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Comparison of the catches of European hake (*Merluccius merluccius*, L. 1758) taken with experimental gillnets of different mesh sizes in the northern Tyrrhenian Sea (western Mediterranean)

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SUMMARY: The impact of the gillnet fishery on *Merluccius merluccius* (European hake) was investigated in the northern Tyrrhenian Sea, western Mediterranean. Four mesh sizes were tested: 53, 62.5, 70 and 82 mm. Horse mackerel (*Trachurus trachurus*), hake and tub gurnard (*Chelidonichthys lucerna*) dominated the catches, from a minimum of 89% (82 mm mesh) to a maximum of 97.8% (70 mm) of the biomass caught. Efficiency of the four meshes was not significantly different with respect to the total hake catches. Selectivity on *M. merluccius* was assessed by Sechin and SELECT methods. Tangling was an important catch modality for hake, as evidenced by the results of the Sechin model which described only the first mode of the size distributions corresponding to the entangled specimens. SELECT showed that the bi-modal function gave the best adjustment to the length-frequency distributions; the modal catch sizes were 33, 39.2, 43.6 and 51 cm total length respectively for the 53, 62.5, 70 and 82 mm mesh sizes. Taking into account the size of first maturity for females (35.1 cm TL), 62.5 mm is the most adequate mesh for exploiting hake as it gives some protection to both immature specimens and large females.

Keywords: European hake, gillnet, selectivity, Sechin method, SELECT method, western Mediterranean, artisanal fishery.

RESUMEN: Comparación de las capturas de merluza (*Merluccius merluccius*, L. 1758) obtenidas con redes experimentales de enmalle de diferentes tipos de malla, en el norte del mar Tirreno (Mediterráneo noroccidental). – Se estudió el impacto de la pesquería con redes de enmalle sobre la merluza, *Merluccius merluccius,* (merluza europea) en el norte del mar Tirreno, Mediterráneo noroccidental. Se utilizaron cuatro tamaños de malla: 53, 62.5, 70 y 82 mm. Los peces *Trachurus trachurus*, *M. merluccius* y *Chelidonichthys lucerna* dominaron la biomasa capturada, con un mínimo del 89% (malla de 82 mm) y un máximo del 97.8% (malla de 70 mm). La eficiencia de las cuatro mallas no resultó estadísticamente diferente. La selectividad sobre *M. merluccius* fue estudiada con los métodos Sechin y SELECT. El enredamiento resultó una importante manera de captura, como evidenció el método Sechin, con un buen ajuste sólo para la primera moda de las distribuciones de talla, correspondiente a ejemplares capturados por enmalle. Con el modelo SELECT la función bimodal fue la mejor para describir las estructuras de talla; las tallas modales de captura fueron 33, 39.2, 43.6 y 51 cm de longitud total, para las mallas de 53, 62.5, 70 y 82 mm respectivamente. Teniendo en cuenta la talla de primera madurez, la malla de 62.5 mm es probablemente la más adecuada para la explotación de la merluza, permitiendo una cierta protección tanto de los inmaduros como de las hembras grandes.

Palabras clave: merluza, redes de enmalle, selectividad, método Sechin, método SELECT, Mediterráneo noroccidental, pesca artesanal.

INTRODUCTION

European hake, *Merluccius merluccius* (Linnaeus, 1758), is one of the most valuable resources of the Mediterranean fishery. According to the data series provided by FAO, a total of 21000 tonnes of hake was landed in this area in 2002 (FAO, 2005). This species is the twelfth most abundant in overall landings (1.6% of the total Mediterranean landing) and the most abundant when only the demersal species are considered (Lleonart and Maynou, 2003).

M. merluccius is exploited by trawl, long-line and gill net fleets (Aldebert *et al.*, 1993; Martín *et al.* 1999), even though in many areas most of the landings come from bottom trawl. This type of gear exploits mainly small specimens (Martín *et al.*, 1999), as the large individuals are not as vulnerable. However, the use of a wide opening trawl in many areas allows more specimens with a total length (TL) of up to 25-30 cm to be caught (Martín *et al.*, 1999). The presence in the trawl landings of bigger specimens is rather infrequent or restricted to certain periods of the year (Sartor *et al.*, 2003).

Artisanal fishery is a very important sector for the Mediterranean fisheries. According to recent studies (Cannas, 2001) in 1999 in Italy this fleet accounted for about 10000 vessels. For the majority of these vessels, hake represents a by-catch mostly caught during winter, when some specimens draw near to the coast. However, in some areas there are well developed artisanal fisheries targeting this species. Information available for the north-western Mediterranean coast shows that this activity is carried out during specific periods of the year with different gears, depending on the geographic location. More accurate information for this type of fishery is available for the north-eastern Spanish coasts (Catalonia), where hake exploitation is carried out mostly between May and September by long-liners and gillnetters (Martín *et al.*, 1999; Sartor *et al.*, 2001), for the Gulf of Lyons where the activity is carried out by French gillnetters and Spanish long-liners (Aldebert *et al.*, 1993) and for the Tyrrhenian Sea (the Western coast of Italy) where the artisanal vessels exploit this species exclusively with gillnets, mostly in the winter-spring season (Sartor *et al.*, 1996, 2001; Colloca *et al.*, 2000).

