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Trawl gear selectivity and the effect of mesh size on the deep-water rose shrimp (*Parapenaeus longirostris*, Lucas, 1846) fishery off the gulf of Cádiz (SW Spain)

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Abstract

The deep-water rose shrimp (*Parapenaeus longirostris*, Lucas, 1846) is a typical shrimp which is one of the main target species in the demersal fishery in the Spanish south Atlantic region. In this paper, the selectivity parameters of this species have been studied in two different selectivity survey designs (research vessels and in commercial fishing vessels). We have found 2 mm difference between both methods in the 50% retention length (L_{50}). The selection factors obtained from the oceanographic vessels range from 0.37 to 0.49, while those from the commercial vessels are lower, from 0.32 to 0.39. The effects of mesh size changes in the present exploitation pattern are also considered. The present exploitation pattern is far from to optimal due to an overexploitation of the smaller sizes. The different simulations of changes in mesh size do not show great differences in maximum sustainable yields, but important market variations occur above 30% and 50% over the present obtained values. In reference to the immediate effects which could produce an increase of the mesh size, losses of 36%, 51% and 62% for the referred mesh sizes (50, 55 and 60) using the selectivity parameters obtained from the surveys of research vessels are estimated. If obtained from the surveys of the commercial vessels, these values correspond, respectively, to 27%, 42% and 73%.

Keywords: *Parapenaeus longirostris*; Shrimp; Selectivity; Gulf of Cadiz; SW Spain

1. Introduction

The deep-water rose shrimp (*Parapenaeus longirostris*, Lucas, 1846) is one of the three species of the genus *Parapenaeus* that inhabits the Atlantic Ocean (Pérez-Farfante and Kensley, 1997). It has a wide geographical distribution, being found in the Eastern Atlantic, from the north of Spain (Olaso, 1990) to south Angola (Crosnier et al., 1968), as well as in the Mediterranean and its adjacent seas (Karlovac, 1949; Maurin, 1960; Massuti, 1963, Audouin, 1965). This species is the target of a large fishing fleet in eastern Atlantic waters off the south of Spain and Portugal (Pestana, 1991; Sobrino et al., 1994), off Morocco, Mauritania Senegal, Guinea Bissau, Gabon and Angola (Cervantes and Goñi, 1985; Cervantes et al., 1991; Sobrino and García, 1991, 1992a, b).

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The Gulf of Cádiz is defined as the area included in the ICES Division IXa. This region is considered by the Community Fishery Policy as a zone of exception with respect to the statistical divisions of the north-eastern Atlantic, allowing the use of a minimum mesh size of 40 mm for the trawl fleet. The bathymetric range of the deep-water rose shrimp off the Gulf of Cádiz is between 40 and 650 m., but the fishery exploits this resource, from bottoms of 100 to 300 m (Sobrino, 1998), where the maximum abundance occurs.

Nowadays, a trawl fleet of 273 vessels operates off the Gulf of Cádiz. The mean characteristics of this fleet are 25 GTR, 215 HP and 13.9 m. length. This fleet shows great heterogeneity in its exploitation pattern, fishing different species depending on the vessel's characteristics, the landing port, the season of the year and the personal criteria of the fishing skipper. The catch is always landed fresh, and the most important landing ports are: El Puerto de Santa María; Isla Cristina; Sanlúcar and Huelva (Fig. 1).

The mean annual catch of this fleet is 12000 t, with the normal interannual variations. No particular species can be referred to as the principal one. Only the octopus (*Octopus vulgaris*) represents as much as 10% of the overall catch. This is indicative of the species diversity of the landings which can include over 70 different species. The deep-water rose shrimp fishery of this area has landed from 300 to 1000 t depending on the years, and is a prime target species of the fishery, due to its high economic value.

The selectivity studies and the effects of mesh size changes are considered of great importance for the management of this resource as demonstrated by different researchers (Cardador, 1993; Fernandez et al., 1986; Jones, 1974; Trujillo et al., 1993). The present paper analyses the results of selectivity experiments carried out with the fishing gear used, doing some simulations on the expected effects of some modifications on the actual exploitation pattern would have on the deep-water rose shrimp population.

