowed (as in 2005 and 2006). Also, oceanographic conditions strongly influence harvesting effort, and together might explain the harvesting decline in 2002 (median SWH in 2002 was >2.2 m, whereas in the other years it was <1.8 m) as well as maintaining

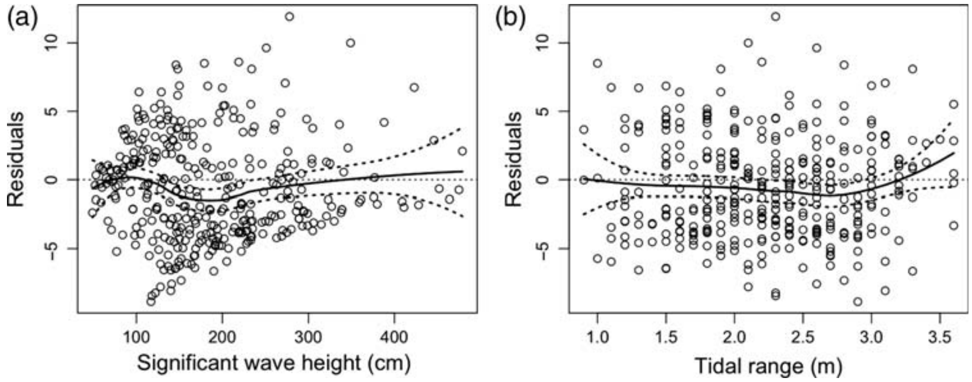

Figure 9. Standardized residuals for the optimal GLM plotted against (a) SWH and (b) TR. The LOESS smoother (span 0.65; solid line) and 95% confidence limits (dotted lines) are also shown.

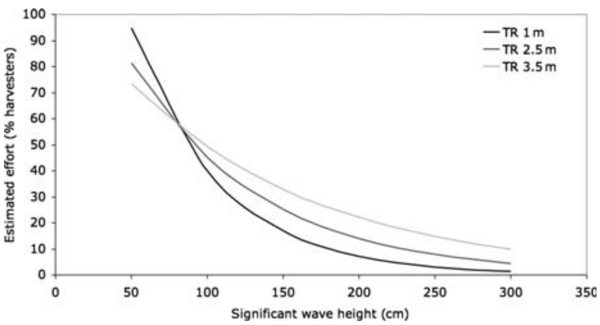

Figure 10. Estimated percentage of harvesters operating plotted against SWH, for three TR scenarios (1, 2.5, and 3.5 m).

generally low harvesting pressure on the target population (∼20% of the theoretical maximum allowed).

It seems that the system has been responding well to the harvesting pressure applied, with an average annual production of ∼16 t. When comparing the annual production of *P. pollicipes* at Berlengas Nature Reserve with the annual production in different regions of Galicia with similar length of exploitable coast (∼17 km), such a quantity falls within the range of sustainability (assuming that barnacle populations along the Galician coast are exploited sustainably). For example, between 2000 and 2004 (www.pescadegalicia.com), an average annual 15 t of *P. pollicipes* was sold by harvesters belonging to the cofradía San Cibrao (17.8 km of exploitable coast) and 41.4 t by harvesters belonging to the cofradía Aguiño (16.8 km of exploitable coast). Using statistics from the fisheries authority of Galicia for the years 1998–2001, Castro (2004) estimated an annual commercial production of 1.14 t of *P. pollicipes* per kilometre of Galician exploitable coastline. For the rocky shores of Alentejo (SW Portugal), Castro (2004) estimated an annual harvest of *P. pollicipes* of 33.4 t (fresh weight, unsorted) from 17.2 km of coast (observations made from 1994 to 1999 on commercial and recreational fishing), corresponding to 1.94 t of *P. pollicipes* per kilometre of Alentejo's exploitable coastline. The same author considered that the stock of the species was highly to fully fished on the coast of Alentejo. Therefore, we believe that neither the harvesting activity nor the resource itself is at risk of collapse if such levels of pressure are maintained in the Berlengas Nature Reserve.

Nevertheless, results are unpredictable if harvesting pressure increases, for instance if there are slight changes in what we have observed, such as changes in the harvesters and/or in oceanographic conditions. Although the harvesters are currently mainly professionals, there is great variability in both individual effort and the quantities harvested, contributing to the maintenance of low harvesting pressure. However, variability may diminish if the harvester population changes, if, for example, some harvesters that normally harvest for a few days in a year begin to harvest on more days, or are replaced by new, more active harvesters. Oceanographic conditions play a major role in maintaining sustainable levels of resource usage, and atypical (calm) oceanographic conditions might lead to an increase in effort. Also, there is still some (unquantifiable) amount of poaching at the Berlengas Nature Reserve, so because surveillance is limited, the sustainability of the activity may be compromised if poaching increases.

The proportion of licensed harvesters harvesting on a particular day depends on the oceanographic conditions. Daily harvesting was considered a function of two predictive variables (SWH and TR) and of their interaction. According to the model, most men harvest when the waves are small (<1 m wave height), but when waves are larger (>1.5 m wave height), it is more probable that harvesting takes place during days of greater TR (spring tides). Modifications of temporal closures, number of licenses, and harvest quantity regulations need to take into account physical variability, and our model may help to define strategies of regulatory measures and surveillance. The effect of oceanographic variability on harvesting effort is one of the main sources of variation in exploitation patterns at the Berlengas Nature Reserve, and its relevance might be similar in other regions where pedunculate barnacles are harvested. System dynamic models such as that proposed by Bald *et al.* (2006) may be important tools in assisting management strategies and would probably be improved if such effects are taken into account.

The management plan at the Berlengas Nature Reserve (especially its temporally restrictive measures, number of licenses, and bag limitation) and oceanographic conditions seem to be of great importance in maintaining the harvesting pressure at levels that allow the system to recover from one year to the next. Monitoring and regular evaluations of all the regulatory measures included in the management plan for barnacle harvesting in the reserve need to be integrated to improve the management strategies and maintaining sustainable use of the resource.

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