Scientia Marina 82(3)
September 2018, 147-157, Barcelona (Spain)
ISSN-L: 0214-8358
https://doi.org/10.3989/scimar.04764.18A

# The influence of mesh size and shape on the size selection of European hake (*Merluccius merluccius*) in demersal trawl codends: An investigation based on fish morphology and simulation of mesh geometry

Adnan Tokaç [1*], Bent Herrmann [2,3*], Gökhan Gökçe [4], Ludvig Ahm Krag [5], Davud Sadegh Nezhad [6]

[1] Ege University, Fisheries Faculty, TR-35100 Bornova, İzmir, Turkey.
(AT) (Corresponding author) E-mail: adnan.tokac@ege.edu.tr. ORCID iD: https://orcid.org/0000-0002-2968-7315
[2] SINTEF Ocean, Fishing Gear Technology, Willemoesvej 2, 9850 Hirtshals, Denmark.
[3] Norwegian College of Fishery and Aquatic Science, University of Tromsø, 9037 Breivika, Tromsø, Norway.
(BH) E-mail: bent.herrmann@sintef.no. ORCID iD: https://orcid.org/0000-0003-1325-6198
[4] Çukurova University, Fisheries Faculty, TR-01330 Sarıçam, Adana, Turkey.
(GG) E-mail: gokhan.gokce@ymail.com. ORCID iD: https://orcid.org/0000-0003-1830-0733
[5] DTU Aqua, Technical University of Denmark, North Sea Science Park, DK-9850 Hirtshals, Denmark.
(LAK) E-mail: lak@aqua.dtu.dk. ORCID iD: https://orcid.org/0000-0002-1531-1499
[6] Ege University, Graduate School of Natural and Applied Sciences, Fisheries Department, TR-35100 Bornova, İzmir, Turkey.
(DSN) E-mail: davut.sn@gmail.com. ORCID iD: https://orcid.org/0000-0003-3725-9705

* These authors contributed equally to the work and should be considered co-first authors of the study

**Summary:** European hake (*Merluccius merluccius*) is an important commercial species for several European bottom trawl fisheries. Therefore, understanding the influence of codend mesh size and shape on the size selection of European hake is critical for defining technical measures for fisheries targeting this species. Based on morphology data collected on European hake, the influence of mesh size and shape on bottom trawl codend size selectivity was investigated by simulation using the FISHSELECT methodology successfully applied previously for other species. The predicted size selection for European hake was found to agree well with previous experimental results for a wide range of mesh sizes if it was assumed that the codend meshes had a relatively small opening angle, between 20° and 40°, during trawling. This study enables detailed prediction of size selectivity for European hake and offers a potential explanation for previous experimental size selectivity results.

**Keywords:** European hake; trawl codend; size selectivity; fish morphology; mesh geometry; Mediterranean Sea.

**Influencia del tamaño y la forma de la malla en la selección del tamaño de la merluza europea (*Merluccius merluccius*) en red de arrastre demersales: una investigación basada en la morfología de los peces y la simulación de la geometría de la malla**

**Resumen:** La merluza europea (*Merluccius merluccius*) es una especie comercial importante para varias pesquerías europeas de arrastre de fondo. Por lo tanto, la comprensión de la influencia del tamaño y la forma de la malla de red en la selección del tamaño de la merluza Europea es fundamental para definir medidas técnicas para las pesquerías dirigidas a esta especie. En base a los datos de morfología recolectados en merluza Europea, se investigó la influencia del tamaño de malla y la forma en la selectividad del tamaño de la red de arrastre de fondo mediante simulación utilizando la metodología FISHSELECT previamente aplicada con éxito para otras especies. La selección del tamaño predicho para la merluza Europea coincidió con los resultados experimentales previos para una amplia gama de tamaños de malla si se suponía que las mallas de red tenían un ángulo de apertura relativamente pequeño, entre 20 y 40 grados, durante la pesca de arrastre. Este estudio permite una predicción detallada de la selectividad de tamaño para la merluza Europea y ofrece una posible explicación para los resultados previos de selectividad de tamaño experimental.

**Palabras clave:** merluza europea; red de arrastre; selectividad de tamaño; morfología de los peces; geometría de malla; mar Mediterráneo.

**Citation/Como citar este artículo:** Tokaç A., Herrmann B., Gökçe G., Krag L.A., Nezhad D.S. 2018. The influence of mesh size and shape on the size selection of European hake (*Merluccius merluccius*) in demersal trawl codends: An investigation based on fish morphology and simulation of mesh geometry. Sci. Mar. 82(3): 147-157. https://doi.org/10.3989/scimar.04764.18A

**Editor:** P. Martín.

**Received:** February 8, 2018. **Accepted:** July 31, 2018. **Published:** September 25, 2018



## INTRODUCTION

European hake (*Merluccius merluccius*) are commercially important demersal fish stocks and are exploited along the northeast Atlantic shelf, from Norway in the north to Mauritania in the south and into the Mediterranean Sea and along the southern coast of the Black Sea (Cohen et al. 1990). European hake is usually found between 70 and 370 m depth, but may also occur within a wider depth range, from inshore waters (30 m) to 1000 m (Cohen et al. 1990). The species is primarily targeted by demersal trawls at depths ranging from 100 to 400 m in both directed hake fisheries and more mixed species fisheries (Bensch et al. 2009), and it is also fished mainly by bottom trawlers at 30-700 m depth in the Mediterranean (Casey and Pereiro 1995).

Global catch production of European hake was 142190 t in 2016 (FAO 2018). European hake is commonly caught in mixed fisheries and targeted by small-scale fishing gears (e.g. gillnet and longline) and also demersal trawls using different mesh sizes, and is subjected to a varying minimum conservation reference size (MCRS) and technical legislation throughout its range. It is subjected to an MCRS of 27 cm in European waters except the Mediterranean Sea, 20 cm in both European Mediterranean (EC 2006b) and Turkish territorial waters (TFR 2016) and 30 cm in the Skagerrak/Kattegat (EC 1998).

In addition to the MCRS mentioned above, the following technical measures are in place: a minimum mesh size of 70 mm in the Bay of Biscay and of 100 mm for otter trawls when European hake comprises more than 20% of the total catch (EC 2004). However, in 2006 the provisions were introduced to provide a voluntary alternative to the mandatory use of bottom otter trawls with a 100 mm codend mesh size (EC 2006a). These provisions permit the deployment of otter trawls with a minimum codend mesh size of 70 mm provided that a 100-mm square mesh panel (SMP) is inserted into the middle of the top panel of the rear tapered section of the trawl just in front of the untapered section comprising the extension piece and codend, a configuration intended to improve the selectivity for undersized fish (Alzorriz et al. 2016). Trawl codends should comply with the legal minimum mesh size of 40 mm square or alternatively 50 mm diamond in the Mediterranean according to the Council Regulation (EC 2006b).

European hake in the northeastern Atlantic are divided into a northern and a southern stock (Casey and Pereiro 1995). The northern stock of European hake, as for the majority of stocks which are found in the North Sea and the Skagerrak, and off the Atlantic coasts of the UK, Ireland and France. The southern stock of European hake is located off the Atlantic coasts of the Iberian Peninsula supports a major coastal commercial fishery (Casey and Pereiro 1995) and is especially important for Spanish and Portuguese fishing fleets. The importance of European hake as a commercial species has led to several selectivity studies in the North Sea, along the Atlantic coast of Europe, and in the Mediterranean Sea. The studies examine the effect on selectivity of design parameters such as mesh size in traditional diamond mesh codends (Campos and Fonseca 2003) or applying square mesh codends as an alternative to diamond meshes (Campos et al. 2003a,b). In the Mediterranean, studies have compared selectivity in diamond and square mesh codends (Ordines et al. 2006, Lucchetti 2008, Özbilgin et al. 2012). In addition to mesh size and type, other codend designs such as an SMP codends (Bahamon et al. 2006, Tokaç et al. 2010) and differences in codend circumference (Sala and Lucchetti 2011 and Sala et al. 2016) have been investigated. These experiments have established selectivity estimates for specific mesh sizes, mesh types or codend constructions, and the results have been to some extent case-specific or are limited to a specific mesh size or gear design.