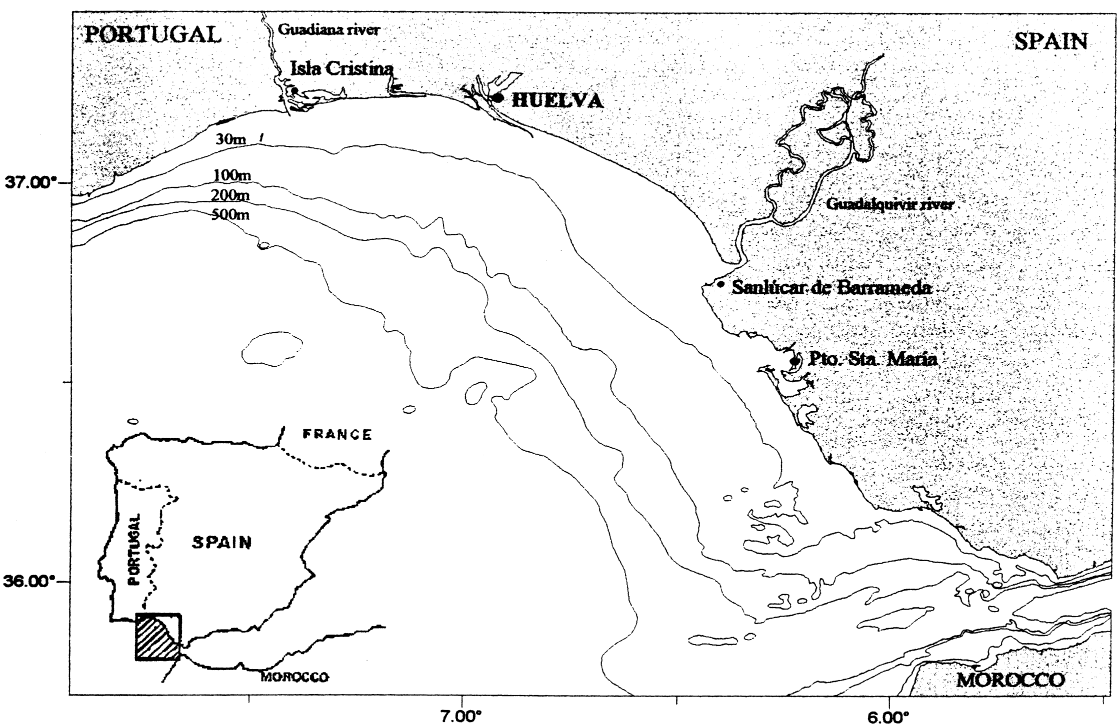

Fig. 1. Spanish south Atlantic region (Gulf of Cádiz).

2. Material and methods

The selectivity experiments were done using the covered cod-end method. Two different selectivity survey designs were applied: firstly, using different mesh sizes and a fixed trawl duration (1 h) on board of an oceanographic vessel, and secondly, carrying out the selectivity survey on board commercial fishing vessels, using the standard fishing gear of the fleet at variable trawl duration times. In all the cases, the cod-end cover was 20 mm.

The surveys carried out on research vessels were all on board the R/V Cornide de Saavedra with 66.7 m in length, has a gross tonnage of 1150 and 1650 hp main engine. These surveys were all carried out in the Gulf of Cádiz covering a wide spectrum of mesh sizes (Table 1). The mesh size measurements were done with an ICES calliper at 4 kg. measuring force. In each of the fishing stations, a separate size frequency distribution of the catch from the cod-end and the cod-end cover was obtained. Caparax length (CL) was measured, from the ocular orbit to the extreme of the cephalothorax, to the nearest inferior 0.5 mm.

To study the selectivity of the commercial gear used in the Gulf of Cádiz, a series of four surveys was carried out (SELCOM series) in two different vessels, one in each trimester of the year (4°, 1993 and 1°, 2°, and 3°, 1994) and similar nets (Table 1). In each commercial haul, with variable trawling duration, was applied the same methodology as in the research cruises.

The data from different hauls were combined prior to analysis. A logistic model was used for the estimation of the selectivity parameters, as expressed in the following function:

$$P = \frac{1}{1 + e^{-(a+b\mathrm{CL})}}, \qquad (2.1)$$

where P is the percentage of retention, CL the cephalotorax length (mm), a and b are parameters to estimate.

The fit was done following the maximum likelihood function, evaluating the statistical significance of the model by the ''WALD'' statistic (SPSS, 1997). This fit makes it possible to obtain the retention sizes to 25% (L_{25}), 50% (L_{50}) and 75% (L_{75}), as well as the selection factor values (SF), that is the relationship between L_{50} and the mesh size used, and the selection range, the difference between L_{75} and L_{25}.From the results of each mesh size, a linear relationship between mesh size and retention size, both at 50% and at 75% was obtained

$$L_{50} = a_1 + b_1 \times \mathrm{mesh}, \qquad (2.2)$$

$$L_{75} = a_2 + b_2 \times \mathrm{mesh}. \qquad (2.3)$$

With these theoretical values, we can calculate the parameters of any logistic model as a function of the mesh size to be utilised.

