Management strategies for the fishery of the red shrimp *Aristeus antennatus* in Catalonia (NE Spain)

Giulia Gorelli[1*], Joan B. Company[1], Francesc Sardà[1]
[1]Institut de Ciències del MarPasseig Marítim de la Barceloneta, 37-49. E-08003 Barcelona

Abstract

Red shrimp (*Aristeus antennatus*) is the most important demersal resource in the Northwest Mediterranean. In Northeast Spain it is fished by bottom trawling and constitutes a large part of the income for local fishermen's associations. In Palamós, the most important harbour for this fishery in the area, a management plan regulating this fishery was established in May 2013, aiming to reduce fishing effort and protect juveniles. We investigate whether the management strategy adopted in Palamós is appropriate and how it could be improved according to the stock status and fishery characteristics. For this purpose we analyze the trends of several historical series of data including fishing effort, landings, catch per unit effort (CPUE) and size frequencies in the catches. We found that fishing effort directed to this species has increased massively starting form the second half of the last century, accompanied by a marked decline in CPUE. Overfishing of the stock has been evident since 1984. Given the results obtained in this work, we consider the management strategy recently established in Palamós will be appropriate to achieve the aim of sustainability for the red shrimp fishery.

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*Correspondence: Giulia Gorelli
Email: gorelli@icm.csic.es

Introduction

The red shrimp *Aristeus antennatus* is one of the most important target species for trawl fisheries in the western and central Mediterranean. It is a deep-sea shrimp found from depths of 100 m to 3000 m (Sardà *et al*., 2004). It is widely distributed across the whole Mediterranean although it decreases eastwards, as the abundance of another deep-sea red shrimp species, *Aristaeomorpha foliacea*, increases.

The biology and ecology of this species has been widely studied, except for the larval phase which is still largely unknown (Carbonell *et al*., 2010). *A. antennatus* displays marked sexual dimorphism, in terms of secondary sexual characters and growth characteristics. Females have a longer life span compared to males, 4/5 years against 3/4 years respectively, and can reach up to 76 mm cephalothorax length, against 54 mm for males (Sardà and Demestre, 1987, Demestre 1990) (Figure 1).

Figure 1. Red shrimp individuals: female on the left and male on the right. In this species the two sexes display marked differences in growth characteristics.

In Catalonia (NE Spain), *A. antennatus* is fished exclusively by bottom trawling at depths ranging from 300 m to 900 m. In the northern part of the region, the fishing grounds are located along the heads, margins and slopes of a system of submarine canyons, whose geomorphology influences the ecological behavior of this species. Reproduction occurs from late spring to early summer, when aggregations made up mainly of mature females form on the mid-slope at depths between 600 m and 800 m. In autumn and winter, density on the mid-slope decreases and aggregations of juveniles appear at shallower depths in the submarine canyon heads (areas of high productivity where food availability is enhanced) between 500 m and 600 m, (Sardà *et al*., 1994, Sardà *et al*., 1997, Tudela *et al*., 2003, Sardà *et al*., 2003, Sardà *et al*., 2004). These aggregations are actively targeted by the fishermen and contribute to keeping their income stable throughout the year (Sardà *et al*., 1994, Sardà *et al.*, 1997).

However, the landings of red shrimp are highly variable both within and between years. These fluctuations have been related to the ecology and tendency to form aggregations and also to the strong environmental influence of currents (Canals *et al*., 2006, Company *et al*., 2008). These currents form periodically in the area, and have been shown to play an important role in lowering the abundance of the red shrimp in the fishing grounds and enhancing recruitment in the following years. The red shrimp is a high value species at market reaching peaks of 200 €/kg during particular periods such as Christmas or summer holidays. Catches are mainly constituted of females (80-90% in weight), which dominate the population at the depth range of the fishing grounds, where they make up 70% of the population (Sardà *et al*., 2003, Sardà *et al.* 1994, Sardà *et al*., 2004). By virtue of their larger size, females are also more valuable.

The red shrimp fishery is an extremely important one for the Fishermen's Associations in the region, which rely in great part on this fishery for their income. Even though it is economically important, there is no European or national level official management established for its exploitation, not even a minimum landing size (MLS).