In the last decade a broader understanding of the selection processes has been established using the morphology-based FISHSELECT methodology (Herrmann et al. 2009) for some key commercial species (Krag et al. 2011, Herrmann et al. 2012, Tokaç et al. 2016). The FISHSELECT methodology is a framework that assesses the morphological conditions that determine a fish's ability to physically penetrate a given mesh in a towed fishing gear. The method is based on a combination of laboratory experiments with fish, data collection, data analysis and computer simulations (Herrmann et al. 2009). The FISHSELECT methodology also has the advantage of providing predictions of selectivity across a range of mesh types and shapes.

The aim of this study is to estimate the size selectivity of European hake using FISHSELECT for a range of different codend mesh sizes, mesh types and mesh opening angles (OAs).

## MATERIALS AND METHODS

### The FISHSELECT methodology and experimental selectivity data

We used the FISHSELECT methodology to predict size selection of European hake (henceforth hake) for a wide range of mesh configurations through simulations following Herrmann et al. (2009) and Tokaç et al. (2016). The FISHSELECT software can be obtained from the first author of Herrmann et al. (2009). To evaluate the validity of the results, we compared them with experimental selectivity results from sea trials. Table 1 and 2 summarizes hake experimental selectivity results for diamond mesh (D) and square mesh (S) codends in bottom trawl fisheries. In addition, we used selec-

Table 1. – Experimental selectivity results for Hake in diamond mesh codends. n denotes number of open meshes in codend circumference. $^{fc}$, first cruise; $^{sc}$, second cruise.

| Measured mesh (mm) | L50 (cm) | SR (cm) | n | Study area (Sea) | References |
|---|---|---|---|---|---|
| 69.4 | 17.00 | 3.0 | 106 | SW coast of Portugal | Campos and Fonseca (2003) |
| 79.2 | 18.30 | 4.2 | 93 | | |
| 55.2 | 15.9 | 3.0 | 109 | S coast of Portugal | Campos et al. (2003a) |
| 60.3 | 17.4 | 3.8 | 100 | | |
| 63.5 | 18.0 | 4.9 | 115 | | |
| 69.4 | 20.2 | 3.9 | 106 | SW coast of Portugal | Campos et al. (2003b) |
| 79.2 | 18.8 | 4.4 | 93 | | |
| 40.3 | 10.10 | 3.1 | 230 | Catalan Sea | Bahamon et al. (2006) |
| 49.44 | 11.40 | 4.10 | 400 | Eastern Aegean Sea | Tosunoğlu et al. (2008) |
| 92.5 | 22.31 | 10.89 | 92 | Skagerrak and Kattegat | Frandsen et al. (2009) |
| 42.42 | 11.59 | 4.07 | 300 | Aegean Sea | Tokaç et al. (2010) |
| 44.7 | 10.40 | 3.10 | 400 | Aegean Sea | Aydın and Tosunoğlu (2010) |
| 42.2 | 10.50 | 3.77 | 300 | Aegean Sea | Özbilgin et al. (2012) |
| 48.6 | 12.81 | 3.67 | 275 | | |
| 75.8 | 20.29 | 8.40 | 240 | Bay of Biscay | Alzorriz et al. (2016) |
| 42.8 | 7.60 | 4.01 | 310 | Adriatic Sea | Lucchetti (2008) |
| 45.20 | $8.03^{fc}$ | $3.80^{fc}$ | 280 | Adriatic Sea | Sala and Lucchetti (2010) |
| | $9.12^{sc}$ | $4.72^{sc}$ | 280 | | |
| 46.35 | $10.84^{fc}$ | $7.15^{fc}$ | 326 | | |
| | $9.37^{sc}$ | $5.33^{sc}$ | 326 | | |
| 46.5 | 11.45 | 5.62 | 280 | Adriatic Sea | Sala and Lucchetti (2011) |
| 46.5 | 10.43 | 5.87 | 326 | | |
| 56.75 | 16.25 | 7.56 | 240 | | |
| 56.10 | 11.99 | 7.94 | 280 | | |

Table 2. – Experimental selectivity data for hake in square mesh codends. n denotes number of open meshes in codend circumference; * number of bars; $^{fc}$, first cruise; $^{sc}$, second cruise; $^{SMP}$, square mesh top panel (SMP) codend: a combination of 75 square meshes on the top and 150 diamond meshes on the bottom panel, in total 225 meshes on its circumference.

| Measured mesh (mm) | L50 (cm) | SR (cm) | n | Study area (sea) | References |
|---|---|---|---|---|---|
| 63.3 | 25.0 | 5.6 | 64* | SW coast of Portugal | Campos et al. (2003b) |
| 42.8 | 12.98 | 3.65 | 310 | Adriatic Sea | Lucchetti (2008) |
| 43.25 | $11.97^{fc}$ | $6.11^{fc}$ | 70 | Adriatic Sea | Sala and Lucchetti (2010) |
| | $15.70^{sc}$ | $8.68^{sc}$ | 70 | | |
| 41.7 | 15.20 | 5.89 | $75/150^{SMP}$ | Aegean Sea | Tokaç et al. (2010) |
| 42.4 | 14.40 | 4.80 | 200* | Aegean Sea | Aydın and Tosunoğlu (2010) |
| 42.9 | 15.22 | 4.66 | 150* | Aegean Sea | Özbilgin et al. (2012) |

tivity estimates obtained with the predictive model of Sala and Lucchetti (2011) based on their experimental data. We quantify codend size selectivity for hake by two parameters: L50, the length of hake with a 50% probability of being retained given that they enter the codend; and selection range (SR), the difference in the lengths of fish having 75% and 25% probability of being retained (Wileman et al. 1996).

### FISHSELECT data collection

Individual hake were caught by trawling on daily cruises in the Aegean Sea (İzmir Bay) in September 2014 using the research vessel R/V *EGESÜF*. Several short 20- to 30-minute tows at 30-50 m depth were conducted and individual fish were kept alive in holding tanks until the FISHSELECT measurements were taken (following Herrmann et al. 2009 and Krag et al. 2011). Hake are fragile compared with other species and were therefore transferred to the holding tanks on land, and measurements of the individuals were conducted as quickly as possible thereafter. Holding tanks helped keep the fish alive so that each individual was as fresh as possible when measurements were taken. To obtain the correct morphometric measures for each fish using FISHSELECT, it is very important that the shape of the fish measured is not affected by dehydration, depressurization, rigor mortis, or any other factor that could alter the original shape (Sistiaga et al. 2011). Hake is a physoclistous species. Individuals with overinflated swim bladders, commonly observed when caught in trawl, had difficulties obtaining normal swimming behaviour in the on-board holding tanks, and gently had their swim bladder punctured using a syringe. About 200 individuals were transferred to holding tanks on land, and 74 individuals ranging from 15 to 66 cm in length with all length classes being represented by between one and eight individuals were selected and used in the subsequent FISHSELECT experiments. The 74 hake were selected to cover as wide a length interval as possible and with an approximately uniform size distribution in order to subsequently be able to make predictions for size selection of hake for a wide range of mesh size and shapes based on the collected information.