In order to assess the effect produced by a modification of the present exploitation pattern, the model proposed by Thompson and Bell (1934), adapted to sizes as described by Sparre and Venema (1992) was applied. We have used the mean values of years 1993–

Table 1
Mesh sizes, number of hauls, total and specific catch and number of specimens sampling in the surveys

Survey	Mean	SD	Number	No. of haul	Total catch (kr)	Specific catch		No. of specimen sampling
						(kr)	No.	
ACEDIA-88	35.9	1.8	987	13	650	3.4	1205	1205
ACEDIA-88	46.0	1.98	785	11	580	3.6	1171	1171
ARSA-1092	52.7	1.80	174	21	1964	2.8	350	350
ARSA-0393	42.8	1.80	145	36	2030	3.3	780	770
ARSA-1093	60.2	1.99	128	29	3626	7.7	2242	1497
ARSA-0394	66.3	3.49	181	30	1903	17.1	6448	1856
SELCOM1	40.3	1.4	184	5	1931	235		1270
SELCOM2	39.8	1.5	135	5	74	90		863
SELCOM3	40.5	1.8	165	7	1531	280		971
SELCOM4	40.2	1.3	145	2	315	23		635

Table 2
Growth, size-weight and natural mortality parameters (Sobrino, 1998)

	Growth parameters			Length/weight relationship		Mortality (natural) M
	K	L_∞	t_0	a	b	
Males	0.95	33 mm CL	−0.20	0.00179	2.65341	1.2
Females	0.74	44 mm CL	−0.13	0.00179	2.65341	1.2

1996 of the catch matrix by size and sex range. This data series would correspond to eight cohorts, since two cohorts are produced annually (Sobrino, 1998). As a starting point, it is assumed that the only change in the exploitation pattern of the fishery is derived from introducing into the model different selectivity parameters, and moreover, allowing the model to realise economic considerations (Sparre and Venema, 1992).

The values of the parameters derived from the growth model, from the size-weight relationship and from the natural mortality function correspond to those obtained by Sobrino (1998) in the study area. The fishing mortality value of the plus group was 1, which corresponds to an exploitation rate of 0.45. (Table 2).

The economic approximation in the model corresponds to the market variations of the Deep-water rose shrimp in relation to its size taking into account the selling prices at the fish market. This proportionality is shown in Table 3.

A multiplying factor of the fishing mortality rate was applied to realise the simulations. These factors cover from non-exploited situations ($X = 0$) to triple the actual effort levels ($X = 3$). The production was calculated in 0.2 intervals. The changes of mesh size was also estimated, increasing it to 50, 55, and 60 mm based on the resulting selectivity parameters obtained from the research surveys. The same procedure was applied for the selectivity experiences carried out with the commercial vessels. In this case, the selectivity parameters of the theoretical mesh sizes of 50, 55, and 60 mm were estimated based on the observed 2 mm difference between both methods.

The calculation for the immediate effects of the mesh size changes was made taking into account the retention ratio of the current mesh and the tested mesh for each referred size (García and Le Reste, 1986). All the calculations were done in an EXCEL worksheet applying the algorithms proposed by Jones (1982) and Sparre and Venema (1992).

Table 3
Economic value by size range

Size range	Economic value
10–15	0.1
16–18	0.2
19–21	0.3
22–24	0.6
25–28	1.0
28–31	2.0

3. Results

Table 4 and Fig. 2 presents the results of the different selectivity experiences carried out. The selection factors obtained from the oceanographic vessels range from 0.37 to 0.49, while those from the commercial vessels are reasonably lower, from 0.32 to 0.39.

The mesh size and the values L_{50} and L_{75} (Table 4) were used to fit a linear model (2.2 and 2.3) with determination coefficients (r^2) of 0.87 and 0.90, respectively. This relationship is defined by the parameters: $a_1 = -0.636$ and $b_1 = 0.442$ for the L_{50}, and $a_2 = -3.550$ and $b_2 = 0.576$ for the L_{75} relationship. These values were used to obtain the theoretical selectivity curves (Table 5), as shown in Fig. 3.