The city of Palamós (located 100 km north of Barcelona) is one of the main fishing ports of the Catalan coast for *A. antennatus*. Here, this resource makes up to 10% of the total landings (by weight) for the trawling fleet but constitutes 50% of total income. In the whole region the red shrimp is renowned as "Gamba de Palamós" (Palamós shrimp). In recent years, a collaboration between scientists of the Institute of Marine Sciences of Barcelona, Fishermen's Association of Palamós and the Autonomous Government of Catalonia has been established to seek the sustainable exploitation of this resource. The first important result from this collaboration was the official publication in May 2013 of a management plan at local level regulating the fishing activities in the red shrimp fishing grounds off the port of Palamós and fishing capacity of its trawling fleet. It is the first plan of its kind for the Mediterranean Sea, and includes several measures to reduce fishing effort and preserve the juvenile population. The technical measures established by the plan include: fishery closure during two months in winter when juveniles are in the fishing grounds; use of a more selective mesh size (40 mm square instead of 50 mm diamond); reduction of the number of trawlers in the fleet. The plan will have a five-year duration from the date of its publication, and was implemented by the whole fleet from the first months of 2012, more than one year before the final publication of the Management Plan by the Spanish Government (Boletín Oficial del Estado 2013).

The aim of this work was to investigate whether the management strategy adopted in Palamós is appropriate and how that could be improved according to the stock status and fishery characteristics. For this purpose we analyzed several historical series of data for the red shrimp fishery, including fishing effort, landings, CPUE and size frequencies of catches. The selectivity of the mesh size recently adopted in Palamós (40 mm square) is also analyzed and compared with the selectivity of the previously used mesh size (50mm diamond).

Fishing effort, landings, CPUE assessment and historical evolution of the fleet

Assessment and description of the evolution of fishing effort, landings and catch per unit of effort (CPUE) is fundamental for the understanding of a fishery and its correct management. The aim of this section is to quantify the fishing effort applied to the stock of red shrimp per year in a reliable manner, and then to use this series to calculate CPUE using official landings data.

Methods

To build a historical series of fishing effort, data were obtained from the Ministry of Agriculture, Livestock and Fishery records on the fishing fleets of all the ports of Catalonia from the beginning of the last century to June 2013. These data provided information on the individual vessels such as, type of vessel, period of activity, vessel size, and engine horse power (hp). Data were filtered for trawlers that mainly target red shrimp.

A historical series of fishing effort was then built by summing the engine hp values of selected trawlers per year and by port. However, the hp values are often under-reported when they exceed the 500hp limit set by law. Also, changes to engine power after vessel construction (usually increases) are not reported at all, so evolution of fishing effort is impossible to outline comprehensively. Therefore, we corrected the official values of hp per vessel by conducting personal interviews with members of the Fishermen's Associations. We refer to this corrected series as "real fishing effort". In addition, a 1% yearly increase due to improved fishing technology was applied to the series of real fishing effort starting from 1980. Historical series of CPUE were calculated as kg/hp, using the real hp values corrected per technology increase and the historical series of landings of *A. antennatus* per port. The historical series of landings were supplied by the Autonomous Government of Catalonia.

