Gillnet selectivity in the Ebro delta coastal lagoons

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Abstract

A possible situation of overfishing is detected in three Ebro delta coastal lagoons (North-East of Spain) were artisanal fisheries are carried out almost without control. A vulnerable species inhabiting these brackish waters: the sand smelt, *Atherina boyeri*, is particularly affected, as non minimum size for its fishing has been established yet, thus remaining under an uncontrolled exploitation situation. Multimesh nylon gillnets were set in the lagoons to determine mesh selectivity for the inhabiting fish community. Each gillnet consisted on a series of twelve panels composed by twelve random meshes (5.0, 6.25, 8.0, 10.0, 12.5, 15.5, 19.5, 24.0, 29.0, 35.0, 43.0 and 55.0 mm bar length). SELECT method (Share Each Length's Catch Total) code developed by Millar was used to estimate retention curves under the assumption of five models: Normal location, Normal scale, Gamma, Log-Normal and Inverse Gaussian. Each model was fitted twice, under the assumptions of equal and proportional to mesh size fishing effort. No differences were found between approaches. As expected, larger fish were captured in bigger meshes. The importance of regulate minimum size meshes in order to respect natural maturation length in the coastal lagoons fish community will be discussed. Some measures for a better management of the sand smelt's fisheries are proposed as the abolishment of fyke nets and 5.0 mm mesh size gillnets and the establishment of a minimum landing size for the species.

Keywords: Gillnet, fyke net, mesh selectivity, *Atherina boyeri*, SELECT method, coastal lagoons.

Introduction

Fishing activities reduced the abundance of targeted stocks; there are numerous examples worldwide of depletion through overfishing. Even where stock abundances remain high, effects of size-selective fishing threaten future resiliency and sustainability by markedly reducing average age, size at age and genetic diversity. Classic examples of population collapse where fishing may have played a role, include the sardine stocks of California and Japan in the late 1940's and the anchovy in Peru and Chile in 1972 (Botsford and Castilla, 1997). The temporary or seasonal closure of a fishery is a management tool often used to reduce fishing effort and to limit harvest (Watson, 1993). Other authors showed its preferences for reducing the fishing pressure to a more sustainable level (Frid and Hammer, 2003). Another solution to an overfishing situation, is the regulation on fish minimum size of capture, thus allowing fish to spawn at least once before being caught (Jennings, 1998; Stergiou and Moutopoulos, 2009 ; Stewart, 2008). The Government regulation RD 560/1995 from 7th April lately modified into RD 1615/2005 on 30th December (available at the website : http://www.boe.es/aeboe/consultas/bases_datos/doc.php?coleccion=iberlex&id=2006/00756) establishes the minimum catch sizes for the Mediterranean fishing ground.

Since intensive artisanal fishery is carried out almost without control in the Ebro delta lagoons, an overfishing situation can be expected in a near future. It has been certified (Silvano and Ramires, 2009) that even small-scale artisanal fishing may exert considerable pressure on exploited fish. Moreover, a study reported that the exposure of a population to an overfishing situation has resulted to a change in the direction and magnitude of size selection in just one decade (Sinclair, 2002). Knowledge of the species composition and the way that fishing gears are capturing it in the lagoons is further needed and it is essential to understand the processes that are affecting ecological functions to develop conservation programs (Rueda and Defeo, 2003).

Gillnets are fishing gears widely used as a research tool for monitoring the length distribution of the catches (Hamley, 1975). Due to their high size-selectivity, gillnets have been object of several studies aimed to improve the fisheries management for one or more target species while focusing in adapting or changing mesh size regulations (Dos Santos and Gaspar, 2003; Fonseca and Martins, 2005; Machelis, 1994; Sbrana and Belcari, 2007). Some authors stress the importance on the way that fish are captured by gillnets (Carol and Garcia-Berthou, 2007; Reis and Pawson, 1999; Stergiou and Karpouzi, 2003) meanwhile others compare the efficiency of different fishing tools. The Share Each Length's Catch Total, known as SELECT method implemented by Millar (Millar, 1992; Millar, 1997) it has been widely used in estimation of gillnet selectivity studies (Carol and Garcia-Berthou, 2007; Harada and Tokai, 2007; Revill and Cotter, 2007).

One of the most fished species in the lagoons is the sand smelt, *Atherina boyeri*; a euryhaline teleost fish recently appreciated as a commercial species (Andreu-Soler, 2006; Kottelat, 2007). Catalogued as a vulnerable species (Doadrio, 2001), the knowledge of the size-selectivity of its commercial fishing is crucial for the management of its fishery as well as for purposes of maximizing yield and protecting juvenile fish (Millar and Holst, 1997).

The principal aims of the paper are (i) the study of gillnet selectivity in three Ebro delta coastal lagoons (ii) the establishment for the first time of a Minimum Landing Size for the sand smelt in order to develop conservation and management guidelines.

Material and methods

Study area

IMPORTANT: salinity must be reported using the Pratical Salinity Scale. In the pratcical salinity scale salinity is defined as a pure ratio and has no dimesnsions or units.

Gillnet selectivity experiments were carried out during 2008 in three coastal lagoons in the Ebro River Delta. The Ebro River is the highest flow river on the Iberian Peninsula, with a length of 980 km ends in the Mediterranean Sea on a 320 km^2 delta.

Encanyissada with 1192 ha surface area is the largest lagoon in the delta, its salinity ranges between 3-30 and its mean depth is about 50 cm. Clot lagoon, although it belongs to the Encanyissada lagoon is separated by a floodgate (Fig. 1) that determines differences in the hydrology and ecology between basins. Tancada lagoon has 312 ha surface, 37 cm mean depth and salinity ranges fluctuating between 8-36. Both Encanyissada and Tancada lagoons drain into Alfacs bay (Fig.1).