In the ports where there is artisanal hake fishery, this activity accounts for a non-negligible percentage of the total landings of the species. As a consequence of the high selectivity of gillnets, the size distributions of the catches obtained with these gears show a narrower range, mainly constituted by specimens larger than 22-25 cm total length (TL), with respect to the size distributions of the bottom trawl (Martín *et al.*, 1999; Sartor *et al.*, 2001).

Since the artisanal hake fishery is carried out in fishing grounds which are characterised by high concentrations of adults and often during the species reproductive period, it is very important to evaluate the impact of this fishery on this resource and to provide the basic information for adequate management measures.

For this purpose, a research project funded by the European Union was carried out in the northern Tyrrhenian Sea (western Mediterranean) in the period 1998-1999 (Biagi and Santos, 2000). In this area, which belongs to the FAO Geographic Sub-Area 9 (GSA9; GFCM, 2001) and also includes the Ligurian Sea and the Central Tyrrhenian Sea, there is a large artisanal hake fishery using gillnets.

The focus of the present study was to collect information on catch composition and selectivity of experimental gillnets with different mesh sizes. Although in the past there have been some publications which dealt with gillnet activity and hake catches in the Mediterranean, there is very little information about the impact of different mesh sizes on the hake catch. The main objective of this paper was to analyse the results of the selectivity experiments carried out in the framework of the aforementioned research project.

MATERIAL AND METHODS

The study was carried out in the northern Tyrrhenian Sea (Fig. 1), where hake is exploited by the gillnetters based in the ports of Marina di Campo (Elba Island, 15 vessels), Porto Santo Stefano (5 vessels) (Sartor *et al.*, 2001) and Piombino (5 vessels) (Sartor *et al.*, 1996). Other important artisanal fleets fishing for hake in the FAO Geographical Sub-Area 9 can be found in Ponza Island (11 vessels) and in Terracina (20 vessels), in the central Tyrrhenian Sea (Colloca *et al.*, 2000). Although some vessels can fish for hake all year round, this kind of fishery should be considered as seasonal in all ports, with maximum activity taking place during the winter-spring period.

Information about the construction characteristics and the materials for making commercial gillnets used in the northern Tyrrhenian Sea was col-

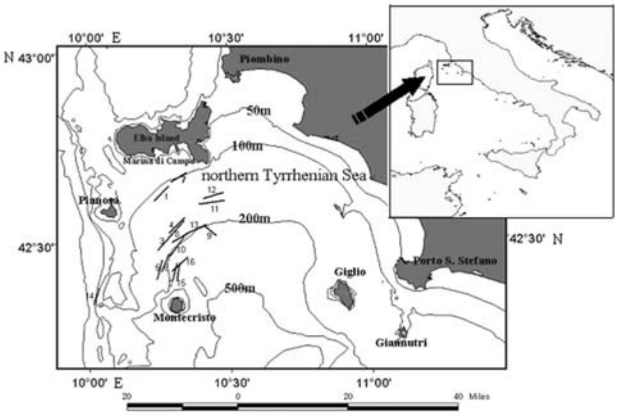

FIG. 1. – *Merluccius merluccius*, northern Tyrrhenian Sea. Study area and location of the experimental hauls.

lected both through direct observations and information from fishermen. Based on this information, monofilament gillnets with four different mesh sizes were constructed; 53 mm, (that are currently used by the fleet of marina di Campo), 62.5 mm, 70 mm and 82 mm stretched mesh size. The three larger meshes were used in the experiment in order to evaluate the reduction in the impact on the immature population of hake. The specifications of each type of net are reported in Table 1. Sheets of the four different meshes (53, 62.5, 70 and 82 mm) were assembled alternately, in order to give them the same catch probability. For each mesh size 13 sheets, each 100 m long and 4 m wide, were used to obtain an overall net of 5200 m long (13x100x4) for the experimental trials; the net had a hanging ratio of 0.5, calculated as the length of the float rope (or lead rope) divided by the stretched net length.

The selectivity trials (16 hauls) were carried out during the period February-April 1999 over muddy bottoms ranging between 95 and 256 m in depth (Fig. 1). A gillnetter from the Marina di Campo fleet was hired. The fishing regime adopted was the one usually performed by the commercial fleet; gillnets were lowered into the sea one to two hours before sunrise, generally parallel to the bathymetric line, in order to allow bottom trawlers to operate in the same fishing grounds and avoid damaging the gear. The soaking time was about 5 hours.

The catches, sorted according to mesh size, were classified to the species level; the total weight was registered for each species; and for hake the total number of specimens. All the catch data were standardised to 1000 m net length.