Results and discussion

Results were calculated for the ports of Palamós and Blanes, two of the main ports of Catalonia for the fishery of the *A. antennatus*. From interviews we found that, out of the 59 vessels checked for the two ports (40 for Palamós and 19 for Blanes), there were only 8 cases where the real engine power coincided with the value reported in the official list. The official data and real data series started to diverge in 1955 for Palamós and 1966 for Blanes. Also, 42.5% of vessels in this study had increased their engine power beyond the legal limit after construction, and these changes were not reported in the official dataset. Most of the increases in engine power at both ports were made between 1990 and 2000, when socio-economic conditions in the area were more favorable. In June 2013, the real value of total hp for the trawling fleet targeting red shrimp was 21600 hp in Palamós and 12270 hp in Blanes (Figure 2). Hp values based on official data were in both cases less than half, cf. 10679 hp and 5147 hp, for Palamós and Blanes respectively. In 1950, when no differences between official and real vessel power were detected in either of the two ports, the total engine power of the fleet targeting shrimp was 330 hp in Palamós and 120 in Blanes. The percentage increase in total hp from 1950 to 2013 for Palamós was of a 6445% according to real data, and of a 3618% according to official data. Considering technological improvements, the fishing capacity of Palamós has increased by 8782%. For Blanes, the percentage increase according to real data has been 10125%, while according to official data it was a 4189%. Including technological improvements, the percentage increase for this port was 13405%. Total landings of *A. antennatus* were available until 2012 starting from 1963 for Palamós and from 1983 for Blanes (Figure 3). Both ports show high inter-annual fluctuations. In Blanes, landings show a decline from 1983, while in Palamós, apart from a steep decline from 1963 to 1981, no clear trend can be detected. The historical series of CPUE (kg/hp) displays declining trend in both ports. In Palamós, the average value of CPUEs for the decade 1963-1972 was 27.9 kg/hp. In the decade 2003-2012 it had dropped to 4.1 kg/hp. In Blanes, the average value for the decade 1983-1992 was 8.3 kg/hp, and in the last decade of the series, 2003-2012, it had dropped to 3.8 kg/hp (Figure 3).

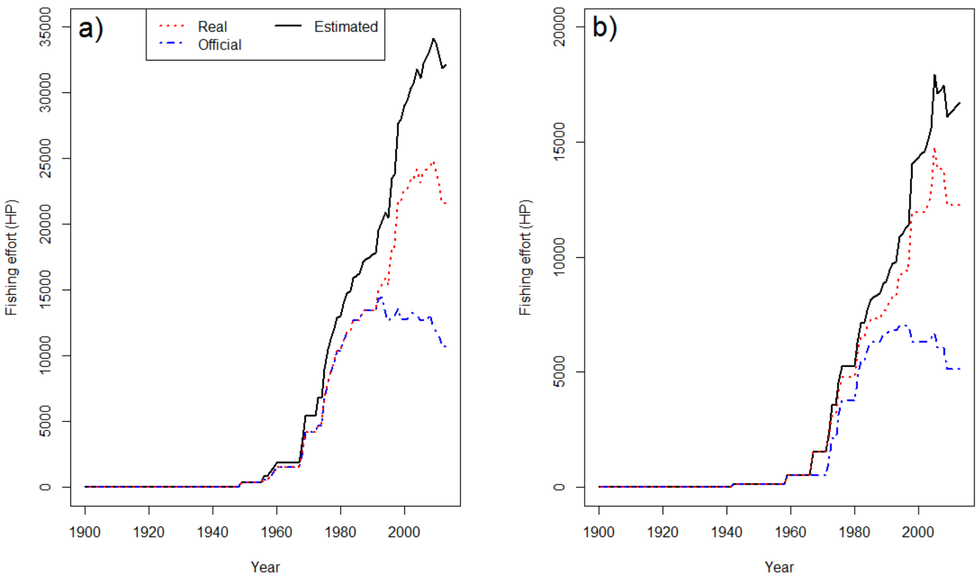


Figure 2. Historical time series of fishing effort for trawlers targeting red shrimp for the ports of a) Palamós and b) Blanes (NW Mediterranean). Official hp values were obtained from governmental sources; real from personal interviews at each Fishermen Association; Estimated real hp adding an 1% of annual increase (starting from 1980) after new technological equipment to fishing vessels, such as net sensors, bathymetry data, etc.