Fig. 4 represents the evolution by size range of the virgin biomass and the existing one with the present exploitation pattern (40 mm mesh size), as well as, the corresponding equilibrium states, once an increase of mesh size to 50, 55 and 60 mm was produced. In all the cases, we have considered the selectivity parameters obtained both from the research vessels (a), and the commercial vessels (b). It can be observed

Table 4
Results of selectivity curve fit (SF: selection factor; SR: selection range)

	Mesh size									
	Research vessels						Commercial vessels			
	35.9	42.8	46.0	52.7	60.2	66.3	40	40	40	40
a	−10.15	−6.86	−6.44	−5.08	−7.57	−4.72	−9.56	−5.25	−11.5	−10.51
b	0.712	0.329	0.335	0.263	0.288	0.160	0.65	0.41	0.73	0.69
L_{25}	12.71	17.52	15.94	15.15	22.45	22.74	13.02	10.13	14.25	13.64
L_{50}	14.26	20.85	19.22	19.33	26.26	29.63	14.71	12.80	15.75	15.23
L_{75}	15.80	24.19	22.50	23.51	30.07	36.51	16.40	15.48	17.26	16.82
SF	0.40	0.49	0.42	0.37	0.44	0.45	0.37	0.32	0.39	0.38
SR	3.09	6.67	6.56	8.36	7.62	13.77	3.38	5.35	3.01	3.18
n	439	529	542	341	840	1314	1324	1685	1016	315

Table 5
Parameters of the theoretical selection curves for the different mesh sizes

Mesh	L_{50}	$L_{75}-L_{25}$	L_{25}	L_{75}	a	b
25	10.4	0.9	10.0	10.9	25.84	2.48
30	12.6	2.2	11.5	13.7	12.45	0.99
35	14.8	3.6	13.0	16.6	9.13	0.62
40	17.0	4.9	14.6	19.5	7.62	0.45
45	19.2	6.3	16.1	22.4	6.76	0.35
50	21.5	7.6	17.7	25.3	6.20	0.29
55	23.7	8.9	19.2	28.1	5.82	0.25
60	25.9	10.3	20.7	31.0	5.53	0.21
65	28.1	11.6	22.3	33.9	5.31	0.19
70	30.3	13.0	23.8	36.8	5.13	0.17
75	32.5	14.3	25.4	39.7	4.99	0.15
80	34.7	15.7	26.9	42.5	4.87	0.14
85	36.9	17.0	28.4	45.4	4.77	0.13
90	39.1	18.3	30.0	48.3	4.69	0.12
95	41.3	19.7	31.5	51.2	4.62	0.11
100	43.6	21.0	33.0	54.1	4.55	0.10

how with the present exploitation pattern both curves are similar up to CL 16 mm. CL sizes between 23 and 26 provide the greatest part of the virgin biomass in the model. However, these sizes represent a rather scarce biomass in the present state of exploitation. This indicates that the present exploitation pattern is far from optimal due to an overexploitation of the smaller sizes. The results obtained from the mesh changes maintaining the present exploitation scheme show how the stock biomass progressively get closer to the virgin biomass stock.

The production curves obtained by modifying the effort level for each of the situations produced by mesh size changes is shown in Figs. 5 and 6. In the present state with reference to the mesh size, we are close to the maximum sustainable yields, with values of 830 or 717 t, according to the selectivity data considered. This is far from the maximum revenues, which would be attained only with a fishing effort reduction of 20% (Table 6). The different simulations of changes in mesh size do not show great differences with respect to maximum sustainable yields. However, important revenue variations occur above 30% and 50% over the present obtained values.

Increases of the mesh size to 50, 55 and 60 mm produce in the short-term losses of 36%, 51% and