### Measuring fish morphology

The FISHSELECT methodology is based on establishing descriptions of the significant cross-section

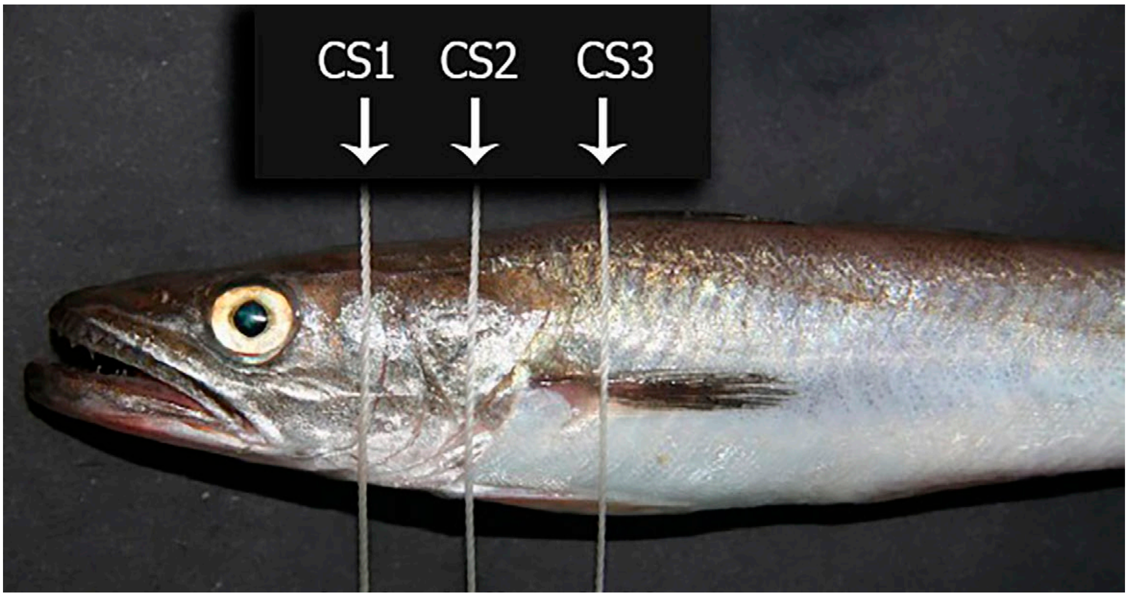


Fig. 1. – Illustration showing the positions along a hake of the three cross-sections (CS1, CS2 and CS3).

shapes determining size selection for the given species. We first determined the most relevant cross-section for mesh penetration for hake. The morphological measurements of four hake were thoroughly examined during an initial laboratory experiment. Extensive cross-section measures on these individuals, combined with fall-through trials, revealed three cross-sections to be potentially critical for mesh penetration (Fig. 1). CS1 represents the widest bony part of the fish's head. CS2 is larger but more compressible than CS1 and is positioned at the posterior end of the opercula. CS3 is the largest, but most compressible cross-section of the three and represents the maximum girth of the fish, i.e. stomach girth. The cross-sectional morphology was measured for each fish using a morphometer (Herrmann et al. 2009) (Fig. 2A, B) and the shapes formed by the morphometer were scanned and converted into digital images using a flatbed scanner (Fig. 2C, D). The outlines of the cross-sections were modelled using four different parametric models: ellipse, flexellipse 1,

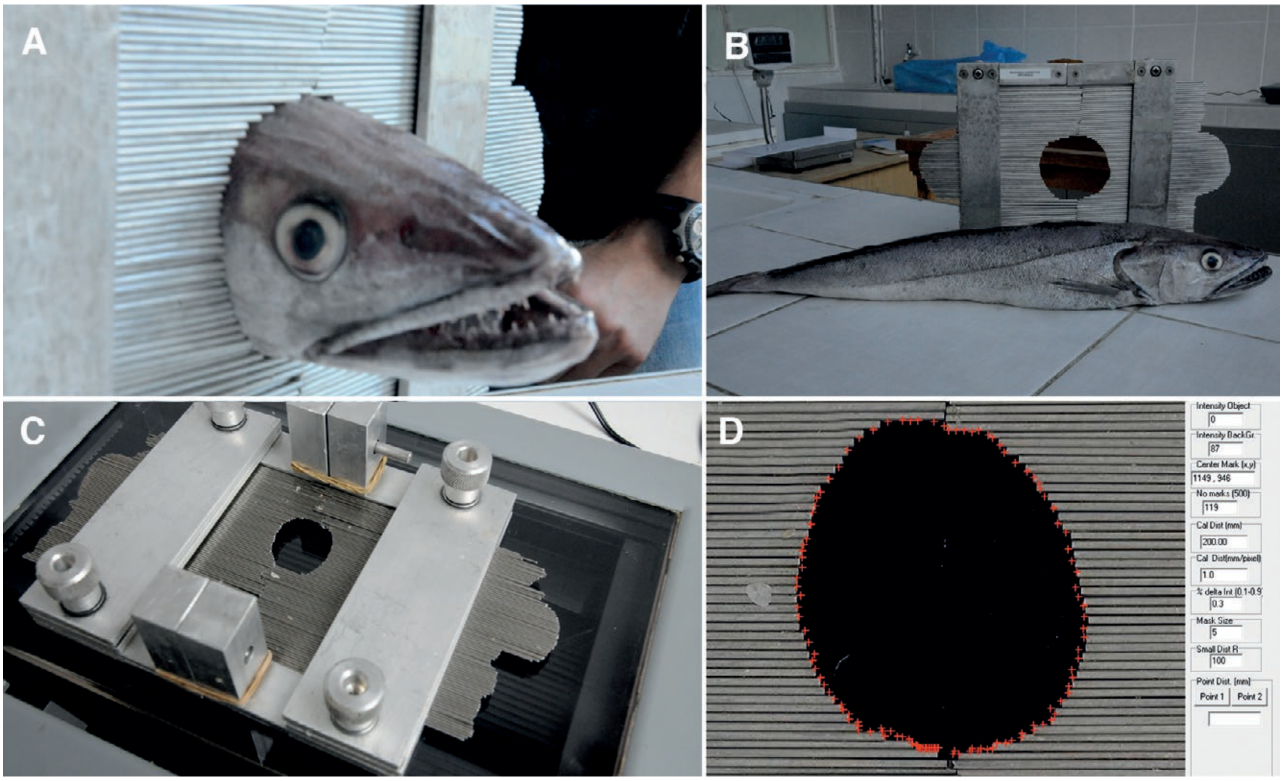


Fig. 2. – Extraction of cross-section shapes (CS) for a randomly selected hake (*Merluccius merluccius*). A, a hake (*Merluccius merluccius*) positioned in a morphometer at cross-section. B, the cross-section (CS) shape extracted by the morphometer. C, the morphometer is placed in a flatbed scanner for digitizing the shape into a computer image. D, the computer image of edge detection of CS.

flexdrope and superdrope [see Appendix A in Tokaç et al. (2016)]. The ellipse is fully described by two parameters, $c_1$ and $c_2$, while each of the three other shapes requires an additional parameter, $c_3$ [see Appendix A in Tokaç et al. (2016) for a mathematical description of the shapes]. The Akaike information criterion (AIC) (Akaike 1974) and $R^2$ were calculated for each individual for each of the four models for CS1, CS2 and CS3 [see Appendix A in Tokaç et al. (2016) for details].