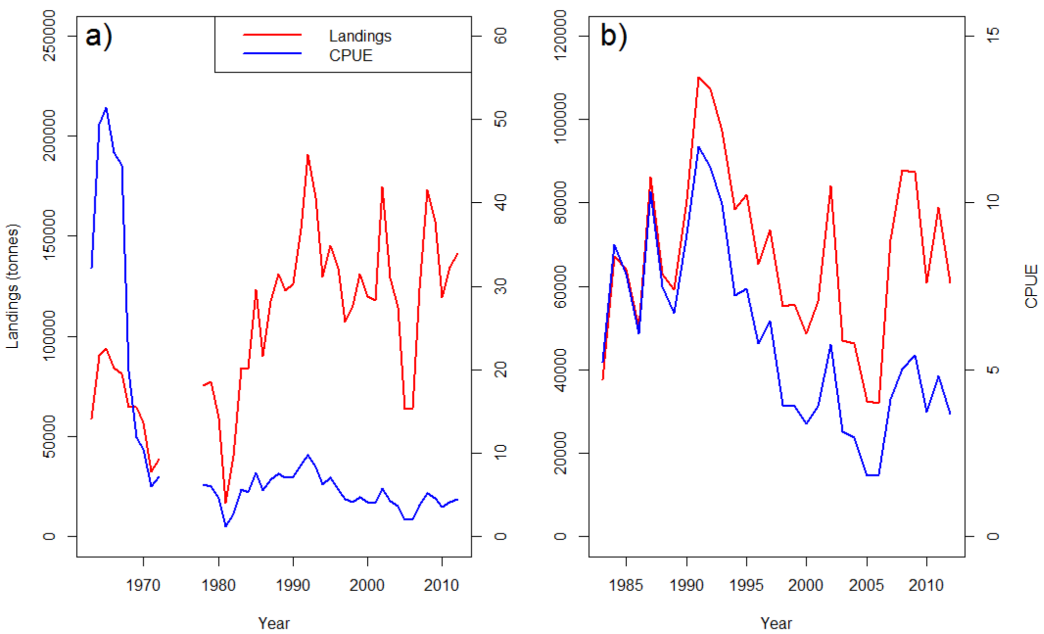


Figure 3. Historical series of landings of *A. antenntus* and CPUEs for the ports of a) Palamós and b) Blanes

Stock assessment

Stock assessment is an analytical procedure that aims to evaluate the state of an exploited stock. Usually, fishery and biological data are used to estimate population parameters, such as biomass, recruitment, fishing mortality and other reference points, through a mathematical model. Our goal here was to assess the state of this fishery in 2012 using data from a survey in Palamós, and to compare its status in recent years to that of twenty years ago using data from four other ports of Catalonia.

Methods

Data for the stock assessment were collected from sampling carried out every two / three weeks onboard a fishery trawling vessel from Palamós harbour between January 2012 and December 2013. The study area was the submarine canyon of Palamós, around which the fishing grounds for *A. antennatus* are located. Three sampling stations were chosen corresponding to three fishing grounds at different levels of the canyon: Rostoll, on the canyon head (average depth 431 m); Sant Sebastiá, on the canyon wall (average depth 498 m); and Gamba de Llevant, on the adjacent northern open slope (average depth 598 m). One trawl per fishing ground every day of sampling was performed using commercial fishing gear. For the first 5 months of 2012, a 50 mm diamond mesh codend was used. Afterwards, the gear was changed to a 40 mm square mesh, according to the newly implemented Management Plan. Sampling stations were chosen in order to capture the population fluctuations of abundance at different levels of the canyon in different times of the year due to the ecological behavior of the red shrimp. The data were collected on the cephalotorax length (from the orbital margin to the mid posterior edge of the cephalothorax), sex, sexual maturity, and total weight of catches. For the analysis, we used only data relative to 2012 as the series relating to 2013 was not yet completed. In addition, similar data collected during a previous survey carried out by the Autonomous Government of Catalonia during years 2008-2010 were evaluated. Here, data were collected onboard trawlers from three other ports of Catalonia, Blanes, Arenys and Vilanova. Another similar data series for the period 1984-1989, relative to the catches of the fishing fleets of Blanes, Arenys and Barcelona , was obtained from the literature (Demestre, 1990).