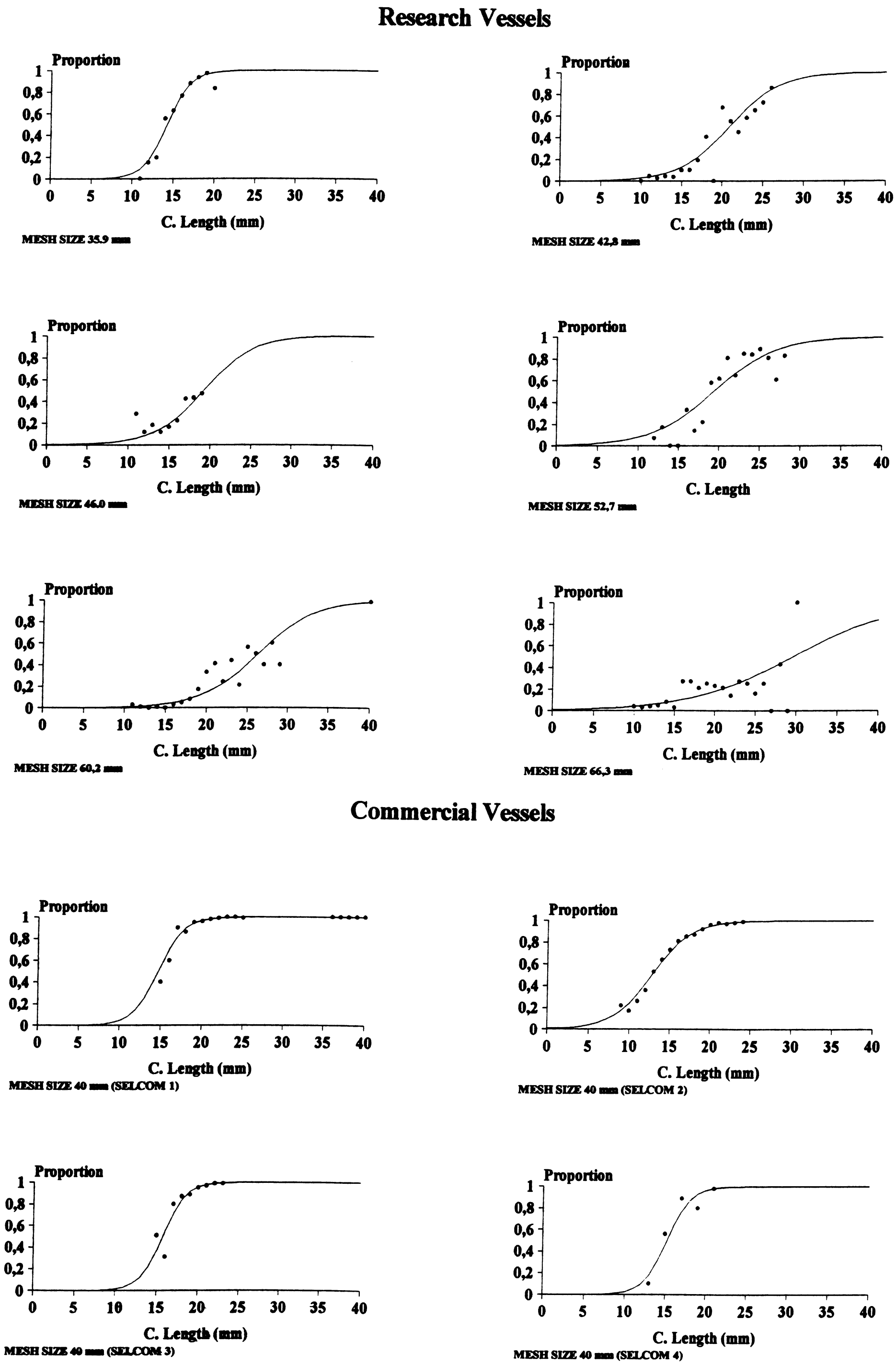

Fig. 2. Selectivity fits for the different surveys carried out.

Table 6
Results obtained from the simulations of the mesh size changes in the long-term

F-factor	Total yield				Total value			
	Mesh size	Mesh size	Mesh size	Mesh size	Mesh size	Mesh size	Mesh size	Mesh size
	40	50	55	60	40	50	55	60
Research vessels								
0.0	0	0	0	0	0	0	0	0
0.2	199	154	129	106	218	190	166	140
0.4	397	309	258	211	407	366	322	274
0.6	586	463	386	316	548	522	466	400
0.8	747	613	513	420	606	647	594	516
1.0	830	749	636	522	526	718	686	620
1.2	816	840	749	623	370	686	759	709
1.4	793	853	828	718	297	598	730	772
1.6	778	854	854	797	223	512	659	787
1.8	716	849	858	837	201	438	617	703
2.0	674	842	860	855	170	417	557	672
2.2	624	796	845	855	152	368	448	640
2.4	669	822	813	858	162	352	419	605
2.6	708	755	839	863	170	220	424	560
2.8	542	749	769	839	107	217	368	446
3.0	576	785	800	855	114	227	370	449
Commercial vessels								
0.0	0	0	0	0	0	0	0	0
0.2	181	151	130	76	195	179	162	106
0.4	359	301	260	152	359	341	312	208
0.6	526	449	389	227	475	478	446	306
0.8	660	588	514	302	507	573	556	399
1.0	717	699	629	377	412	595	627	487
1.2	694	741	718	450	279	506	626	567
1.4	681	736	745	523	225	407	543	638
1.6	633	720	742	594	174	348	479	698
1.8	615	697	735	660	153	306	382	738
2.0	585	715	721	699	141	278	360	705
2.2	560	667	727	727	136	193	347	630
2.4	593	701	689	750	142	202	283	625
2.6	613	675	645	757	141	194	188	614
2.8	530	680	670	751	112	194	195	590
3.0	530	667	676	760	104	189	196	577