Field work

A total of 24 multimesh nylon gillnets of 30 x 1.5 m in length and height respectively, were set on the lagoons. Each gillnet consist on a series of twelve panels (2.5 meters width) composed by twelve random meshes ranging from 5 to 55 mm bar length (see Table 1 for specific mesh sizes). Hanging ratio of the panel nets oscillated among 0.493 and 0.5 depending on the mesh size. Nets were set on late afternoon and hauled the next morning, hence being an average soak time of 12 hours. Twenty-four fyke nets 2 meters long with a hoop diameter of 80 cm were set and hauled at the same time and sampling points as gillnets. At the laboratory, all fish were identified to species level and weighted to the nearest 0.1g. Fork length (hereafter FL) was measured to the nearest millimetre.

Length measurements were considered instead of girths ones due to the fact that (i) there are at least three different ways to measure girth (Stergiou and Karpouzi, 2003) (ii) it was easier, faster and cheaper to measure length than girth (iii) length has been used in most selectivity previous studies (Dincer and Bahar, 2008; Gonzalez and Mendoza, 2008) demonstrating to be as closely related to mesh size as girth (Reis and Pawson, 1999). Fishes that could not be associated with one particular mesh size were excluded from the analysis. The present reported study does not include an analysis of the way the different fish were caught in the mesh.

Data analysis-Estimation of gillnet selectivity

Estimation of gillnet selectivity was done by the SELECT method (Share Each Length's Catch Total) through R (2.8.1 version) code developed by Russell Millar and available at: http://www.stat.auckland.ac.nz/~millar/selectware/R. We complemented R code available, by adding the inverse Gaussian model. Some studies (Erzini and Gonçalves, 2003; Holt, 1963; Hovgård, 1996) noticed the bi-normal model as the best fit when fishes are caught by a combination of different processes (i.e. gilled, entangled, wedged or snagged). We did not consider appropriate its estimation as just gilled fishes were contemplated.

The SELECT method is a generalized linear model that assumes a Poisson distribution of the catches and uses log-likelihood function to optimise the fit between a specified model and the observed catches (Millar, 2000). The selection curve is defined to be the relative probability of a fish of a determinate length to be captured when contacting to a mesh of a determinate size (Millar, 2000).

In the principle of geometric similarity, Baranov's (Baranov, 1948) interpreted gillnet capture as a mechanic process that depends only on the relative geometry of the mesh and the fish, concluding that the selectivity curves for different mesh sizes must be similar (Hamley, 1975). Except normal location, that assumes fixed spread (Millar and Fryer, 1999), all the models fitted are under this assumption, with both length and spread of the curves increasing proportionally with mesh size.

All five models (normal location, normal scale, gamma, log-normal and inverse Gaussian) are unimodal and consist of two parameters describing the location and dispersion of the curves. The normal location and normal scale models are based on the normal distribution, whereas the other three are skewed curves with positive asymmetry (Carol and Garcia-Berthou, 2007).

Each selection curve was fitted twice, first under the assumption of equal effort and the again assuming fishing power to be proportional to mesh size.

The goodness of fit was made by referring model deviance to a chi-square distribution with d.f. degrees of freedom (Madsen and Holst, 1999), thus P<0.05 values indicated lack of fit.

Total length was used to estimate the minimum landing size (hereafter MLS) for the sand smelt using Sostoa's data from 1983 (unpublished data). The relationship between total fish length of sand smelt and its probability to be mature was estimated with a logistic regression model. Crosstabs were done to analyse the proportion of mature individuals among meshes. Several ANOVA's analyses were done to examine the differences between both gillnets estimation approaches (equal and proportional fishing power), the dependence of the model deviance on the fish species, differences between the best model and the rest, and possible interaction between models.

Pearson's coefficient analyses were done to check both lineal relations between the deviance and captures, and between the deviance and number of meshes in which one species was captured. Tukey Post-Hoc tests were done to analyse any similarities among the models. All statistical analyses were performed using SPSS 17.0 software.

Results

1. Fitting selectivity curves

During the full survey (24 nets), a total of 3298 fishes belonging to 20 different fish species were gillnet captured (Table 1). *Anguilla anguilla* (*N* = 1), *Barbus graellsii* (3) , *Sygnathus abaster* (1), *Sparus aurata* (6), *Silurus glanis* (2) and *Solea senegalensis* (1) were low represented, so they were not considered in gillnet selectivity methods. Furthermore, both *Pomatoschistus microps* (28) and *Engraulis encrasicholus* (12) were only captured in one (5.0 mm) and two (6.25 and 8.0 mm) mesh sizes respectively, being deleted for further analysis. Therefore, the 12 fish species considered in gillnet fish estimation analysis were captured at least in four different meshes and in enough number of individuals (Table 1). As expected, the mean length of captured fish increased with mesh size, see figure 2 for length-frequency distribution of the 12 fish species. Nevertheless, although fish not clearly gillnet captured were excluded prior to analysis, for instance wedged or entangled fishes, there were a few fish in mesh sizes larger than expected (e.g. one 199 mm *Mugil cephalus* in the 15.5 mm mesh) or in smaller meshes than expected (e.g. one 316 mm *Liza ramada* in the 8 mm mesh or several *L. saliens*). Although all panels caught a wide range of size classes and, as expected, the mean length of catches augmented with mesh size, it was also quite apparent the increased size variability of catches with increasing meshes (i.e. geometric similarity) particularly in fish species with huge number of captures such as the sand smelt, *Liza* sp. or the topmouth gudgeon (Fig. 2). A contrasting capture pattern was found in accordance with the observed fish species length range. Whereas the sand smelt, thinlip grey mullet, topmouth gudgeon, and bleak were mainly captured by the smaller mesh sizes; the both common carp and the goldfish were principally captured by larger mesh sizes. The rest of fish species, due to its length range, were captured in a wider number of meshes (Table 1).