The shape model with the lowest mean AIC value was chosen to describe each of the three cross-sections individually. The mean $R^2$ value was applied to judge how well the selected models described the cross-section shapes on average. When the best shape models had been chosen for CS1, CS2 and CS3, the parameters describing these shapes ($c_1$, $c_2$, and $c_3$) were related to total fish length and these functions were used to simulate the cross-sections (CS1, CS2 and CS3) for a virtual population of 5000 individuals with uniform length distributed between 1 and 90 cm to be subsequently used in the simulation of size selection.

## Fall-through experiments

After measuring fish morphology, we conducted fall-through experiments in order to examine and quantify potential compression of the measured cross-sections during a mesh penetration. A total of 478 stiff mesh templates, including diamond, square, rectangular, and hexagonal meshes with different mesh sizes and OAs were made with 5-mm-thick nylon plates (see Tokaç et al. 2016). In the fall-through trials, each fish was held by the tail and lowered vertically head-first and with optimal orientation for penetration into each of the 478 stiff mesh templates, and the results in terms of penetration (yes or no) were recorded. We used the pull of gravity as a proxy for fish swimming ability during mesh penetration, following Krag et al. (2011), as shown in Figure 3. A total of 35372 fall-through trials were carried out (74 fish × 478 mesh templates).

## Simulation of mesh penetration and selection of a penetration model

The cross-section shape and its compressibility will determine whether or not a fish will be able to pass through a mesh. The penetration models implemented in FISHSELECT simulate the compressibility of the fish for each measured cross-section. An initial inspection of the deformability of hake carried out by simply squeezing the tissue of a few individuals by hand revealed that the dorsal and the ventral compressibilities of the species are not symmetric. Therefore, we applied a penetration model which allows asymmetrical compression. This model, previously used for redfish (*Sebastes* spp.) by Herrmann et al. (2012) and for red mullet (*Mulllus barbatus*) by Tokaç et al. (2016), included the estimation of three parameters representing the dorsal, lateral and ventral compressibility of the fish. To establish an optimal penetration model for hake, each CS1, CS2 and CS3 individually

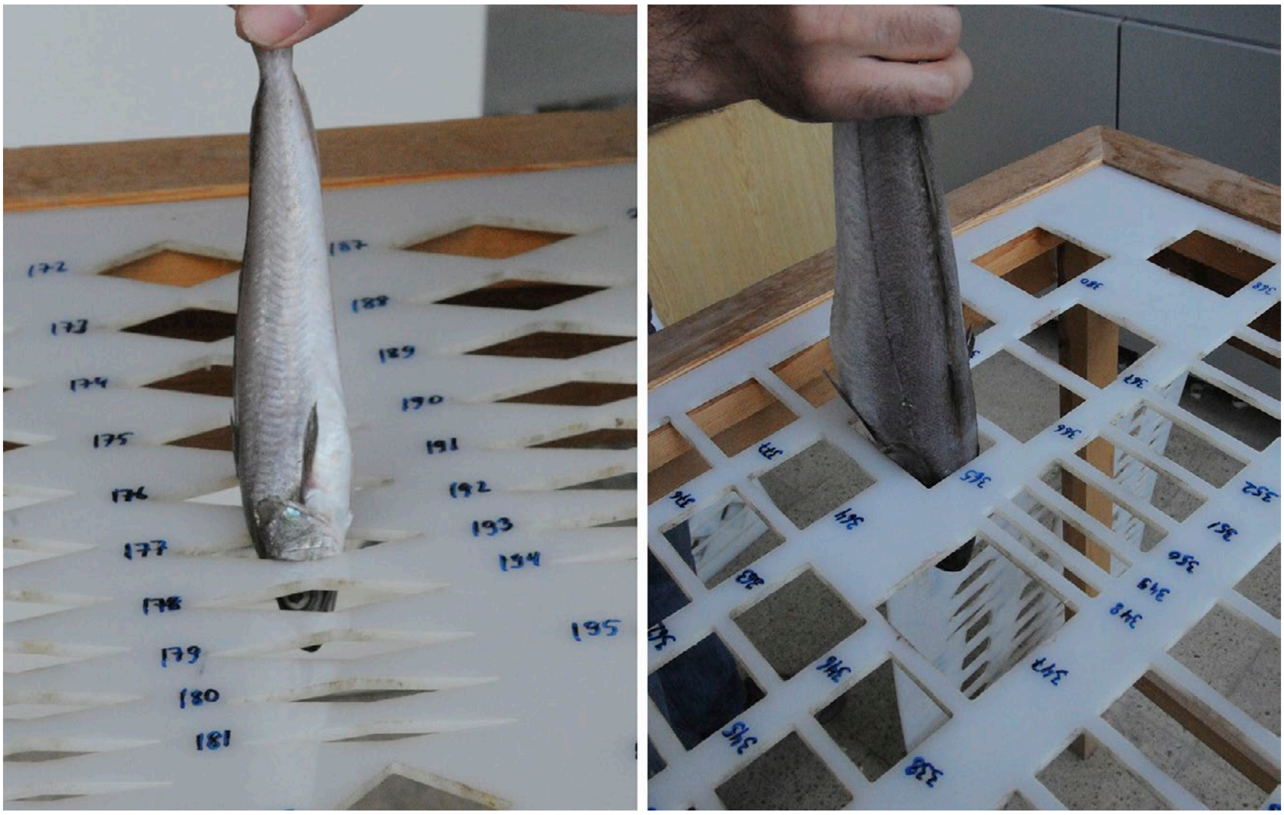


Fig. 3. – Fall-through experiments using stiff mesh templates of different mesh sizes and shapes. Left, example of diamond mesh template; right, example of square and rectangular mesh template.

and combined was tested with compression models with different assumed values for the dorsal, lateral and ventral compression. Thus, we simulated the penetration of the modelled CS1, CS2 and CS3 shapes of each fish through the 478 different mesh templates included in the fall-through trials using the FISHSELECT software. Models considering one cross-section at a time were created, where the dorsal, lateral and ventral compression were varied independently from 0% to 32% in 2% and 4% increments. This made 216 penetration models for each CS1 and CS2, 324 penetration models for CS3, and 15116544 combined models. Finally, we compared the results obtained from all the different penetration models with the experimental fall-through results using the FISHSELECT software. The evaluation was based on the degree of agreement value (DA-value) for the different models. The DA-value expresses the percentage of the fall-through results where the simulated result from FISHSELECT was the same as that obtained experimentally ("yes" or "no").

### Modelling of mesh shapes for diamond and square mesh codends during fishing

We needed an appropriate description of how the meshes in diamond and square mesh codends would behave during fishing in order to predict size selection of hake in codends relevant to the bottom trawl fishery.

For the diamond mesh codends, we assumed that because none of the mesh bars is perpendicular to the towing direction, there would be tension in all the four mesh bars of a diamond mesh during the fishing process (Krag et al. 2011, Herrmann et al. 2012, Tokaç et al. 2016). Further, we assumed that the diamond meshes will remain diamond-shaped and the mesh openness will not change when a hake attempts to escape through the mesh.

For square mesh codends, the circumferential mesh bars are perpendicular to the towing direction during fishing, which implies that these mesh bars are not under tension. For partly open square meshes we used the model established in Krag et al. (2011), assuming that the fish can bend or distort the circumferential mesh bars outwards during an escape attempt as these mesh bars are not under tension. Krag et al. (2011) approximated this situation with the hexagonal mesh description. Definitions of OAs for diamond and square meshes are completely different. One is an angle between adjacent bars; the other is the angle through which a single bar is distorted. Two related measures are applied to describe the openness of a diamond mesh and a hexagonal modelled distorted square mesh. These are the OA and the relative openness (OP), which quantifies the circumferential opening of the mesh relative to the longitudinal opening. More detailed information and a diagram regarding the definition of OA for a diamond mesh and a hexagonally distorted square mesh can be found in Tokaç et al. 2016.