For the analysis, length frequency distributions were combined to include catches from the whole of Catalonia, and assumed to be representative of the region. The analysis of the three data series allows investigation of the status of the fishery of the red shrimp in 2012 and comparison with its status in recent years and 20 years ago. The method used for stock assessment was the pseudo-cohort analysis, followed by a yield per recruit analysis, both performed using the program VIT (Lleonart & Salat 1997). The pseudo-cohort analysis is a method especially developed for stocks in data-poor situations, when only one or a few consecutive years of data are available. The model uses age or length structured data, total catches and certain biological parameters. In return, it provides estimates of population biomass, mean age and length and fishing mortality (F). For this model to be applied, the equilibrium of the stock (constant mortality and recruitment) has to be assumed. Then, the yield per recruit analysis, based on the pseudo-cohort analysis results, calculates the yield per recruit value at the current value of F. It also provides a reference point for F which corresponds to the level of fishing mortality at which the yield per recruit would be optimized, or the optimum level of exploitation. The reference point calculated by the yield per recruit analysis is the $F_{0.1}$, which is considered a good proxy for F_{msy} (the F providing the maximum sustainable yield) (Gabriel & Mace, 1999). The biological information required for the analysis was available in literature, in particular: the Von Bertalanffy growth parameters (L_{inf}, k, t_0) in Sardà and Demestre (1987), natural mortality estimates (M) in Demestre and Martín (1993), and the estimates of the length-weight relationship parameters (a, b) in Demestre (1990) (Table 1). Given the biological differences between females and males (growth and natural mortality rates), all the analysis were performed separately for the two sexes.

Table 1. Parameters used for the Pseudo-Cohort analysis. These include the parameters of the Von Bertalanffy equation (L_{inf}, k, t_0), the parameters of the length-weigth relationship (a,b), and natural mortality (M)

	L_{inf}	k	t_0	a	b	M
Males	54	0,25	-0,5	0,004024	2,31769	0,8
Females	76	0,3	-0,07	0,00264	2,46604	0,5

Results and discussion

The mean length frequency distributions in the catches of *A. antennatus* for each period of study are shown in Figure 4. The length frequency distribution for females in 2012 looks narrower and shifted to lower size values with respect to the two other periods. In fact, the value of mean size for females was 30.7 mm in 2012, 37.6 mm in 2008-2010 and 36.5 mm in 1984-1989. For males, mean size values were 23.9 mm, 25.0 mm and 25.3 mm, for the periods 2012, 2008-2010 and 1984-1989 respectively.

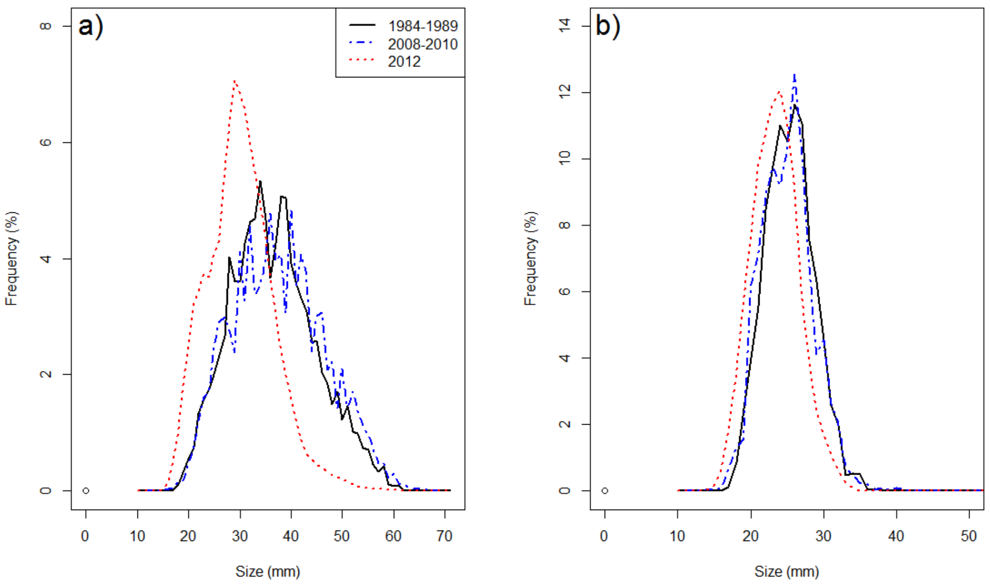


Figure 4. Average length (or size) frequency distributions in the catches for the three periods of study (1984 – 1989, 2008 – 2010 and 2012) shown for a) females and b) males.