Model parameters estimated by the SELECT method for all models and fish species are shown in Table 2. Overall, all fish species did not show a common pattern, since selected method varied with fish species. Therefore, assuming equal fishing power for all meshes, normal scale (proportional spread) was the best model showing the lowest deviance value (indicating a better fit) for flathead grey mullet, bleak, common carp and topmouth gudgeon (Fig. 3). For thicklip mullet, golden grey mullet, goldfish and sea bass (but only on the third decimal place), the best fit was the inverse Gaussian model (Fig. 3). Gamma gave the best fit for sand smelt and thinlip grey mullet. For leaping mullet the best fit was the lognormal model; and for pikeperch was the normal location (fixed spread model) but only on the third decimal place (Table 2; Fig. 3). For all fish species the normal location model was the worst fit (in 9 species) or the normal spread model (in 3 species) (Table2). Similar results referred to model selection were obtained assuming fishing power relative to mesh size, instead previously reported equal fishing power approximation. However for both leaping mullet and pikeperch the best fit changed to inverse Gaussian model instead of previously reported lognormal and normal location models, but with similar deviance results. Thus, both approaches were valid to estimate gillnet selectivity.

For all fish species, goodness of fit tests (Chi-square tests, Table 2) indicated no deviation of the observed catch for the model predictions ($P > 0.82$). Interestingly any model showed a lack of fit ($P < 0.05$) indicating the accuracy of results obtained. Model deviance (Table 2) did not show significant differences between both gillnet estimation approaches (ANOVA, $F_{1, 44} = 0.75$, $P = 0.39$). However, model deviance significantly depended on fish species ($F_{11, 44} = 51776.4$, $P < 0.0001$) but was an effect of sample size (correlation between deviance and captures; Pearson's $r = 0.258$, $P = 0.004$) and mainly due to the number of meshes in which one species was captured (Pearson's $r = 0.673$, $P < 0.0001$), because species with larger samples sizes and captured by a wide range of meshes had much larger deviances than less captured species or captured by only a few meshes (Table 1 & 2). There was also a significant model ($F_{4, 44} = 373.41$, $P < 0.001$) and model species interaction ($F_{44, 44} = 121.92$, $P < 0.001$) effects, because generally normal location was the model with highest deviance values followed by the normal scale model and both had significantly higher deviances than the other three models (Tukey's Post-Hoc tests, $P < 0.001$ in all cases), which did not show significant deviance differences among them (Post-Hoc tests, $P > 0.8$ for all comparisons). Interaction effect was because the fit of different models presented opposite patterns in different species; for instance when the normal scale model was the best fit (lowest deviance), normal location was the worst (e.g. topmouth gudgeon and bleak) when the normal location or lognormal were the best, normal scale was the worst (e.g. pikepearch and leaping mullet). There was no significant evidence for both approach × model or approach × species interactions ($P > 0.16$) effects.

2. <u>Sand smelt, fisheries effects and management analysis</u>

During the study a total of 2399 sand smelt were captured using both fyke nets and gillnets. Whereas sand smelt comprised only over 3.8 % of the fyke nets captures, being the fourth species on captures importance (N = 453), following the *Pomatoschistus microps* (N = 6161), *Gambusia holbrooki* (N = 3890) and the highly endangered Spanish toothcarp (*Aphanius iberus*) (N = 694). It was the most fished fish by gillnets (N = 1946) corresponding to the 59 % of the total gillnet captures; although it only appeared in smaller meshes (5.00 to 10.00 mm mesh, Table 1). The sand smelt were mainly caught by the 6.25 mm (μ = 61.56 ± 3.92) mesh size, while the least were captured with the 10.0 mm (μ = 80.80 ± 8.62), the largest mesh size. Both 5.00 mm (μ = 49.08 ± 3.21) and 8.00 mm (μ = 74.21 ± 5.48) mesh sizes captured similar number of individuals (Table 1). Sand smelt fork length significantly differed between gears (ANOVA, $F_{1, 1413}$ = 444.1, P < 0.001), since fyke nets is not a selective method, fish length (μ = 46.66 ± 12.52) was smaller than those captured by all gillnet meshes (μ = 61.14 ± 10.50). Fork length differences were also significant among mesh sizes ($F_{4, 1410}$ = 870.89, P < 0.001). As expected, fyke nets captured similar sizes than those fished by 5.00 mm mesh, but significantly small (Tukey test, P < 0.04). While fish captured by 6.25 mm mesh were larger than those on 5.00 mm mesh but smaller than those present in 8.00 mm mesh, which was equal to fish captured by 10.00 mm mesh size (P < 0.0001 in all cases, Post-hoc sequence were Fyke nets < 5.00 mm << 6.25 mm << 8.00 mm = 10.00 mm). Thus, fyke nets captured fewer and smaller individuals than gillnets, seeming than the 6.25 mm mesh and up were the best meshes for sand smelt's fishery; since an increase in captures and lengths were observed.

We studied the relationship of sand smelt length with fish sexual maturity. As expected, fish sexual maturity probability was positively related to fish total length (Wald's χ^2 = 18.80; P < 0.0001) (Fig. 4). Our results shown that all fish with a total length under 45 mm were sexually immature; while fish with a length over ca. 55 mm were mature. Therefore, the range between 45 - 55 mm of total length was critical to reach maturity. Our model predicted that a total length of ca. 52.27 mm fish had a 50 % probability to reach the sexual maturity ("A" approach in Fig. 4); while only less than 2 mm more (ca. 53.92 mm) was necessary to have a 75 % probability to reach the sexual maturity ("B" approach in Fig. 4). Fish with a 56.67 and 59.12 mm total length showed a 95 % ("B" approach in Fig. 4) and 99 % probability to reach the sexual maturity, respectively. Interestingly, and in concordance with previous results about captures, length pattern showed by both fyke nets and gillnets gears, the percentage of mature individuals captured significantly differed among meshes, independently of the supposition undertaken ("A – C") (Crosstabs, $G_4 > 1495.393$; $P < 0.0001$ for all suppositions). Furthermore, number of mature fish captured was positively related to mesh size ($r_s > 0.542$; $P < 0.0001$ for all suppositions) (Fig. 4). Therefore, fyke nets and 5.00 mm gillnet mesh, captured less number of fish, smaller and with a higher percent of immature fish, than larger meshes. Surprisingly, increasing only 1.25 mm the gillnet mesh size (6.25 mm mesh size) the number of captures augmented drastically and the percentage of mature individuals is close to 100 % (Fig. 4).