To predict size selection of hake in diamond and square mesh codends, the population of 5000 virtual fish was simulated with a total of 528 diamond meshes of 40 to 100 mm mesh size ranging from 10° to 90° OAs and 1085 hexagonally distorted square meshes of 40 to 100 mm mesh size with 10° to 180° OAs using the FISHSELECT software. We followed the same protocol as that described by Tokaç et al. 2016 for the modelling of mesh shapes of diamond-and square-mesh codends during fishing.

### Investigating the effect of number of meshes in codend circumference

Sala and Lucchetti (2011) established an empirical model based on experimental data describing the effect of number of meshes in the circumference of the codend for hake. They found that values of L50 tend to decrease if the number of meshes in circumference in the codend increase, in agreement with the theoretical findings in Herrmann et al. (2007). From a mechanical point of view, the mechanism can be explained if we assume that the codend diameter is nearly independent of the number of meshes in circumference. This assumption implies that the OA value tends to decrease with an increasing number of meshes around (n). To investigate this in more detail, we plotted L50 values estimated from the model of Sala and Lucchetti (2011) for a codend mesh size of 50 mm for the number of meshes in the circumference equal to 240, 260, 280, 300 and 320. Then, based on FISHSELECT, we determined the extent to which we obtained a similar pattern for the L50 values assuming that OA is a specific decreasing function of n. A detailed explanation of the steps needed to apply the model to be used in the investigation of this effect can be found in Tokaç et al. 2016.

## RESULTS

### Fish shape and cross-section analysis

Based on AIC values (Table 3), the flexellipse1 model was chosen to model CS1 and CS3 while the flexdrope was chosen to model CS2. The mean $R^2$ values indicate that the cross-section shapes were well described by these models. Table 4 contains the values for the parameters describing CS1, CS2 and CS3 as a function of the length for hake.

### Fall-through results and penetration model

Based on the results from the 35372 fall-through trials, we selected a penetration model (compression model) to use for simulating size selection of hake. CS1 gave a DA value at 97.67% which was the highest. This result indicates that CS1 to a large extent determines the morphological limits for size selectivity for hake. We also tested combined models, CS1-CS2 and CS1-CS3, to find the best model, and they resulted in a DA value of 97.70% and 97.62%, respectively. Although the CS1-CS2 combined model gave a marginally higher DA value than CS1, we decided to use the CS1 single model as a best model for the predictions. The left panel of Figure 4 illustrates the fits of CS1 to the cross-section of a hake. The compressibility for this model of CS1 was 8% lateral, 0% dorsal and

Table 3. – Mean $R^2$ and AIC values for different shape descriptions of hake. The highest $R^2$ and lowest AIC values for each cross-section are in bold and represents the penetration model for the single cross-sections.

| | | Ellipse | Flexellipse1 | Flexdrope | Superdrope |
|---|---|---|---|---|---|
| CS1 | AIC | 198.3346 | **187.0137** | 190.1425 | 262.7069 |
| | $R^2$ | 0.7842 | **0.8040** | 0.7988 | 0.6096 |
| CS2 | AIC | 214.1890 | 211.7718 | **209.5100** | 276.9813 |
| | $R^2$ | 0.7912 | 0.8026 | **0.8137** | 0.6529 |
| CS3 | AIC | 243.8898 | **229.0969** | 237.9247 | 298.2263 |
| | $R^2$ | 0.8212 | **0.8549** | 0.8470 | 0.7397 |

Table 4. – Functions in terms of length for the three parameters used to describe CS1, CS2 and CS3. All models are power models, as for example (see Herrmann et al. 2009 for details). Input for length is in mm. Output for $c_1$, $c_2$ and $c_3$ is in mm. Formulae for cross-section models are in Appendix A in Tokaç et al. (2016). SD denotes standard deviation.

| | CS1: Flexellipse1 | | | CS2: Flexdrope | | | CS3: Flexellipse1 | | |
|---|---|---|---|---|---|---|---|---|---|
| | $c_1$ vs. length | $c_2$ vs. length | $c_3$ vs. length | $c_1$ vs. length | $c_2$ vs. length | $c_3$ vs. length | $c_1$ vs. length | $c_2$ vs. length | $c_3$ vs. length |
| a | 0.02255 | 0.07197 | 0.00227 | 0.02853 | 0.04691 | 0.00776 | 0.02106 | 0.04501 | 0.00002 |
| SD(a) | 0.00143 | 0.00389 | 0.00334 | 0.00208 | 0.00369 | 0.01063 | 0.00211 | 0.00405 | 0.00003 |
| b | 1.17 | 0.98 | 0.90 | 1.14 | 1.07 | 0.66 | 1.20 | 1.09 | 1.81 |

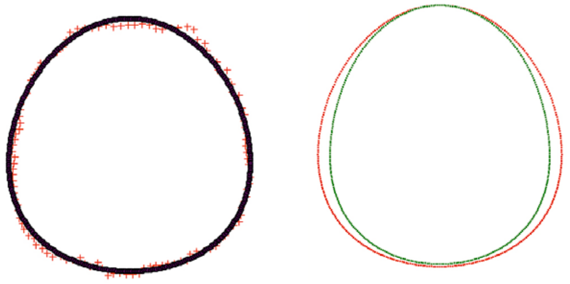

Fig. 4. – The fit of the cross-section and penetration model for hake. Left, example of a fit of the model selected for CS1 (Flexellipse1) to describe the cross-section; right, penetration model of CS1. The red (outer) curve represents the uncompressed outline and the green (inner) curve the compressed outline during mesh penetration according to the penetration model.

0% ventral. The right panel of Figure 4 illustrates the selected penetration model where the red (outer) curve represents the uncompressed fish and the green (inner) curve the maximal compressibility of a hake during a mesh penetration.

## Comparing FISHSELECT predictions with experimental selectivity data

We compared our FISHSELECT-based simulations of the selectivity of diamond meshes with experimental results for diamond mesh codends (Table 1). It is clearly seen in Figure 5 that the Italian data are different from the other experimental results. To show this difference more clearly, we plotted five linear trend lines with a 5° increment between the minimum (OA 20°) and maximum (OA 40°) L50 values for mesh sizes ranging from 40 to 100 mm (Fig. 5). The exception is the Italian estimates (Lucchetti 2008, Sala and Lucchetti 2010, 2011) which generally report lower selectivity, suggesting a lower and narrower OA range (20° to 30°) in the codend (Fig. 5). As a general result, the range of FISHSELECT predictions represents the experimental data fairly well, and most experimental results correspond to the size selection in diamond meshes with OAs of between 20° and 40° (Fig. 5). We will therefore use this range to predict the expected size selection in diamond mesh codends for hake.

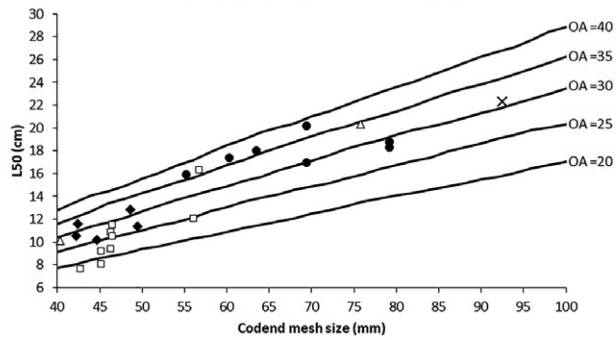


Fig. 5. – Predicted L50 values for diamond mesh codends for mesh sizes between 40 and 100 mm and opening angle of 20° and 40°, and linear trend lines and previously published L50 data from field experiments (Table 1). Black diamonds represent Turkish experimental results, white squares Italian ones, black circles Portuguese ones, white triangles Spanish ones and the cross the Danish one (see Table 1).