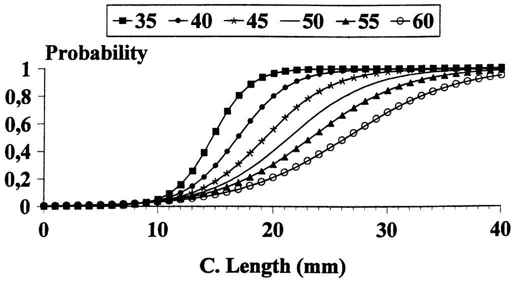

Fig. 3. Theoretical selectivity curves.

62%, respectively. In case of using the parameter from the survey of commercial vessels, these losses correspond to 27%, 42% and 73%, respectively.

4. Discussion

Control of the exploited sizes constitutes one of the most important tools for the adequate management of the fishing resources, especially when dealing with

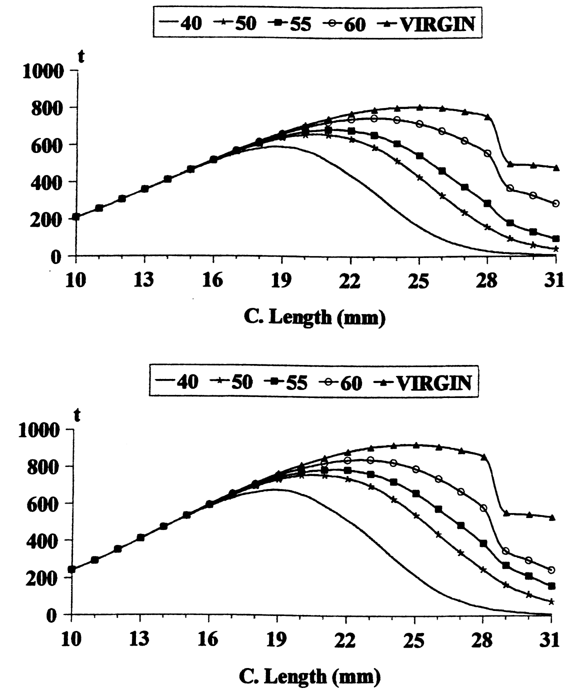

Fig. 4. Evolution of the biomass by size range for the different exploitation schemes: (a) research vessels; and (b) commercial vessels.

fast growing species in which the surviving individuals compensate through their growth for the losses produced by natural mortality (García and Le Reste, 1986), but its application is being discussed in the penaeid fishery. In this way, Lindner in García and Le Reste, 1986, questions its application emphasising on the need to increase considerably the mesh to vary the selectivity on these species, which consequently, would lead to considerable unacceptable losses. This opinion is shared by Lhome (1977) who experimented with mesh sizes from 20, 25, 30, 35, 40 and 50 only obtained differences in the selectivity curves starting from the 40 mm mesh.

In our case, we have found a progressive increase of the L_{50} in respect to the mesh size ($p < 0.05$), finding differences between the selectivity curves in the different mesh sizes. The results are in agreement with those found by other authors (García and Le Reste, 1986), although contrary to the results of Grande and Arias (1991).

Another reasons to doubt methods is that the selective process is not efficient for these species, due to the presence of rostrum and appendices (Gulland, 1972). However, in our case, we have found significant fits, despite the various experiences carried out. These results are similar to other researchers, such as Pestana and Ribeiro-Cascalho (1991) who estimated in Portuguese waters, a selection factor of 0.45 with the mesh of 55 mm, while in Moroccan waters, Goñi (1985), (1986) obtained the selection factors of 0.51 and 0.42 for mesh sizes of 39.2 and 59.7, respectively.

In reference to the selectivity experiment carried out on board the commercial vessels, three of the results show great similarity, with a value for the L_{50} of approximately 15 mm. Small differences were observed in the second survey in which L_{50} was 12.9 mm, but it had a greater selection range. This difference can be due to a greater abundance of particular size classes during the season in which the survey was undertaken. When comparing the different L_{50} obtained from the commercial vessels' surveys with the theoretical selectivity curves of the equivalent mesh, only a small difference was observed (around 2 mm). The sizes of the first catch obtained through experimental trawling were lower, due to a greater saturation of the gear as a consequence of a longer trawl duration. We should take into account that the degree of saturation which directly depends on the abundance of the accessible biomass to the gear and to the increase of trawl duration, provokes an increase of the captured biomass.