Results of the Pseudo-cohort analysis and yield per recruit analysis are shown in Table 2. Results are reported per year, for both sexes. Mean population age and length of females in 2012 was smaller than for any other year studied. For the same year and sex, estimated mean F was greater than for any other year. Also, for females in 2012, estimates of population mean biomass was smaller than catches. Mean biomass is the value of biomass present at sea in average at each moment of the year: If catches are over this level, it means that at the end of the year, it has been fished more than the overall input from recruitment and growth to the population. The same was not true for any of the other data series, denoting a higher level of exploitation for this year.

The historical series of yield per recruit values for females shows a tendency to decrease from 1984 to present, showing the lowest value in 2012. The comparison of $F_{0.1}$ with the current value of mean F ($F_{0.1}$/Mean F) highlights a situation of overexploitation of the resource (both sexes) in all years studied, even though the level of overexploitation (the gap between mean F and the $F_{0.1}$ reference point) is bigger in 2012 than for any other year studied. The biological differences between the two sexes in *A. antennatus* lead to a difference in the degree at which they are affected by the fishery and in their overall response. In fact, the results obtained for females are not always obtained for males. However, females constitute the great majority of catches and according to General Fishery Commission for the Mediterranean guidelines evaluations for management purpose should be based on the most abundant sex in the captures.

In general, the results for 2012 are quite different from the other years studied. This is probably due to the fact that the 2012 data series, unlike all the others, was obtained sampling exclusively one port, cf. Palamós. This port has got one of the biggest fleets targeting mainly red shrimp in the region. Juveniles are specifically targeted, especially in winter, when there are aggregations of young shrimp in the canyon head. Our results suggest that the fishery of the red shrimp in Palamós has specific characteristics, and it's probably not representative of the catches from the rest of the Catalan region. In particular, our findings on the length frequency distribution of the catch and yield per recruit highlight the extent of pressure on the smallest sizes of the population, stressing the need for a specific management in order to preserve the juveniles. Increasing size at first capture is actually one of the most efficient measures to increase yield per recruit values (Sparre & Venema, 1998). The measures included in the management plan, such as mesh size regulation and a winter fishery closure, are going some way towards this, even though long terms effects such as the increase in population mean size and yield per recruit values will require a monitoring of the stock in the following years to be detected.

Table 2. Results of the pseudo-cohort and yield per recruit analysis for Catalonia shown per year and for females and males separately

	1984	1985	1986	1987	1988	1989	2008	2009	2010	2012
FEMALES ♀										
Mean pop biomass(t)	392.33	571.91	416.26	234.81	378.96	393.48	1066.91	1068.31	724.07	453.88
Tot. Catch (t)	253	315	212	217	327	265	628.86	580.85	455.72	495.94
Mean Age	1.581	1.712	1.699	1.586	1.481	1.604	1.49	1.63	1.50	1.23
Mean Length	28.727	30.394	30.04	29.267	27.608	29.079	27.13	29.13	27.53	23.92
Mean F	1.086	1.051	0.879	1.239	1.525	0.961	0.98	1.24	1.29	1.57
Y/R	9.39	9.68	8.99	10.39	9.11	9.32	8.14	9	8.57	7.53
$F_{0,1}$	0.52	0.54	0.52	0.63	0.53	0.5	0.45	0.51	0.49	0.42
$F_{0,1}$/Mean F	0.48	0.51	0.59	0.51	0.35	0.52	0.46	0.41	0.38	0.27
MALES ♂										
Mean pop biomass(t)	42.35	51.76	40.1	40.34	72.18	145.36	90.55	70.84	48.01	131.92
Tot. Catch (tons)	30	35	24	35	51	88	48.52	44.63	30.38	100.65
Mean Age	1.59	1.598	1.644	1.603	1.489	1.537	1.13	1.52	1.34	1.27
Mean Length	21.769	21.842	22.155	21.955	20.927	21.312	17.72	21.21	19.60	19.11
Mean F	1.745	1.903	1.38	1.703	1.151	1.802	0.94	1.70	1.11	1.61
Y/R	2.91	2.9	2.78	3.26	2.68	2.63	1.77	2.63	2.26	2.41
$F_{0,1}$	0.99	0.93	0.94	1.28	0.92	0.94	0.73	0.87	0.82	0.72
F0,1/Mean F	0.57	0.49	0.68	0.75	0.8	0.52	0.78	0.51	0.74	0.45