Analysis of variance (ANOVA) was applied in order to evaluate differences in weight between yields obtained with the four different mesh sizes, taking into account both the total catch and the hake catch. ANOVA was also applied to hake abundance data.

Each *M. merluccius* individual caught was measured (total length, TL) to the nearest 0.5 cm below and weighed (to 0.1 g). A representative sample of specimens (914 and 558 respectively) was measured for maximum body girth (Gmax) and head girth (Gh).

Length-frequency distributions were computed for the hake catch obtained with each mesh size and compared using the Kolmogorov-Smirnov test (Siegel and Castellan, 1988). The sex in a representative sample (528 specimens) of hake was determined and sex ratio (SR), expressed as number of males (M) compared to number of females (F), was computed for each mesh size. The Chi-square test was applied to evaluate differences from the theoretical sex ratio value of 1:1 in the catch obtained from each mesh size.

Selectivity of *M. merluccius* was estimated by applying the indirect Sechin method (Reis and Pawson, 1992) and the direct SELECT method (Millar and Holst, 1997).

Sechin (1969) and Kawamura (1972) derived theoretical selectivity curves from the assumptions that: a) fully selected fish are those with a maximum girth greater but head girth smaller than the mesh perimeter;

TABLE 1. – *Merluccius merluccius,* northern Tyrrhenian Sea. Characteristics of the gillnets used in this study. Data refer to a sheet 100 m long.

Mesh size (mm)	53.0	62.5	70.0	82.0
Float rope length (m)	100	100	100	100
Lead rope length (m)	100	100	100	100
Number of bolshes	378	356	358	349
Bolsh size for the float rope (m)	0.265	0.281	0.28	0.287
Bolsh rope ø for the float rope	210/27	210/27	210/27	210/27
Bolsh rope ø for the lead rope	210/27	210/27	210/27	210/27
Number of meshes per bolsh	10	9	8	7
Number of meshes in height per panel	75	64	58	49
Number of meshes in length per panel	3774	3200	2858	2440
Net line ø	0.3 mm	0.3 mm	0.3 mm	0.3 mm
Hanging ratio (float rope, lead rope)	50%	50%	50%	50%

and b) girths among any one length class of fish are distributed normally, with a common variance, σ^2, for all length classes. This method allows selectivity to be predicted from hake maximum girth and head girth measurements, provided that gilling or wedging are the main means of capture and the analysis is independent of size distribution data for gillnet catches. In this study the Sechin model, as modified by Reis and Pawson (1992), was adopted:

$$S_j = \phi \left(\frac{2M - Gh_j}{\theta h} \right) \left[1 - \phi \left(\frac{2M - G\max_j}{\theta \max} \right) \right]$$

where Sj is the selectivity in the j[th] length class, $\Phi(x)$ is the cumulative standardised normal distribution function for variable x, Gh_j the mean head girth in the j^{th} length class, θh the mean standard deviation of the head girth, $Gmax_j$ the mean maximum girth in the j^{th} length class, θmax the mean standard deviation of the maximum girth and 2M the mesh perimeter. S_j ranges between 0 and 1: it is 0 when the j^{th} length class is not caught and 1 when its catch probability is 100%. Gh_j and $Gmax_j$ were estimated by linear regression. As this simplified model does not include the correction coefficients for body compressibility at the retention point and for elasticity of the netting material, the selection curve parameters were multiplied by a correction factor in order to fit the catch data better (Fabi *et al*., 2002). A rather high correction factor (1.22) was applied to each mesh size; this indicates that hake

TABLE 2. – *Merluccius merluccius*, northern Tyrrhenian Sea. List of the species caught during the experimental trials, sorted according to biomass rank