## Comparing FISHSELECT results with square mesh codend experimental data

For square meshes we simulated the size selection for meshes between 40 and 100 mm. We plot these FISHSELECT predictions (Fig. 6) against experimen-

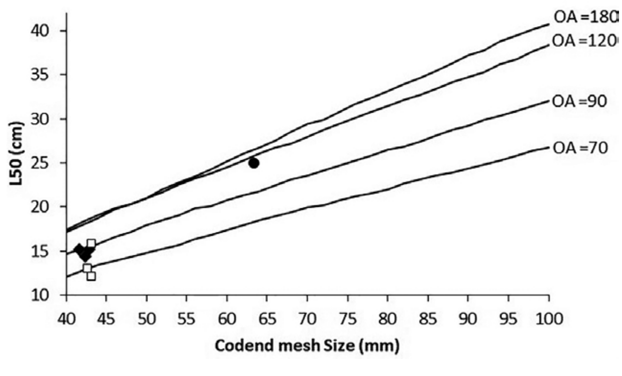


Fig. 6. – Predicted L50 values for square mesh codends for mesh sizes between 40 and 100 mm and opening angles between 70° and 180° (FISHSELECT 100% open) (solid lines) and previously published experimental L50 data (black diamonds represent Turkish experimental results, white squares Italian ones and black circles Portuguese ones) (Table 2).

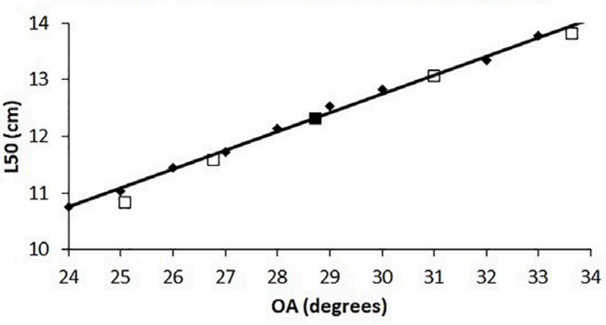


Fig 7. – L50 vs. mesh opening angle for 50 mm diamond from FISHSELECT and 50 mm diamond mesh for the Sala and Lucchetti (2011) model (unfilled square). Black square is the prediction for 280 meshes in circumference. The curve and black diamonds represent FISHSELECT L50 values.

tally obtained historical data in Table 2. The few available experimental results show that the experimental L50 values mostly correspond to those of meshes that are far from fully open. We see from Figure 6 that the FISHSELECT predictions represent the experimental square mesh codend selectivity data well for OAs between 70° and 120°, and we therefore use this range for comparison with diamond mesh codend size selection, as seen in Figure 8. FISHSELECT values for OA=180° represent a mesh that is fully open in Figure 6.

## Effect of number of meshes in circumference for diamond mesh codends

L50 values for a diamond mesh codend depend on the mesh OA. To investigate this, we plotted L50 values for 240, 260, 280, 300 and 320 meshes in the codend circumference based on the model of Sala and Lucchetti (2011) for a codend mesh size of 50 mm. These values were plotted against values obtained from FISHSELECT simulations and compared for similarity. Figure 7 compares the results from the model of Sala and Lucchetti (2011) for 240, 260, 280, 300 and 320 meshes around the codend (squares) with those obtained from FISHSELECT (curve), which are represented by black diamonds. The black square corresponds to the result for 280 meshes in circumference, which has been applied to find the expected codend diameter. The unfilled squares are then placed according to the calculated OA, assuming that codend diameter is constant over this range of meshes around the circumference. We are now able to model and predict the effect of number of meshes in the codend circumference for hake size selection in diamond mesh codends.

## Comparison of expected size selectivity for diamond and square mesh codends

When comparing FISHSELECT results with diamond and square mesh codend experimental results, we assumed the most suitable OA to be between 20° and 40° in diamond mesh codends and 70° and 120° in square mesh codends for prediction of the size selection of hake. For these ranges, we plotted the minimum and maximum L50 values predicted by FISHSELECT for mesh sizes ranging from 40 to 100 mm. We con-

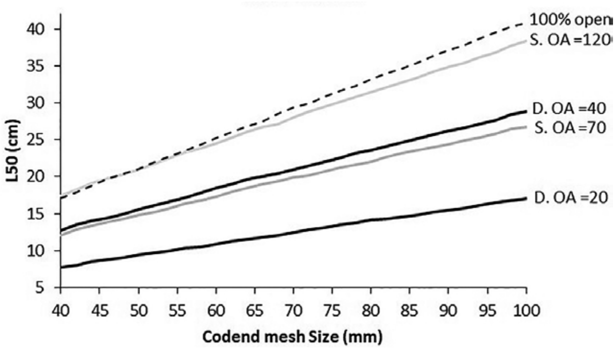


Fig. 8. – Expected ranges for L50 versus mesh size for both diamond and square mesh codends. The dashed black line represents fully open mesh, black solid lines represent minimum (20°) and maximum (40°) opening angles for diamond mesh codends and grey solid lines minimum (70°) and maximum (120°) opening angles for square mesh codends.

sidered a fully open square mesh codend as the most likely mean situation and therefore also plotted FISHSELECT predictions based on OA=180° (Fig. 8). It is clearly seen in Figure 8 that square mesh codends in

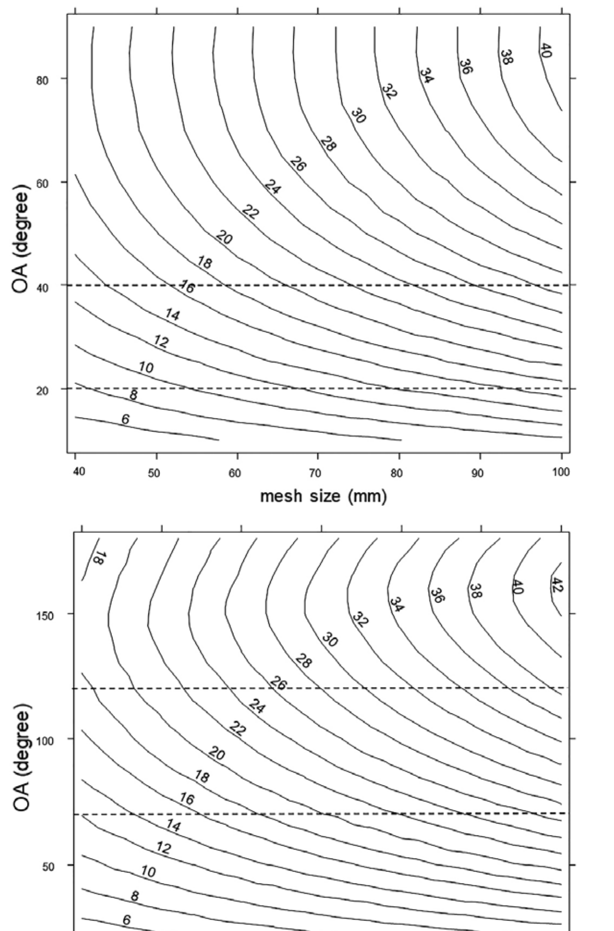


Fig. 9. – Design guides for diamond meshes showing L50 iso-lines (cm) for OA values between 10° and 90° (top) and for hexagonally distorted square meshes showing L50 isolines (cm) for opening angles between 10° and 180° (bottom) of hake for mesh sizes between 40 and 100 mm.

practice are more size-selective for hake than diamond mesh codends, simply because the square meshes are closer to being fully open during fishing than the diamond meshes. This is illustrated by Figure 8, which shows that the square mesh has an expected L50 range closer to that of the 100% open mesh than the diamond mesh.