Summarizing, fyke nets did not seem a good gear to sand smelt fisheries, since is not a selective method. Thus, sand smelt captured with fyke nets were smallest, and the proportion of immature individuals captured was the highest. Similar values were reported when 5.00 mm gillnet mesh size was analyzed. Nevertheless when mesh size is increased 1.25 mm (6.25 mm mesh) the mean length and mature proportion was highly increased, highlighting that the mature proportion was really close to the 100 %. Finally, Minimum Landing Size for the sand smelt has to be established near 60 mm of total length; and with gears over 6.25 mesh size.

Discussion

1. Gillnets and fit of the selectivity curves

Fish community was composed by both freshwater and marine species. For the gillnet selectivity analysis only fish captured in at least four different meshes and in enough number of captures were considered. Atherinidae, Mugilidae, Cyprinidae and Percidae were the families finally selected for the study (Table 1).

Any model showed a lack of fit thus suggesting the accuracy of our results. No common pattern for the best fit was found between different species; thus suggesting that each fish or group of fish were caught differently depending on its body shape (Fonseca et al., 2005) and its differences in behavior towards the fishing gear (Campos and Fonseca, 2003). In general, Gamma was the best fit when having higher number of captures, while Inverse Gaussian used to be the best model with lower N's. Normal fixed was the worst approximation, probably due to its fixed spread, which estimated the curves ºassuming no geometrical symmetry (McAuley and Simpfendorfer, 2007). The Inverse Gaussian model had the best fit in five out of the twelve fish species. The Normal scale model had the best fit in four cases. Gamma and Lognormal models were best fit in two and one case respectively.

Gillnet selectivity curves may approach normal curves when most fish are wedged or gilled (Hamley, 1975), when the curves are skewed to the right, fitting better to gamma or lognormal models, means fish had been mostly entangled (Dos Santos et al., 2003 ; Hamley, 1975). Typical unimodal selectivity curves have been described to be bell-shaped, similar in shape for all mesh sizes, but located further to the right for progressively larger mesh (Hamley, 1975). So, in general gillnet selectivity curves are broader and more skewed to the right when many fish are tangled, and may approach the normal curve when most fish are wedged. Thus suggest, that fish of our study were mostly tangled or wedged instead of gilled. Some authors (Carol and Garcia-Berthou, 2007; Hamley, 1975; Sbrana et al., 2007) agree that when fish are caught in several ways, selectivity curves may be multimodal rather than unimodal; so the binormal model would have been a good approximation.

Model deviance did not show significant differences between both gillnet estimation approaches (equal and fishing power proportional to mesh size); however, model deviance significantly depended on fish species, which means that model deviance significantly depended on sample size, mainly due to the number of meshes in which one species was captured. The existence of model interaction was shown by opposite model patterns in different species.

SELECT method is a good approximation to estimate selectivity curves and allow us to known the length distribution of the population and its probability to be caught by a specific gillnet mesh. One advantage of the SELECT method is that mesh size is part of the models, so modal length for any mesh size can be predicted (Carol and Garcia-Berthou, 2007). Gillnets can be a very useful tool, because they are very size selective.

2. Gillnets as a conservation tool: The sand smelt's case

A total amount of 2399 individuals were both fished with gillnet (N = 1946) and fyke nets (453) in the lagoons. Gillnets caught individuals just in the smaller meshes (5.00 to 10.00 mm). Significant differences between panels and fisheries tool were found, thus fyke net captured less and smaller fish than all gillnet meshes; 6.25 mm gillnet mesh panel was the one registering higher number of captures. Moreover, fyke nets and 5.00 mm mesh gillnets reached the highest percentage of immature individuals (Fig.4).

The fishing activity in Ebro's delta coastal lagoons is done almost without control using Trammel nets. The problematic resides in that compare to gillnets, trammel nets selectivities are lower and catches of small organisms and non-target species are common (Hovgård, 2000). One of the oldest, and most commonly used tools in fisheries management, is to limit the size of individuals that may be retained (Stewart, 2008). Such control may be through either regulating legal minimum lengths or gear selectivity (Wallace and Fletcher, 2000). According to MAH663/2007, just autochthonous species are required to have a minimum size regulation. In the lagoons, six out of the seven autochthonous species were under the minimum size regulation. Mugilidae family (*C. labrosus, L. saliens, L. ramada* and *L. aurata*) minimum size has been established in 160 mm of total length (hereafter TL). *D. labrax* cannot be fished under 230 mm TL. Although being quite abundant in the lagoons, the sand smelt was the only native species without a regulation on its Minimum Landing Size (MLS); a technical measure used to manage fisheries with the aim of allowing enough juveniles to survive and spawn (Stergiou et al., 2009).

Future recommendations for the sand smelt's fisheries management proposed in this paper are:

(i) Abolishment of the fyke nets fisheries on the lagoons.

(ii) Substitution of trammel nets for 6.25 mm mesh size gillnets. Gillnets are a very handle selective tool, cheap to use and purchase (FAO, 2001-2010; Rosman, 1980). Directional fishing can be done by gillnets due to the specific relation species-mesh selection.

(iii) Establishment of sand smelt Minimum landing size on 60 mm TL (99 % of mature population) (following EU Council Regulation 850/98).

Although the present study was the first one to propose a fisheries regulation on sand smelt, species it should be noted that quite small fish can be entangled in larger meshes and this problematic cannot be solved by the establishment of a minimum size regulation alone (Dos Santos et al., 2003). Nevertheless, the importance of this fact should not be scorn as some studies have shown that genetic changes in growth may occur in response to size-selective fishing (Swain and Sinclair, 2007). Other papers have reported the early appearance of maturity in response to a fisheries stress (Trippel, 1995). Studies like that are important because frequently in fisheries, fish are captured with smaller meshes than they should do, so immature individuals became caught when they should not.