	Mesh size							
	53.0		62.5		70.0		82.0	
Species	kg	%	kg	%	kg	%	kg	%
Trachurus trachurus	314.5	72.5	346.6	69.6	295.4	62.2	102.6	36.1
Merluccius merluccius	85.2	19.6	118.5	23.8	132.5	27.9	124.2	43.7
Chelidonychtys lucerna	10.3	2.4	13.9	2.8	22.2	4.7	25.2	9.8
Lepidopus caudatus	4.1	0.9	4.9	1.0	10.6	2.2	6.4	2.2
Sarda sarda	3.0	0.7	5.8	1.2	6.1	1.3	6.8	2.4
Micromesistius poutassou	2.2	0.5	1.9	0.4	2.4	0.5	3.9	1.4
Xiphias gladius							10.0	3.5
Trachurus picturatus	3.5	0.8	2.6	0.5	2.0	0.4		
Scomber scombrus	4.0	0.9	0.7	0.1	1.1	0.2	1.2	0.4
Scomber japonicus	1.0	0.2	1.0	0.2	1.3	0.3		
Mullus surmuletus	1.5	0.4	0.6	0.1				
Zeus faber	0.8	0.2			<0.1	<0.1	0.9	0.3
Lophius piscatorius							1.2	0.4
Nephrops norvegicus					0.4	0.1	0.6	0.2
Trisopterus minutus capelanus	0.6	0.1	0.1	<0.1	0.1	<0.1	0.1	<0.1
Illex coindetii	0.5	0.1	0.1	<0.1	0.1	<0.1		
Ancistroteuthis lichtensteini					0.5	0.1	0.2	0.1
Lophius budegassa							0.6	0.2
Raja miraletus	0.5	0.1						
Eledone cirrhosa			0.4	0.1			0.1	<0.1
Eledone moschata	0.5	0.1						
Trigla lyra			0.3	0.1				
Todaropsis eblanae			0.3	0.1				
Octopus salutii	0.3	0.1						
Phycis blennoides			0.3	0.1				
Scyliorhinus canicula	0.3	0.1						
Phycis blennoides	0.2	0.1						
Pagellus erythrinus					0.2	<0.1		
Parapenaeus longirostris	0.1	<0.1	0.1	<0.1	<0.1	<0.1		
Citharus linguatula	<0.1		0.2	<0.1	<0.1	<0.1		
Aspitrigla obscura	0.2	<0.1			<0.1	<0.1		
Octopus vulgaris		¡	0.2	<0.1				
Scorpaena elongata							0.1	<0.1
Trigla lyra							0.1	<0.1
Spicara flexuosa	0.1	<0.1						
Boops boops					0.1	<0.1		
Eutrigla gurnardus gurnardus			0.1	<0.1				
Aspitrigla cuculus			<0.1	<0.1			<0.1	<0.1
Lepidorhombus boscii							<0.1	<0.1
Argentina sphyraena					<0.1	<0.1		
Lepidotrigla dieuzeidei					<0.1	<0.1		
Total	433.5	100.0	498.3	100.0	475.0	100.0	284.2	100.0
Number of species	23		22		21		19	

compresses its body and/or stretches the mesh while swimming through the net.

According to Millar and Holst (1997), the SELECT method is a general statistical model that is appropriate for estimating gillnet selection curves (i.e. retention probabilities) from comparative gillnet catch data. In this method the expected catch proportions are fitted to the observed catch proportions using the maximum likelihood, under the assumption that the catches are Poisson random variables (Millar, 1994). In the SELECT method, fitting expected proportions correspond to sharing the total catch of each length class amongst the gears deployed (Millar, 1994). This method utilises the known properties of maximum likelihood. In particular it uses likelihood ratio tests for model selection, and obtains an approximate covariance matrix for the estimated parameters from the second derivate matrix of the log-likelihood. The different models available in SELECT (unimodal curves: Normal Scale, Normal Location, Gamma and Log linear and bi-modal curves) were applied in this study. The best fitting model was considered to be the one that showed the lowest deviance value (Millar and Fryer, 1999).

RESULTS

A total of 41 species (32 fishes, 7 cephalopods and 2 crustaceans) were collected during the experimental trials (Table 2). A slight decrease in the number of species was observed going from smaller (23 species) to larger (19 species) mesh size. Although the total number of species was rather high, the majority of them only appeared occasionally in the catch. In terms of frequency of occurrence and biomass, the three most important species, hake, horse mackerel (*Trachurus trachurus*) and tub gurnard (*Chelidonichthys lucerna*), represented about 90% of the biomass caught with each mesh size. Horse mackerel was by far the most significant species in biomass for all mesh sizes, with the exception of the largest one, where hake was the largest contributor, accounting for 43.7% of the total biomass.

The mean yields of the total catch and the hake catch were characterised by high variability, as shown by the consistent standard deviation values associated with the means (Fig. 2). Although a trend could be identified, the statistical comparisons (one-way ANOVA) did not show significant differences between the four mesh sizes, neither for the yields in terms of biomass for total catch (p = 0.1179) nor for abundance (p = 0.1977) or biomass (p = 0.4707) for hake.