### Design guides

The size selection predicted by FISHSELECT can be applied to produce design guides in the form of iso-curves for L50 values dependent on mesh size and mesh OAs. Figure 9 shows design guides for both diamond meshes and hexagonally distorted square meshes. For example, for diamond mesh sizes of 40, 44 and 50 mm for OAs fixed between 20° and 40°, L50s are predicted to be between 7.8 and 12.8 cm, 8.2 and 14.0 cm and 9.4 and 15.8 cm, respectively. The results demonstrate that for diamond meshes used in demersal trawl codends L50 increases with increasing mesh size and OA value. We used OAs fixed at 20° and 40° to predict the expected size selection in diamond mesh codends for hake because most experimental results corresponded to the size selection L50 parameters between these ranges of OAs.

From this design guide, we also see that for 40-mm square mesh sizes and OAs between 70° and 120°, L50s are predicted to range from 12 to 17.7 cm (Fig. 9). The design guides also show that L50 varies considerably with OA for a given mesh size. Figure 9 illustrates that much higher L50 can be obtained especially for square mesh codends if the mesh OA can be controlled.

## DISCUSSION

In this study we establish a better understanding of size selectivity of hake based on the FISHSELECT morphology method and investigate and predict the influence of mesh size and mesh OA on the size selection of hake in both diamond and square mesh codends for bottom trawls. The FISHSELECT method quantifies the mechanical aspects which determine size selectivity and does not explicitly account for behavioural aspects. However, the strong similarity found between the FISHSELECT predictions and the experimental results shows that the size selection of hake in diamond and square mesh codends can be explained to a large extent by mechanical aspects of fish morphology and mesh geometry. We examined three cross-sections to define the best penetration model for hake and concluded that the selective properties of hake are governed by CS1, as in the findings for e.g. cod and haddock (Herrmann et al. 2009, Krag et al. 2011). Maximum girth (CS3) does not describe the ability of hake to penetrate different mesh shapes, as CS3 can be compressed enough to become smaller than CS1.

Several selectivity studies based on both indirect estimation and direct measurements of mesh OAs have found that realistic OA values in diamond mesh codends during fishing are in the range of 15° to 75° (Herrmann et al. 2009) or 25° to 65° (Tokaç et al. 2016). For square mesh codends these values are about 66° to 180° (Krag et al. 2011) and 75° and 180° (Tokaç et al. 2016). The predictions of size selectivity for hake in the current study are in agreement with the experimentally obtained selectivity estimates when these OA ranges are assumed. The exception is the Italian estimates (Lucchetti 2008, Sala and Lucchetti 2010, 2011), which generally report lower selectivity, suggesting a lower and narrower OA range (20° to 30°) in the codend (Fig. 5). Trawl codends in the Italian studies are made from knotless netting, which may help explain the observed differences in selectivity. However, other design factors, such as twine thickness and material stiffness, are known to potentially affect codend size selection and may also contribute to the differences in observed L50 values (Sala et al. 2007, Sala and Lucchetti 2010, O'Neill et al. 2016). Further codend catch size have been found to influence size selection in diamond mesh codends in some cases by affecting OA for the meshes (Herrmann 2005b, Sala et al. 2006). This can thereby potentially cause differences in size selection between studies despite using identical codend design. All these aspects may beside number of meshes in codend circumference contribute to explain the variation observed in Figure 5.

The FISHSELECT predictions of size selectivity were in agreement with the experimentally obtained estimates when an OA value range of 20° to 40° was assumed for diamond mesh codends and from 70° to 120° for square mesh codends. Compared with that of previously studied species, hake selectivity occurs at rather lower mesh OAs of the trawl codend. Hake individuals are not able to decompress during the trawl retrieval process, resulting in them quickly losing their normal swimming orientation. This means that size selectivity of hake primarily may occur during towing on the seabed, where there is the most tension in the netting and therefore the lowest OA. This could provide an explanation for why experimental L50 results, stated as solid findings for hake size selectivity, are obtained at lower mesh OAs than those observed for most other species.

Reduced numbers of meshes in the diamond mesh codend circumference imply increased OA values for a given circumference, and our results explained those reported by Sala and Lucchetti (2011) and Tokaç et al. (2016). The FISHSELECT method demonstrated that the number of meshes in codend circumference plays a key role in the relation between mesh OAs and L50. There is very good agreement between the effect on L50 of changing the number of meshes in codend circumference predicted by Sala and Lucchetti (2011) and the results obtained in the current study. Similar agreement has also been found for red mullet (Tokaç et al. 2016).

When the selectivity of hake in square mesh codends is examined, the few experimental L50 values available suggest that the meshes are far from being fully open. This finding is in line with that of Krag et al. (2011). This situation for square mesh codends is also supported by the underwater in situ photos of square mesh codends presented in Robertson (1986). Further, an experimental study by Sala et al. (2016) explained why L50 values tended to decrease with an increasing number of meshes in circumference for square mesh codends.

We establish design guides which predict L50 values for hake over a large range of relevant mesh sizes and OAs. The design guides demonstrate the importance of mesh OAs during fishing. This effect of OA demonstrates that technical measures such as codend round-straps and lastridge ropes can affect L50 value because they restrict the codend meshes or help them open as the catch builds up during the fishing process (Herrmann et al. 2006). For diamond mesh codends, the OA value is not completely fixed, as it can vary with location along the codend (Herrmann et al. 2007) and is affected by the amount of catch (Herrmann 2005a,b). This was the case for diamond and square mesh codends, which are both legal alternatives for the demersal trawl fishery. In the current study, L50 values were predicted to be 9.4 to 15.8 cm for diamond mesh sizes of 50 mm and 12 to 17.7 cm for square mesh sizes of 40 mm. Considering the L50 values estimated in this study, it is concluded that square mesh netting is practically more selective for hake than diamond mesh netting, because during fishing activity square mesh has a wider opening than diamond mesh. However, these ranges of L50 values for hake for both 50 mm diamond and 40 mm square codends are well below the MCRS of 27 cm in European waters except the Mediterranean, as well as for the 20 cm MCRS in both European Mediterranean and Turkish territorial waters (TFR 2016), and even further from the mean size at first maturity [Lm of 29 cm for males and 38 cm for females reported by Recasens et al. (1998)].

For sustainable exploitation of marine resources, a meaningful relationship between the mesh size regulation and the MCRS is necessary. The results of this study indicate that a much better selectivity for hake is possible if better control of mesh OAs can be achieved during fishing activities. However, the study clearly indicates that the legal minimum mesh size and minimum conservation measurement size for the hake fishery currently in force are insufficient, considering the first maturity length of the fish.

Optimal mesh sizes and shape for a towed gear is greatly complicated in a multispecies setting in which species with different morphologies and minimum landing sizes are caught together (Krag et al. 2011). The ability to model complex cross-sectional shapes of hake as outlined in this study highlights the power of this method for predicting size selectivity based on morphological measures.