More studies are needed to improve the actual situation of the fish on the lagoons bearing in mind that reasonable multispecies management it is usually difficult to implement in real ecosystems (Sainsbury and Punt, 2000). As said by Campos and Fonseca (2003) the management of a species fishery based simply on mesh size regulation is very difficult, but is the first step to improve an uncontrolled fishing situation.

Conclusions

The abolishment of fyke nets and 5.00 mm mesh gillnets in the lagoons and the restriction of the fishery's minimum mesh size to 6.25 mm gillnet bar length would reduce the catches of immature sand smelt individuals, which made have benefits for stock recovery and future sustainability. Further revision on the fisheries lagoons law is strongly recommended. It is also recommendable to control this fisheries tool as fyke-nets are catching big amounts of the endangered species Spanish toothcarp (*Aphanius iberus*).

Even if it is not one of the goals of the paper; we considered important to remark that due to the elevate number of captures (N = 3890), fyke-nets could be used as a tool to regulate *Gambusia holbrooki* population. Fyke nets should be hauled few moments after being set in order to let the other species present on the net to survive.

As said by McAuley (2007) due to the size-selective nature of gillnets, mesh size regulations can be an effective tool for managing the size composition of the catches. In this way knowledge of how species catches are influenced by the size selectivity of gillnets is important for developing sustainable harvest strategies. Further evaluation of the current state of the fisheries in the lagoons using this fishing tool is needed for responding to the reductions in recruitment that are expected as a result of the recent period of overexploitation.

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Fig. 1. Upper part: Map showing Ebro's river basin. Lower part: Localization of the 12 gillnets and fyke-nets (white spots) settled in the study area.

Fig. 2. Total captures by total length and different mesh sizes for eight fish species ($N \geq 20$). (figures shown above lines bar length in mm).

Fig. 3. Unimodal selection curves showing best fit for species with $N \geq 20$ assuming equal fishing power. Meshes are shown in size ascending order (see Table 1).

Fig. 4. Relationship between maturity stage of sand smelt with fish total length. Spots shown the maturity of the individuals (0; immature and 1; mature) and black line corresponds to the predicted probability to be mature at a determinated length (Above). Per cent mature (■) and immature (□) individuals captured by Fyke nets and different Gillnets mesh sizes supposing : "A" = 50 % , "B" = 75% and "C" = 95 % probability to be mature by logistic regression model (below).

Table 1. Total gillnet captures by species and mesh size. Species mean size and range (mm) is also shown. ***N:*** Number of captures.

Fish species			Mesh size (mm)														
Species name	Common name	Species code	*N*	5.0	6.25	8.0	10.0	12.5	15.5	19.5	24.0	29.0	35.0	43.0	55.0	Fork length Mean	Range
Atherina boyeri	Sand smelt	ABO	1172	361	500	303	8									65	40-90
Chelon labrosus	Thicklip grey mullet	CLA	16			1	7	1	1		2	2	1	1		190	72-360
Liza saliens	Leaping mullet	LSA	341	15	65	53	56	78	51	17	6					140	32-310
Liza aurata	Golden grey mullet	LAU	29		4		1	6	6	4	5		1	1	1	206	55-387
Liza ramada	Thinlip grey mullet	LRA	389		3	14	86	130	44	43	48	10	6	3	2	184	64-395
Mugil cephalus	Flathead grey mullet	MCE	26				1		1	1	12	3	2	5	1	247	83-495
Alburnus alburnus	Bleak	AAL	29	2		14	2	6	5							91	45-136
Cyprinus carpio	Common carp	CCA	36						3	5		5	13	5	5	187	81-331
Carassius auratus	Goldfish	CAU	12						1	1	2	2	3		3	177	82-324
Pseudorasbora parva	Topmouth gudgeon	PPA	175	1	45	75	48	5			1					70	41-96
Sander lucioperca	Pikeperch	SLU	18					1	5	3	5	4				251	215-281
Dicentrarchus labrax	European seabass	DLA	12					1	2	5		2		2		198	110-337

Table 2: Statistics summarizing the fit of the five models tested using the SELECT method by species (in bold best model fit). Parameters 1 and 2 are k and σ for Normal location model; k_1 and k_2 for Normal scale model (spread proportional to mesh size); α and k for Gamma model; μ_1 and σ for Lognormal model and k_1 and k_2 for Inverse Gaussian model. Deviance statistic measure goodness of fit . $P < 0.05$ indicate lack of fit.