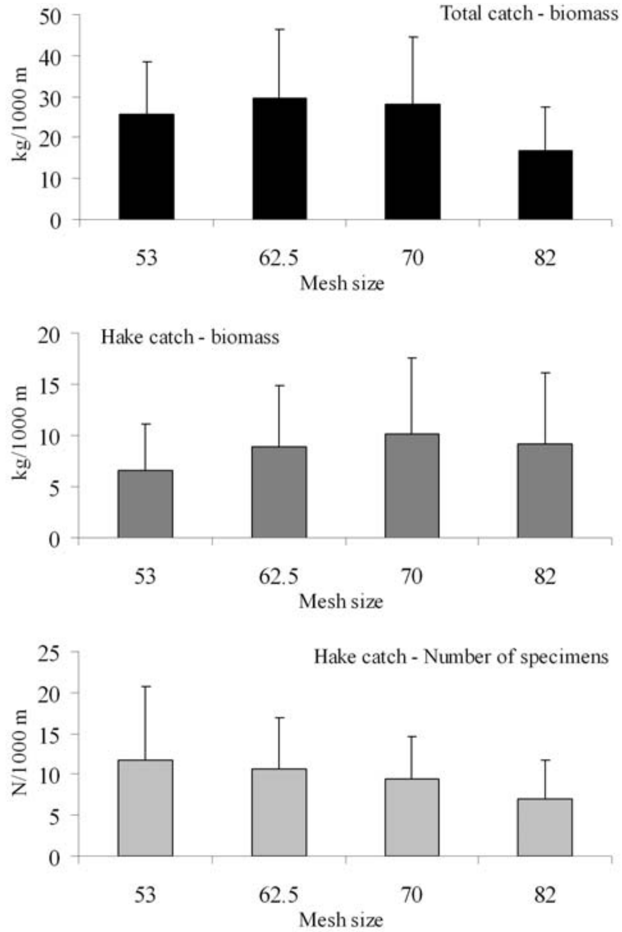

FIG. 2. – *Merluccius merluccius*, northern Tyrrhenian Sea. Mean yields (standardised to 1000 m of net) and standard deviation of the total catches in biomass (above) and of the *M. merluccius* catches, in biomass (middle) and in number of specimens (below).

During the 16 selectivity trials, 807 specimens of hake were caught. Table 3 shows the sex ratio values of *M. merluccius*, calculated according to the different mesh sizes. The chi-square test showed that sex ratio was not different from 1:1 for the 53 mm mesh, while females significantly outnumbered males in the catches of the other three larger mesh sizes.

The size composition of hake caught (Table 4) was characterised by a gradual increase in the mean length (from 39.1 cm TL to 54.8 cm TL) going from the smallest mesh size (53.0 mm) to the largest one (82.0 mm). Wide size ranges were observed and they were largely overlapped for all the employed meshes. Of the total number of hake specimens collected, only one was under the minimum landing size (20 cm TL, EC Reg. No. 1626/94). The mean size according to sex shows a

TABLE 3. – *Merluccius merluccius*, northern Tyrrhenian Sea. Sex ratio (SR) of the catches obtained for each mesh size and significance of the proportion 1:1 at the level of probability p<0.05.

Mesh size (mm)	No. of males	No. of females	SR	Chi-square	P<0.05
53.0	79	83	0.952	0.10	Not significant
62.5	43	98	0.439	21.45	Significant
70.0	21	111	0.189	61.36	Significant
82.0	8	85	0.094	63.75	Significant

general increase from the smallest to the biggest mesh, both for females and males.

In relation to the species reproductive state, taking into account the size at first maturity estimated in the studied area (Belcari *et al.*, unpublished data), no immature males were caught during the experimental trials, while a high percentage of females under this size was observed in the catches from the 53 mm mesh (Table 4).

The length-frequency distributions were bi-modal in the case of the 53, 62.5 and 70 mm mesh sizes and uni-modal for the 82 mm mesh (Fig. 3). The comparison using the Kolmogorov-Smirnov test of the four length-frequency distributions always showed high significant differences (p<0.01).

The selectivity curves estimated with the Sechin model are shown in Figure 3. The relationships between girth and length data for hake applied in the model were found to be G_{max} = -1.9956+0.5067TL and G_h = -0.4407+0.3850TL with correlation coefficients (r^2) equal to 0.93 and 0.92 respectively. The optimal catch sizes estimated by this method were 31, 38, 42 and 52 cm TL respectively for the 53, 62.5, 70 and 82 mm mesh sizes. The selection curves were suitable for describing the first mode of the length-frequency

TABLE 4. – *Merluccius merluccius*, northern Tyrrhenian Sea. Summary of data on the size composition of the catches obtained with the four mesh sizes;* according to the length at first maturity equal to 32.5 cm TL (Belcari *et al.*, unpublished data);** according to the length at first maturity equal to 19 cm TL (Belcari *et al.*, unpublished data).

	Mesh size			
	53.0	62.5	70.0	82.0
Total catch				
Mean size	39.12	45.83	50.61	54.80
Stand. dev.	11.99	11.92	11.22	10.49
Size range	20.0-75.0	24.0-91.0	18.0-81.0	20.0-77.5
No. of specimens	244	222	196	145
Females				
Mean size	44.96	50.11	51.89	56.84
Stand. dev.	12.12	13.12	10.10	8.94
Size range	28.5-75.0	31.5-91.0	32.5-75.0	32.0-77.5
No. of specimens	83	98	111	85
% of immatures *	32.5	9.2	2.7	2.4
Males				
Mean size	31.86	36.02	35.87	40.25
Stand. dev.	10.75	10.55	7.75	10.58
Size range	21.0-51.0	24.0-48.5	24.0-56.5	24.0-54.5
No. of specimens	78	42	19	6
% of immatures **	0.0	0.0	0.0	0.0