The results suggests that important economic benefits can be obtained by increasing the actual mesh size. However, there are other elements that should be taken into account. As previously noted, the trawl fishery in the Gulf of Cádiz is composed of numerous small vessels that jointly exploit a great number of species. The landings of deep-water rose shrimp represent between 8% and 5% of the total over the years, and its importance mainly relies on its economic value. On the other hand, there are no evaluations on the rest of the exploited joint resources, which would suggest that the present effort should not be increased. Therefore, even if a mesh of 60 would produce greater economic benefits from 50% to 79%, it would be at the cost of a greater fishing effort. Thus, its applicability should be analysed in a more

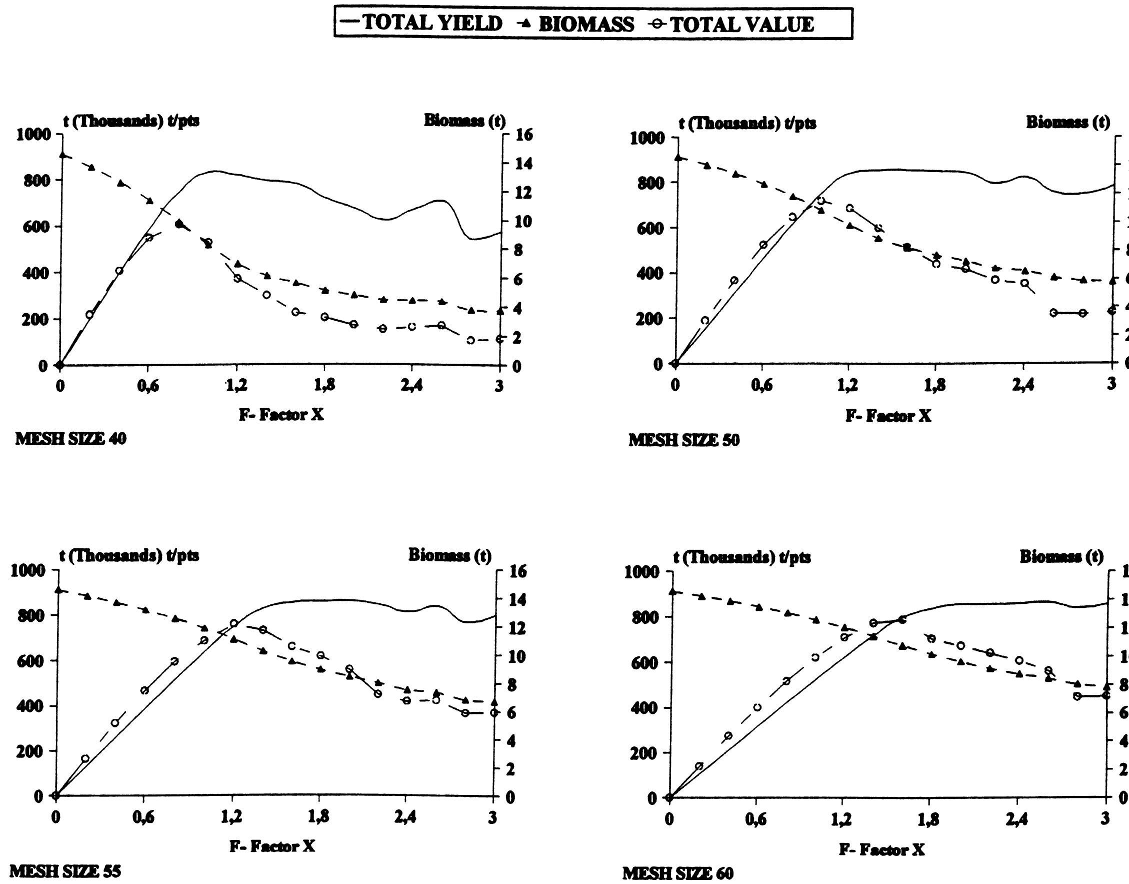

Fig. 5. Production curves using the selectivity values obtained in the research vessels.

general context. However, with increases of mesh size to 50 or 55 mm and maintaining the present effort levels, the economic benefits could increase from 30% to 50%.