Species	Model	Equal fishing power					Fishing power relative to mesh size				
		Par.1	Par. 2	Deviance	df	P	Par 1	Par. 2	Deviance	df	P
***Atherina boyeri* (ABO)**	Normal fixed	9.57	4.21	82.69	142	1.000	9.62	4.22	85.04	142	1.000
	Normal scale	9.74	0.41	42.02	142	1.000	9.78	0.41	42.02	142	1.000
	Gamma	**225.68**	**0.04**	**41.74**	**142**	**1.000**	**226.68**	**0.04**	**41.74**	**142**	**1.000**
	Lognormal	3.88	0.07	42.56	142	1.000	3.89	0.07	42.56	142	1.000
	Inverse Gaussian	9.72	2158.6	42.62	142	1.000	9.76	2168.19	42.62	142	1.000
***Chelon labrosus* (CLA)**	Normal fixed	10.19	63.21	45.78	96	1.000	10.80	63.26	46.86	96	1.000
	Normal scale	11.71	11.11	46.83	96	1.000	12.58	9.67	47.47	96	1.000
	Gamma	13.92	0.81	42.11	96	1.000	14.92	0.81	42.11	96	1.000
	Lognormal	4.45	0.25	40.10	96	1.000	4.51	0.25	40.10	96	1.000
	Inverse Gaussian	**11.16**	**163.45**	**40.04**	**96**	**1.000**	**11.94**	**173.13**	**39.92**	**96**	**1.000**
***Liza saliens* (LSA)**	Normal fixed	11.77	33.68	712.02	102	1.000	12.41	34.53	686.82	102	1.000
	Normal scale	12.62	10.50	766.22	102	1.000	13.43	9.55	775.26	102	1.000
	Gamma	16.66	0.75	672.19	102	1.000	17.66	0.75	672.19	102	1.000
	Lognormal	**4.09**	**0.24**	**640.07**	**102**	**1.000**	4.15	0.24	640.07	102	1.000
	Inverse Gaussian	12.41	200.11	640.27	102	1.000	**13.19**	**210.99**	**638.68**	**102**	**1.000**
***Liza aurata* (LAU)**	Normal fixed	10.60	102.27	106.46	230	1.000	12.57	117.33	110.18	230	1.000
	Normal scale	14.84	25.16	103.93	230	1.000	16.32	20.11	106.59	230	1.000
	Gamma	8.31	1.76	93.64	230	1.000	9.31	1.76	93.64	230	1.000
	Lognormal	4.45	0.37	90.47	230	1.000	4.59	0.37	90.47	230	1.000
	Inverse Gaussian	**14.89**	**100.03**	**90.01**	**230**	**1.000**	**17.30**	**110.83**	**89.69**	**230**	**1.000**
***Liza ramada* (LRA)**	Normal fixed	9.84	55.98	993.76	141	1.000	10.83	59.40	962.22	141	1.000
	Normal scale	10.69	5.22	782.44	141	1.000	11.17	4.91	784.13	141	1.000
	Gamma	**19.21**	**0.56**	**771.94**	**141**	**1.000**	**20.21**	**0.56**	**771.94**	**141**	**1.000**
	Lognormal	4.18	0.24	787.13	141	1.000	4.24	0.24	787.13	141	1.000
	Inverse Gaussian	10.81	173.98	795.73	141	1.000	11.49	183.47	797.20	141	1.000
Mugil cephalus	Normal fixed	8.23	25.00	37.67	173	1.000	8.32	25.23	38.22	173	1.000
	Normal scale	**8.57**	**0.60**	**30.09**	**173**	**1.000**	**8.64**	**0.59**	**30.08**	**173**	**1.000**

(MCE)	Gamma	116.11	0.07	30.44	173	1.000	117.11	0.07	30.44	173	1.000
	Lognormal	4.45	0.09	30.68	173	1.000	4.45	0.09	30.68	173	1.000
	Inverse Gaussian	8.56	959.04	30.68	173	1.000	8.63	967.36	30.68	173	1.000
***Alburnus alburnus* (AAL)**	Normal fixed	8.93	10.26	30.76	102	1.000	9.03	10.32	31.69	102	1.000
	Normal scale	**9.26**	**0.82**	**24.34**	**102**	**1.000**	**9.35**	**0.82**	**24.34**	**102**	**1.000**
	Gamma	99.81	0.09	24.40	102	1.000	100.81	0.09	24.40	102	1.000
	Lognormal	3.83	0.10	24.48	102	1.000	3.84	0.10	24.48	102	1.000
	Inverse Gaussian	9.28	898.95	24.46	102	1.000	9.38	907.97	24.46	102	1.000
***Cyprinus carpio* (CCA)**	Normal fixed	5.41	22.24	49.27	173	1.000	5.48	22.41	48.76	173	1.000
	Normal scale	**5.48**	**0.30**	**37.99**	**173**	**1.000**	**5.54**	**0.30**	**37.98**	**173**	**1.000**
	Gamma	92.97	0.06	39.14	173	1.000	93.97	0.06	39.14	173	1.000
	Lognormal	4.44	0.11	39.81	173	1.000	4.45	0.11	39.81	173	1.000
	Inverse Gaussian	5.49	486.32	39.83	173	1.000	5.55	491.67	39.84	173	1.000
***Carassius auratus* (CAU)**	Normal fixed	4.87	15.84	14.47	58	1.000	4.94	15.99	14.70	58	1.000
	Normal scale	5.08	0.36	14.27	58	1.000	5.15	0.35	14.27	58	1.000
	Gamma	72.13	0.07	14.19	58	1.000	73.13	0.07	14.19	58	1.000
	Lognormal	4.36	0.12	14.18	58	1.000	4.37	0.12	14.18	58	1.000
	Inverse Gaussian	**5.09**	**363.48**	**14.17**	**58**	**1.000**	**5.16**	**368.49**	**14.17**	**58**	**1.000**
***Pseudorasbora parva* (PPA)**	Normal fixed	8.23	10.73	212.43	233	0.829	8.43	11.04	210.31	233	0.855
	Normal scale	**8.59**	**0.82**	**107.77**	**233**	**1.000**	**8.68**	**0.81**	**107.70**	**233**	**1.000**
	Gamma	83.15	0.10	114.58	233	1.000	84.15	0.10	114.58	233	1.000
	Lognormal	3.76	0.11	121.40	233	1.000	3.77	0.11	121.40	233	1.000
	Inverse Gaussian	8.60	661.77	123.50	233	1.000	8.72	670.13	123.61	233	1.000
***Sander lucioperca* (SLU)**	**Normal fixed**	**11.13**	**71.00**	**47.81**	**62**	**0.908**	12.20	79.83	48.02	62	0.904
	Normal scale	12.20	25.52	48.54	62	0.894	14.10	22.41	48.61	62	0.893
	Gamma	9.40	1.43	48.08	62	0.903	10.40	1.43	48.08	62	0.903
	Lognormal	5.10	0.32	47.83	62	0.907	5.20	0.32	47.83	62	0.907
	Inverse Gaussian	13.78	131.87	47.81	62	0.907	**15.28**	**144.43**	**47.79**	**62**	**0.908**
***Dicentrarchus labrax* (DLA)**	Normal fixed	8.45	12.49	6.48	46	1.000	8.52	12.48	6.48	46	1.000
	Normal scale	8.58	0.54	6.11	46	1.000	8.64	0.54	6.11	46	1.000
	Gamma	137.23	0.06	6.02	46	1.000	138.23	0.06	6.02	46	1.000
	Lognormal	4.67	0.09	5.99	46	1.000	4.68	0.09	5.99	46	1.000
	Inverse Gaussian	**8.58**	**1179.5**	**5.99**	**46**	**1.000**	**8.64**	**1188.05**	**5.99**	**46**	**1.000**

Fig. 1 Rodríguez-Climent et al.