Mesh size selectivity

The regulation of the mesh size of the cod end is a useful management tool, as it usually facilitates an increase in size at first capture, thus preserving juveniles, improving yield per recruit values and reducing discards. In an effort to improve size selectivity, the management plan approved for Palamós establishes the use of a 40 mm square mesh instead of the 50 mm diamond mesh which is more commonly used in the Mediterranean. The objective of this section is to analyze the differences in the selectivity of the two different meshes used.

Methods

In order to compare the mesh size selectivity of 50 mm diamond mesh (50d), and the 40 mm square mesh (40s), we used the "covered end method" (Pope *et al*., 1975). This method employs a net cover placed over the cod end of the commercial gear to determine the amount of fish of different sizes that escape through the meshes of the cod end. The selectivity of the gear can then be determined by comparing the amount and sizes of the fish in the cod end with those of the fish in the cover.

Figure 5. Pictures of the two mesh sizes tested for selectivity: a) 50 mm diamond and b) 40 mm square mesh. c) shows the codend covered with a 3 mm mesh size net in order to determine selectivity of the gear

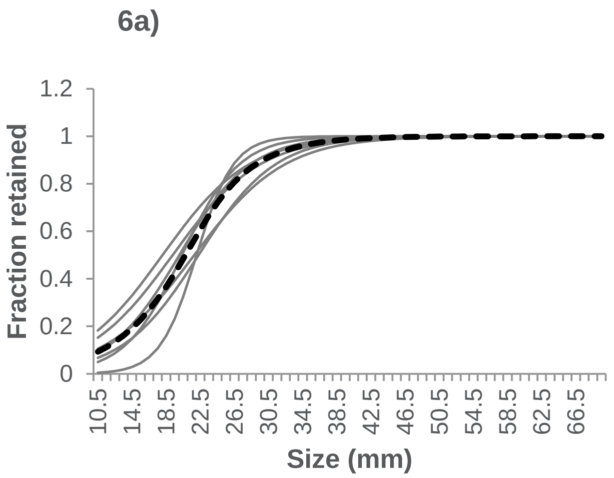
The mathematical expression used to describe the gear selection per size of individuals is a sigmoid curve, known as "gear selection ogive". The simplest mathematical expression for this curve is: $S_L=1/(1+exp(S_1-S_2*L)$, where S_L is the proportion of individuals of size L retained in the code end and S_1 and S_2 are constants (Sparre & Venema, 1998). Experimental data were collected onboard a commercial trawler of the fishing fleet of Palamós. Eleven trawls were made using the 50d during four different fishing trips, while nine trawls during three fishing trips were made using the 40s. The cephalothorax length of individuals in the cod end and in the cover was measured following the methodology in section 3. Only trawls with at least 200 individuals were kept for the analysis: 7 trawls for the 50d and 9 for the 40s were left. The logistic curve parameters were estimated fitting the experimental data and the selection ogives per each trawl were plotted. The values of L_{25}, L_{50} and L_{75}, the cephalothorax length at which respectively 25%, 50% and 75% of individuals are retained in the cod end, were then calculated per each mesh kind and compared by t-test.

Results and discussion

During the experimental trawls a total of 15421 individuals entered the 50d cod end, and a total of 22000 entered the 40s. Of those, respectively 58.2% and 53.8% were retained by the cod end. The gear selection ogives for each trawl for both meshes are shown in Figure5, where the average curves are also plotted. Average values of L_{25} and L_{50} were both bigger for the 40s than for the 50d, and the difference between values was bigger for the L_{25} estimate. Average values of L_{75} were almost coincident (Table 3). These results suggest a higher selectivity at small sizes for the 40s mesh compared to the 50d (higher values of L_{25} and L_{50}), and an equal efficiency in retaining the bigger individuals (similar L_{75}). Despite that, comparison of average values of parameters obtained for the two mesh kinds was made by means of t-test and no significant difference was found. However, the p value for L_{25} (0.079) was very close to threshold of significance, (0.05).