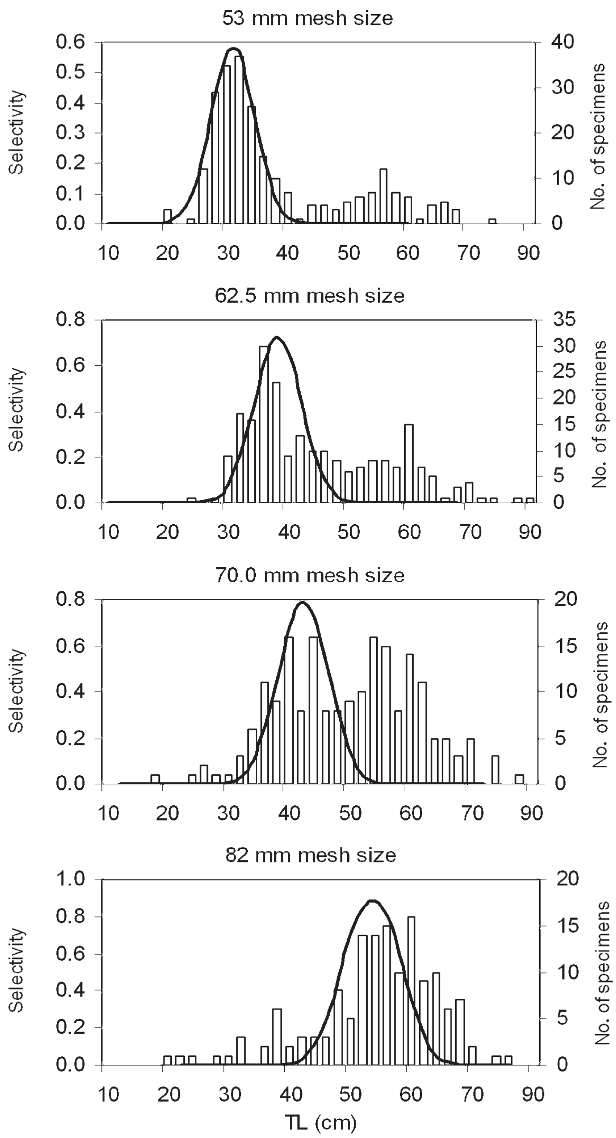

FIG. 3. – *Merluccius merluccius*, northern Tyrrhenian Sea. Length-frequency distributions of the specimens caught (white bars) and selection curves (black lines) estimated using the Sechin method.

TABLE 5. – *Merluccius merluccius*, northern Tyrrhenian Sea. Results of the SELECT method analysis expressed as deviance obtained from the five functions applied to the experimental data.

SELECT models	Deviance values
Normal scale	250.92
Normal location	208.51
Gamma	203.35
Log normal	190.76
Bi-modal	119.46

TABLE 6. – *Merluccius merluccius*, northern Tyrrhenian Sea. SELECT method. Results of applying the bi-modal function to the experimental data. Cmp: common modal point (modal length/mesh size).

Parameters	Estimate	t-Value	p-Value
X_1	0.6228	85.5441	0.0074
X_2	0.0738	12.1360	0.0523
X_3	0.9267	33.6427	0.0189
X_4	0.2286	15.1043	0.0421
X_5	0.6097	6.0056	0.1050
Deviance	df	p-Value	
119.46	88	0.0144	
Mesh size	Modal Length	Spread	Cmp
53.0	33.006	3.9093	6.2275
62.5	38.922	4.6101	6.2275
70.0	43.592	5.1633	6.2274
82.0	51.065	6.0484	6.2274