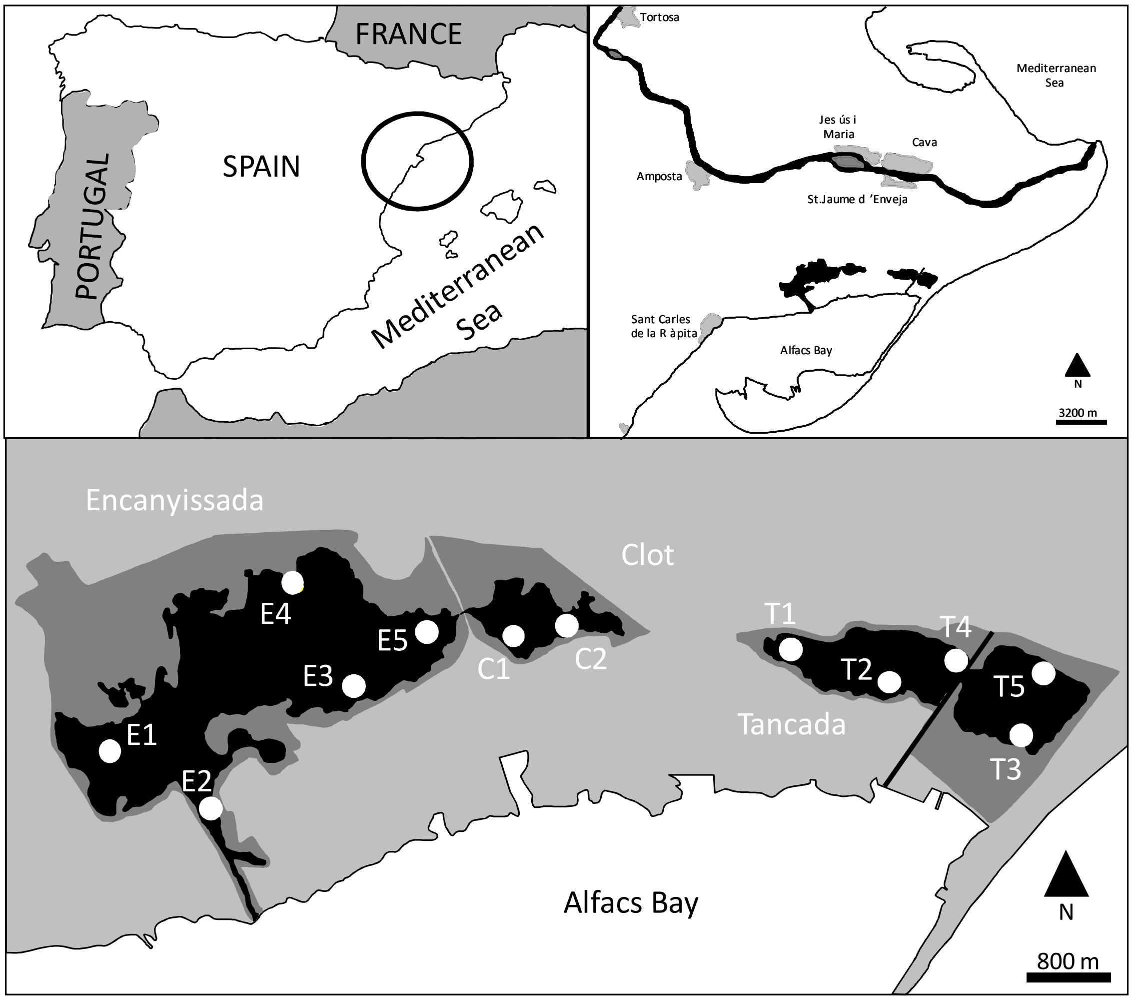

Fig. 2 Rodríguez-Climent et al.