Table 3. Average values and standard error of L_{25}, L_{50} and L_{75} for the 50 mm diamond mesh and the 40 mm square mesh. P values for the t-test performed to compare the average values for the two meshes are shown

	50 mm diamond mesh		40 mm square mesh		
	$\overline{X}$	s.e.	$\overline{X}$	s.e.	p value
L_{25}	15.9	4.9	18.2	2.2	0.079
L_{50}	20.6	3.1	21.6	1.0	0.137
L_{75}	25.2	3.6	25.0	0.6	0.725



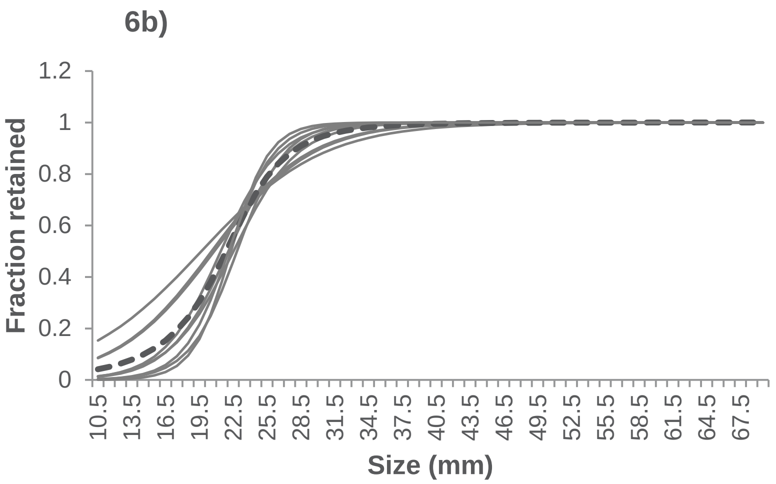


Figure 6. Selection ogives for the a) 50 mm diamond mesh and b) the 40 mm square mesh for each tow. The average curves for each mesh size are also shown

The lower variability in the estimates of parameters for the 40s (smaller standard error) suggests better selectivity for this mesh kind compared to the 50d. It has been pointed out by several authors how the diamond shaped meshes stretch and elongate under tension, as the cod end fills with fish (Robertson & Stewart, 1988). This reduces the probability of the fish of certain body sizes escaping, causing variability in gear selectivity. In contrast, square-shaped meshes remain open when towing increasing size selectivity (Reeves *et al.*, 1992; Petrakis & Kostantinos, 1997). The data show that the percentage of individuals that manage to escape through the square mesh is bigger than for the diamond mesh and this portion is made up of smaller individuals. These smaller individuals have the lowest price in the market but are important to preserve with a view to increasing the mean size of the population and catches, the yield per recruit values, and eventually the incomes for the fishery in the long term.

Conclusions

- The fishing effort for the red shrimp in Blanes and Palmós displayed a spectacular increase in the second half of the last century, increasing its value of about 80 times in average. However, fishing effort is profoundly underestimated in official data.
- CPUE for the two ports studied indicated a declining trend in recent decades, while landings remained stable.
- Overfishing of the resource in Catalonia was detected for all years assessed between 1984 and 2012. This result is consistent with the high values of fishing effort and declining CPUE detected in Blanes and Palamós over this time period.
- In Palamós in 2012 we found higher fishing pressure on the small size classes of the population compared with other years and ports studied. Here, we also detected higher fishing mortality, lower Y/R value, and a higher degree of overfishing.
- The 40 mm square mesh adopted in Palamós with the new regulation was more selective at small size classes while displaying the same efficiency in retaining larger individuals when compared to the 50 mm diamond mesh that was previously employed.
- The management strategy adopted in Palamós aiming to reduce fishing effort is appropriate given the high levels of effort, low CPUEs and persistent overfishing status of the resource detected over the last few decades. Measures adopted in order to protect juveniles are also appropriate, given the high level of fishing pressure on small size classes and low levels of Y/R detected for this port.

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