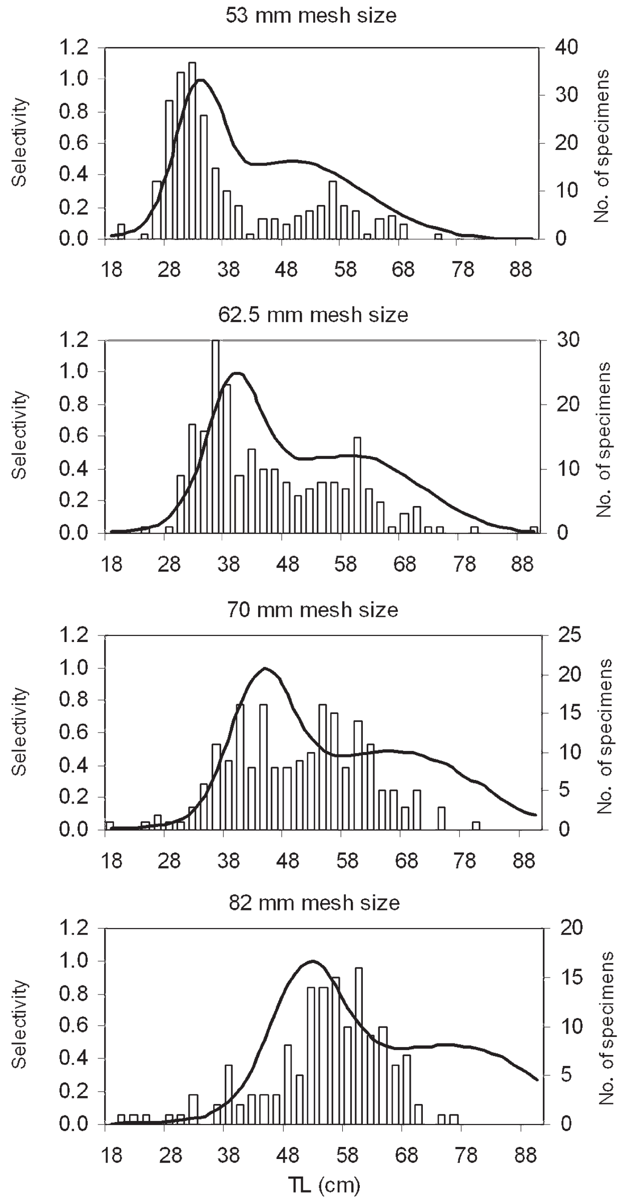

FIG. 4. – *Merluccius merluccius*, northern Tyrrhenian Sea. Length-frequency distributions of specimens caught (white bars) and bi-modal selection curves (black lines) estimated using the SELECT method.

distributions of the catches obtained with the 53, 62.5 and 70 mm mesh sizes and the uni-modal size distribution obtained with the 82 mm mesh. The partial correspondence between the Sechin selection curves and the length-frequency distributions of the catches is a consequence of the tangle effect, which was highly significant, particularly for the 53, 62.5 and 70 mm meshes (Fig. 3). As a high percentage of tangled individuals fell out on the right side of the selection curves (33%, 37%, 49% and 23% for the 53, 62.5, 70 and 82 mm mesh sizes respectively) this method of capture was especially important for the largest specimens. However, in the 70 and 82 mm meshes the tangle effect was also observed for smaller hake. In particular, the percentages of the specimens situated on the left side of the selection curves were 4% and 12% for the 70 and 82 mm mesh sizes respectively.

The SELECT model showed that the bi-modal function gave the best adjustment to the experimental data, with a deviance value of 119.46 (Table 5). The obtained parameters are reported in Table 6. The estimated selection curves for the 53 and 62.5 mesh sizes fitted well with the experimental data (Fig. 4), and were characterised by a first shape mode on smaller sizes and by a spread second mode on the right side, corresponding to larger specimens. For the 70 and 82 mm meshes, a lower concordance between the curves and the length-frequency distributions was obtained, in particular for the larger sizes.

DISCUSSION

The present study was focused on comparing the catches obtained with gillnets of different mesh sizes.

The four gillnets showed high inter-specific selectivity. In spite of the species richness in the catches, only three species (horse mackerel, hake and tub gurnard) accounted for the majority of the biomass and the specimens caught. A very different picture is shown by bottom trawling on the same bottoms, where catches are characterised by a considerably higher species diversity but lower dominance (Biagi *et al.*, 2002).

The efficiency of the four mesh sizes did not show significant differences with respect to biomass, abundance catch rates or the total hake catch. This was mainly due to the high variability of the catch rates. However, this should be considered as a common feature of set net catchability based on the fact that it is highly influenced by several sometimes unpredictable factors, such as meteo-marine conditions, current strength and direction, behaviour of the prey, etc. The similar values of the yields obtained with the four mesh sizes could also be due to the wide and highly overlapping size ranges of the three most abundant species, horse mackerel, hake and tub gurnard.

With respect to the intra-specific selectivity, gillnets are generally considered to be a highly selective gear in relation to the sizes of the specimens caught. This was only partially true in the case of *M. merluccius* in the northern Tyrrhenian Sea. Although the mean size of the catches of this species increased notably with mesh size, a very wide selection range was observed in all cases. The differences in selectivity were evident only because of the appearance of a second mode due to large sizes. The first mode mostly comprised specimens caught by gilling or wedging, as demonstrated by the high overlap with the Sechin selection curves. The second mode was due to specimens caught by entanglement, being this demographic portion outside the estimated Sechin's curve. During the experimental trials it was observed that the largest specimens (too large to be caught by gilling) frequently interacted with the net in a different way compared to the smaller specimens. Initially they would come in contact with the net with their muzzles, becoming hooked up by their sharp teeth, and then they would roll around inside the net and thus became more entangled.

Few catches were detected on the left side of the first mode and out of the Sechin curve; the smaller specimens, which could go through the meshes, were rarely entangled. The experimental trials were carried out on bottoms where large amounts of small hake are concentrated all year round (Belcari *et al*, 2001); in spite of this, small individuals (<20 cm TL) were absent in the catches.

For a species like *M. merluccius*, for which a significant part of the catch is due to entanglement, compound curves describe selectivity best. In fact, the bi-modal function, estimated by applying the SELECT method, gave the best adjustment to the length-frequency distributions both for the enmeshed and the entangled specimens.

The gillnet hake selectivity explained by a bi-modal curve is confirmed by other studies carried out in the Gulf of Lyons (Sacchi, 2001) and along the Portuguese coasts (Santos *et al.*, 2003; Fonseca *et al.*, 2005).