Although the increase of mesh size could cause immediate losses as mentioned earlier, these results should be considered cautiously with the penaeid fishery because it is composed of fast-growing and short-living species (García and Le Reste, 1986). The immediate losses would be compensated during the first year, since it would take the species only five months to grow from 17 mm (L_{50} with the 40 mm mesh) to 23.7 mm (L_{50} with the 55 mm mesh).

As shown in Fig. 4, the mean biomass by size range suffers an important change with the mesh increase, specially in the sizes between 20 and 28 mm. Taking into account that the size at first maturity of females in this area reaches 22.2 mm CL (Sobrino and García, 1998), there would be an important stock biomass increase. Depending on the mesh used (50 or 55 mm), this increase could represent between 200% and 250%. However, at the present exploitation levels, there does not seem to be a relationship between spawning biomass stock and recruitment. Recruitment may be influenced more by variable oceanographic conditions than by stock size (Sobrino, 1998).

The model applied assumes a direct relationship between survival and the probability of escaping from the net. This relationship cannot be assumed as such, because there is no information for this species on the mortality suffered by the specimens that have escaped the net. However, research carried out by Harris et al.

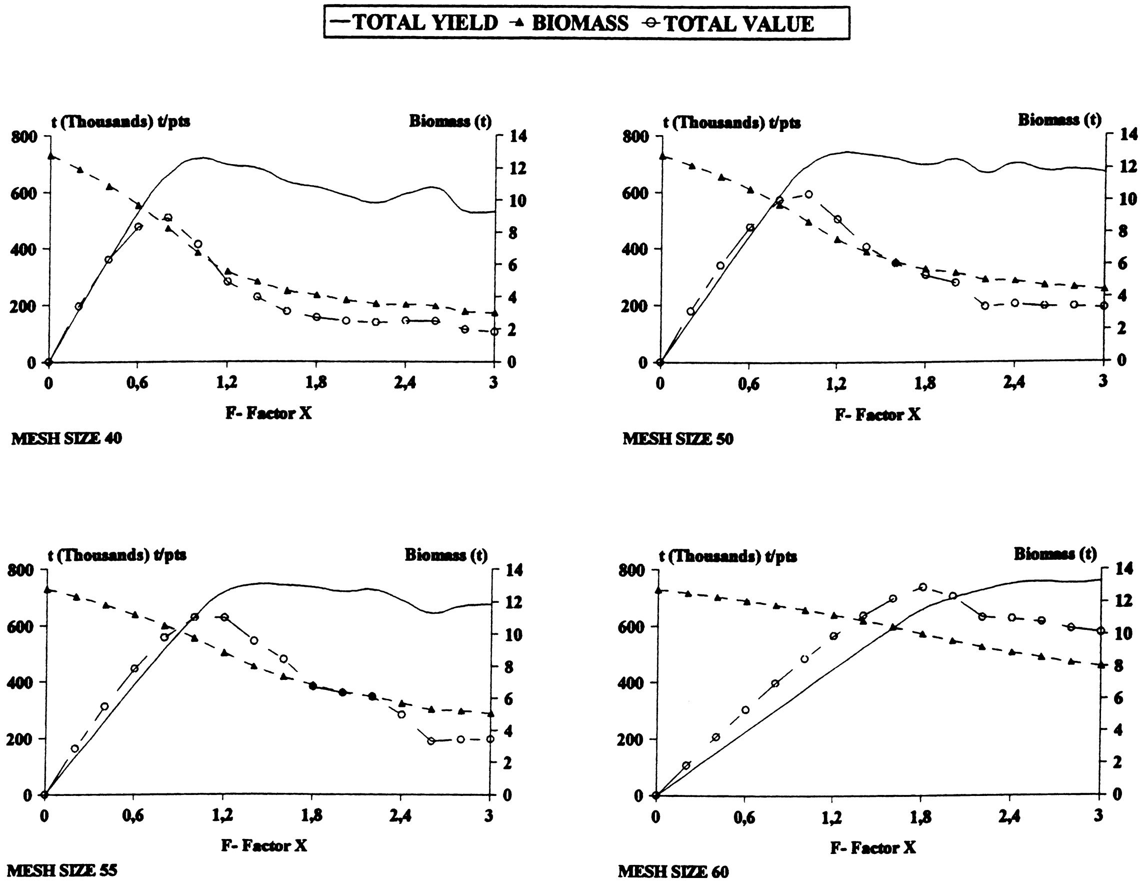

Fig. 6. Production curves using the selectivity values obtained in the commercial fishing vessels.

(1998) on another decapod crustacean (*Nephrops novergicus*) indicates a high survival rate in the escaped individuals.

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