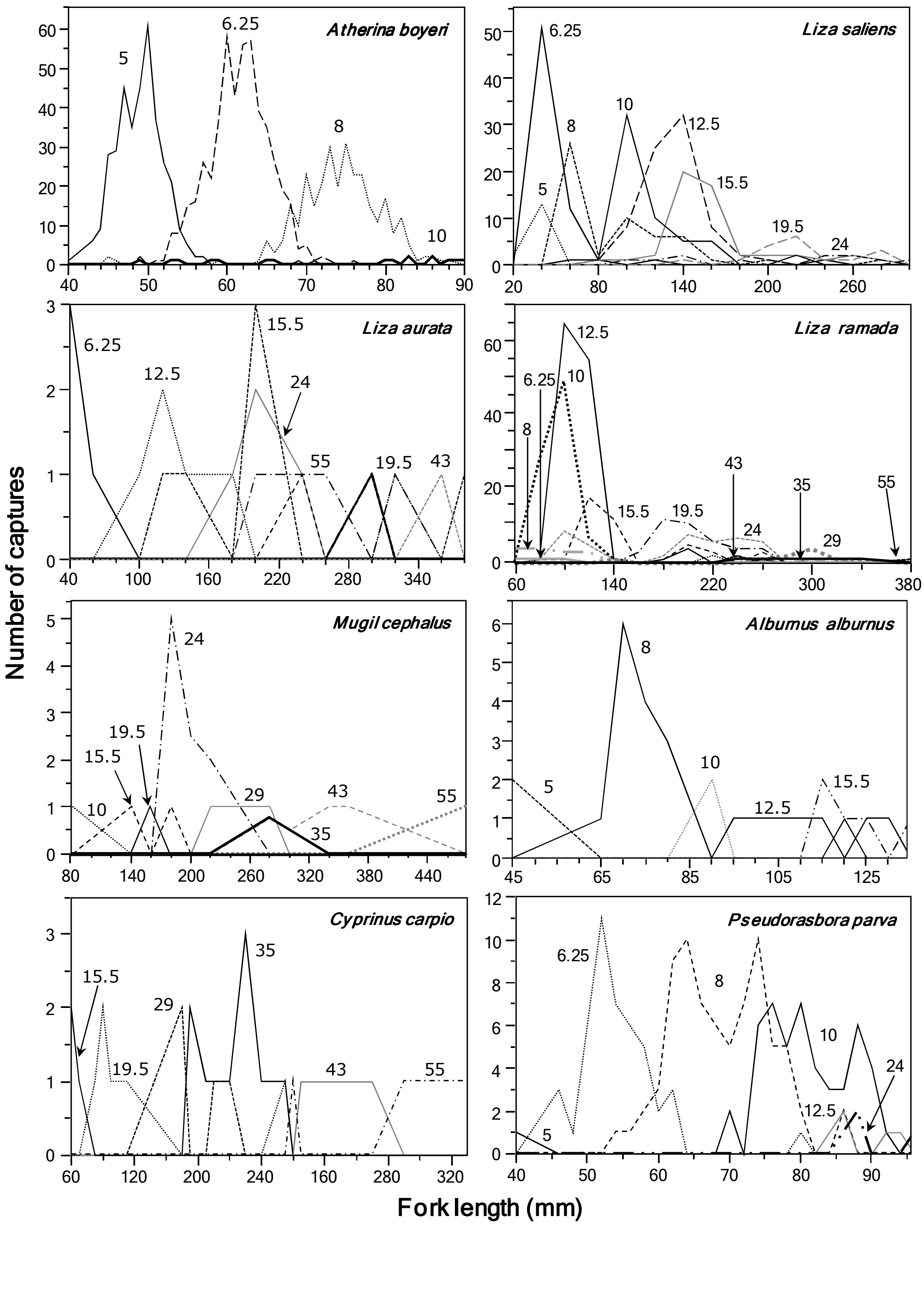

Fig. 3 Rodríguez-Climent et al.

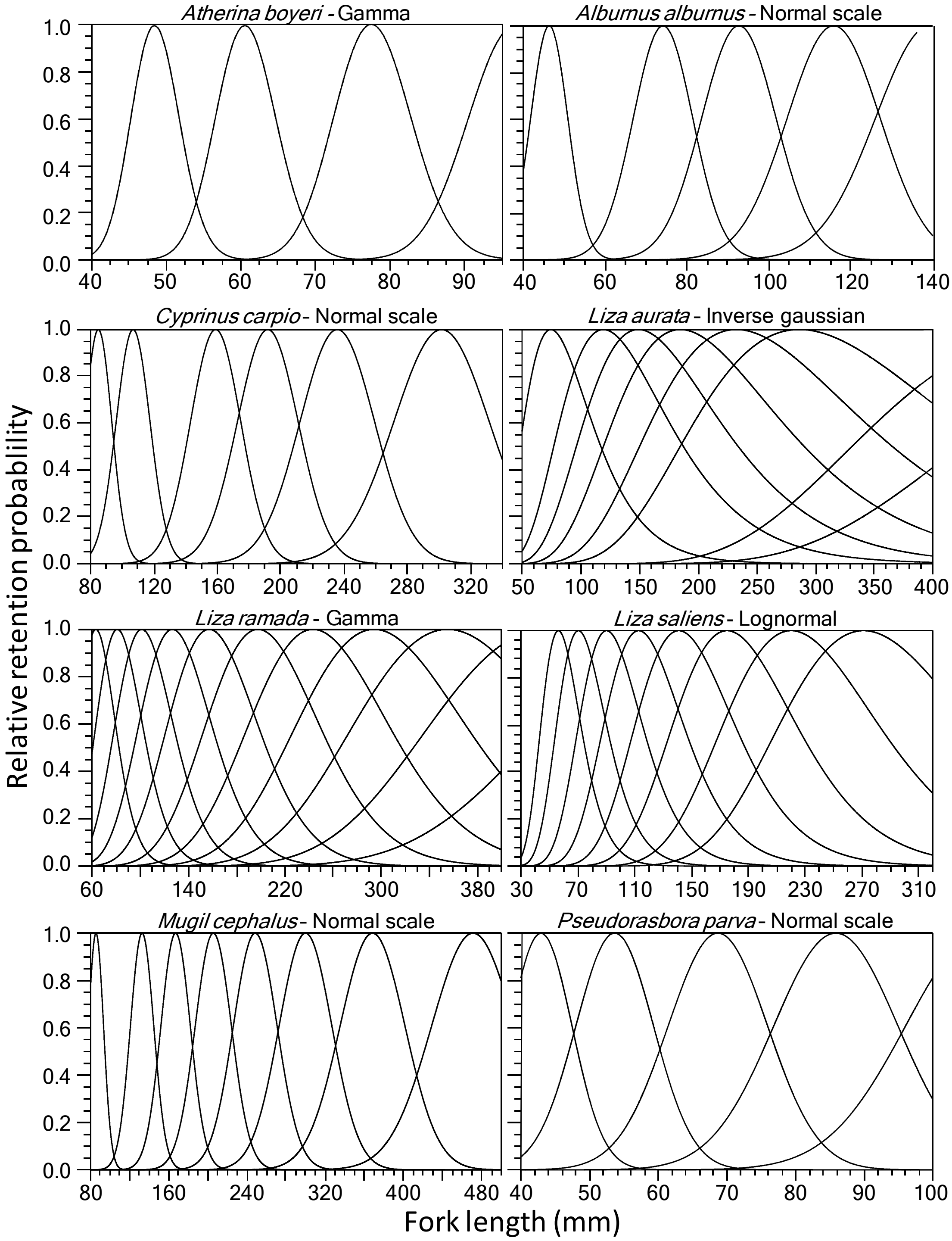

Fig. 4 Rodríguez-Climent et al.