Sacchi (2001) tested five different mesh sizes; the results obtained for the mesh size in common with the present study (70 mm) were quite similar to our results. The common modal point (size of the modal class/mesh size) was 6.25 in the Gulf of Lyons and 6.23 in the northern Tyrrhenian Sea (present study), while the length modal classes were 43.8 and 43.6 cm TL for the Gulf of Lyons and the northern Tyrrhenian Sea respectively.

In the studies carried out in Portugal, four different meshes were used and in this case the mesh in common with the present study was also 70 mm. The modal lengths reported for this mesh size by Santos *et al.* (2003) and Fonseca *et al.* (2005) were 40.1 and 40.3 respectively, which were slightly lower than those obtained in the present study, probably because entangled fish were not taken into account in the analyses.

For the 70 and 82 mm meshes experimented in the present study, the overlap between the curves estimated with the SELECT method and the length-frequency distributions of the catches was lower with respect to that obtained for the two smaller meshes. This aspect is evident when the right side of the selectivity curves obtained for the different meshes is analysed. The limited presence of large sized specimens of *M. merluccius,* i.e. larger than 70 cm TL, produced histograms with a low definition of the second mode for the 70 and 82 meshes, which explains the poor fit of the theoretical selectivity curves. It is noted, however, that large specimens of *M. merluccius*, although scarce in the whole population, are more abundant on deeper bottoms than those in the investigated area (Sbrana, 1995).

From a management point of view, the results of this study have several implications for the exploitation of hake.

In the northern Tyrrhenian Sea the gillnet fishery is important in terms of the exploitation of hake; according to Sartor *et al.* (2001), in 1999 about 70 t of *M. merluccius* were landed by the gillnetters of Marina di Campo and Porto Santo Stefano.

However, in this area *M. merluccius* is mostly exploited by otter trawling; a gear that produces high fishing mortality for immature specimens. Studies carried out in the area highlight growth over-fishing for this resource (Reale *et al*., 1995; Martín *et al*., 1999).

Even though the gillnet landings represent less than 20% of the total hake landings in the two ports, about 90% of these landings are composed of adult specimens larger than 25 cm TL (Sartor *et al*., 2001). The impact of gillnets on the reproductive portion of the population is confirmed by the results of the present study, in which no specimens under the minimum landing size (20 cm TL) were observed during the experimental trials.

M. merluccius is characterised by notable differences in growth between the two sexes. Growth and reproduction studies carried out in the area estimated a theoretical maximum length (L_∞) of 55 cm TL for males and 93 cm TL for females (Biagi *et al*., 1994) and a size at first maturity of 19 cm TL for males and 35.1 cm TL for females (Belcari *et al*., unpublished data). According to these values, 100% of males caught in this study were larger than the size at first maturity and there was only a significant percentage (32.5%) of females under this size with the 53 mm mesh size. The catches obtained with this mesh were characterised by a sex ratio of 1:1, whilst an increase in the mesh size produced an evident shift of sex ratio in favour of females. However, using 70 and 82 mm mesh sizes might result in a higher fishing pressure on the larger sized females.

According to the studies carried out in the northern Tyrrhenian Sea (Lleonart, 2001), the relationship between fecundity and size was described by a multiplicative function showing an exponential increase in fecundity according to fish length increase. Recent studies also demonstrate that for some species the eggs from older females produce larvae that grow faster and are more resistant to starvation (Berkeley *et al*., 2004). Observations of cod and haddock also show that larger females produce larger eggs that presumably produce better larvae (Hislop, 1984). According to Palombi (2004), large females are notably more productive than the small ones. When fisheries cause a decrease in the most productive females, then the whole population suffers. Therefore, using mesh sizes which are too large, associated with a high fishing effort, may produce a significant reduction in the reproductive potential of the population and should be avoided.

These considerations suggest that gillnets with a mesh size of 62.5 mm or one slightly larger are probably the optimal ones in order to obtain the best compromise between high attainable yields and reasonable probability of avoiding a significant decrease in the spawning stock.

Landing and effort data collected in the framework of the research project within which the present study was carried out (Biagi and Santos, 2000; Sartor et *al*., 2001), evidenced a great effort produced by the local gillnets, both in terms of fishing capacity and fishing activity.

From a management point of view, in addition to the measures in force or planned to reduce the trawling effort or the mortality of juveniles (spatio-temporal closures, technical measures, etc.), it is also important to form management advice for the gillnet fishery. An increase in the mesh size currently used by the commercial fleet and some regulations on fishing capacity and fishing effort (length of the net, fishing days per year, closure areas or seasons) could be envisaged for the fleets targeting hake with gillnets. Regulations concerning spatio-temporal closures could be appropriate where there is significant reproductive aggregation in some periods of the year. It is noted that the activity peak of the gillnetters targeting hake in GSA9 is observed during the first months of the year, which corresponds to the main reproductive peak of the species (Biagi *et al*., 1995; Lleonart, 2001).

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