The results obtained for hake in this study are important in themselves. However, in trawl fisheries hake are seldom exploited as the only target species but rather as part of a mixed capture of many species with different morphological features. Therefore, to optimize codend selectivity one must consider a mix of species because a design which is good for one species may not be right for another. The method in this study applied for hake alone could be applied to other species of fish, crustaceans and cephalopods often caught together with hake in mixed demersal trawl fishery and would enable multispecies considerations in the future. However, the full benefit of our results for hake will first be obtained when the basic results are established for several of the species often caught together with hake, because it will then be possible to make complex cross-species investigations to make committed codend design optimizations that account for the trade-off between species that is necessary for mixed-species fisheries. The results presented for hake alone in this study are a necessary first step for enabling this kind of mixed species considerations for fisheries that involve hake.

Regarding SMPs which also are used in fisheries targeting hake (Alzorriz et al. 2016), the FISHSELECT method can provide useful information on the sizes of hake whose morphology will allow them to escape if they contact the SMP and can therefore be used to select mesh size for the SMP. However, the FISHSELECT method cannot account for the behavioural condition for escape (contacting the selection device).

The collection of live hake for morphological measurement in the current study indicated that hake appeared fragile in comparison with most of the other species caught. Unlike several other e.g. gadiforme species (Herrmann et al. 2009; Krag et al. 2011), hake has not been the subject of escape survival studies. Considering the importance of hake in the European fisheries and the effort invested in describing and improving size selectivity for hake, studies describing escape mortality for hake should be conducted.

## ACKNOWLEDGEMENTS

This study was conducted by the Science and Technology Centre of Ege University (Project no 2016 / SÜF / 008). We would like to thank the crew members of the RV *EGESÜF* for their valuable help during the sea trials. We are also very grateful to Dr R.S.T. Ferro for his great help in both scientific and language revision of the manuscript.

## REFERENCES

Akaike H. 1974. A new look at the statistical model identification. IEEE Trans.Autom. Control 19: 716-723. https://doi.org/10.1109/TAC.1974.1100705

Alzorriz N., Arregi L., Herrmann B., et al. 2016. Questioning the effectiveness of technical measures implemented by the Basque bottom otter trawl fleet: Implications under the EU landing obligation. Fish. Res. 175: 116-126. https://doi.org/10.1016/j.fishres.2015.11.023

Aydın C., Tosunoğlu Z. 2010. Selectivity of diamond, square and hexagonal mesh codends for Atlantic horse mackerel *Trachurus trachurus*, European hake *Merluccius merluccius*, and greater fork beard *Phycis blennoides* in the eastern Mediterranean. J. Appl. Ichthyol. 26: 71-77. https://doi.org/10.1111/j.1439-0426.2009.01376.x

Bahamon N., Sardá F., Suuronen P. 2006. Improvement of trawl selectivity in the NW Mediterranean demersal fishery by using a 40 mm square mesh codend. Fish. Res. 81: 15-25. https://doi.org/10.1016/j.fishres.2006.05.020

Bensch A., Gianni M., Gréboval D., et al. 2009. Worldwide review of bottom fisheries in the high seas. FAO Fish. Tech. Pap. No. 522, Rev.1. Rome, 145 pp.

Campos A., Fonseca P. 2003. Selectivity of diamond and square mesh cod ends for horse mackerel (*Trachurus trachurus*), Eu-

ropean hake (*Merluccius merluccius*) and axillary seabream (*Pagellus acarne*) in the shallow groundfish assemblage off the south-west coast of Portugal. Sci. Mar. 67: 249-260.
https://doi.org/10.3989/scimar.2003.67n2249

Campos A., Fonseca P., Erzini K. 2003a. Size selectivity of diamond and square mesh cod ends for four by-catch species in the crustacean fishery off the Portuguese south coast. Fish. Res. 60: 79-97.
https://doi.org/10.1016/S0165-7836(02)00061-9

Campos A., Fonseca P., Henriques V. 2003b. Size selectivity for four fish species of the deep groundfish assemblage off the Portuguese southwest coast: evidence of mesh size, mesh configuration and cod end catch effects. Fish. Res. 63: 213-233.
https://doi.org/10.1016/S0165-7836(03)00060-2

Casey J., Pereiro J. 1995. European hake (*M. merluccius*) in the north-east Atlantic. In: Alheit J., Pitcher T.J. (eds), Hake: Fisheries, Ecology and Markets. Chapman and Hall, London, pp. 125-148.
https://doi.org/10.1007/978-94-011-1300-7_5

Cohen D, Tadashi I., Tomio I., et al. 1990. Gadiform fishes of the world. FAO Fisheries Synopsis, 125. FAO, Rome. 442 pp.

European Commision (EC). 1998. Council regulation (EC) No. 850/98 of 30 March 1998 for the conservation of fishery resources through technical measures for the protection of juveniles of marine organisms. OJL. 125: 52 pp.

European Commision (EC). 2004. Council regulation (EC) No. 811/2004 of 21 April 2004 establishing measures for the recovery of the northern hake stock. OJL. 150: 1-11.

European Commision (EC). 2006a. Council Regulation (EC) No. 51/2006 of 22 December 2005 fixing for 2006 the fishing opportunities and associated conditions for certain fish stocks and groups of fish stocks, applicable in Community waters and, for Community vessels, in waters where catch limitations are required. OJL. 16: 148-149.

European Commision (EC). 2006b. Council Regulation (EC) No 1967/2006 of 21 December 2006, concerning management measures for the sustainable exploitation of fishery resources in the Mediterranean Sea, amending Regulation (EEC) No 2847/93 and repealing Regulation (EC) No 1626/94. OJL. 409: 11-85.

FAO. 2018. Fishery and Aquaculture Statistics. Global capture production 1950-2016 (FishstatJ). Rome. Online.

Frandsen R.P., Holst R., Madsen N. 2009. Evaluation of three levels of selective devices relevant to management of the Danish Kattegat-Skagerrak *Nephrops* fishery. Fish. Res. 97: 243-252.
https://doi.org/10.1016/j.fishres.2009.02.010

Herrmann B. 2005a. Effect of catch size and shape on the selectivity of diamond mesh cod-ends. I. Model development. Fish. Res. 71: 1-13.
https://doi.org/10.1016/j.fishres.2004.08.024

Herrmann B. 2005b. Effect of catch size and shape on the selectivity of diamond mesh cod-ends. II. Theoretical study of haddock selection. Fish. Res. 71: 15-26.
https://doi.org/10.1016/j.fishres.2004.08.021

Herrmann B., Priour D., Krag L.A. 2006. Theoretical study of the effect of roundstraps on the selectivity in a diamond mesh codend. Fish. Res. 80: 148-157.
https://doi.org/10.1016/j.fishres.2006.04.018

Herrmann B., Priour D., Krag L.A. 2007. Simulation-based study of the combined effect on codend size selection for round fish of turning mesh 90 degree and of reducing the number of meshes in the circumference. Fish. Res. 84: 222-232.
https://doi.org/10.1016/j.fishres.2006.10.020

Herrmann B., Krag L.A., Frandsen R.P., et al. 2009. Prediction of selectivity from morphological conditions: methodology and a case study on cod (*Gadus morhua*). Fish. Res. 97: 59-71.
https://doi.org/10.1016/j.fishres.2009.01.002

Herrmann B., Sistiaga M., Nielsen K.N., et al. 2012. Understanding the size selectivity of redfish (*Sebastes* spp.) in North Atlantic trawl codends. J. Northwest Atl. Fish. Sci. 44: 1-13.
https://doi.org/10.2960/J.v44.m680

Krag L.A., Herrmann B., Madsen N., et al. 2011. Size selection of haddock (*Melanogrammus aeglefinus*) in square mesh codends: a study based on assessment of decisive morphology for mesh penetration. Fish. Res. 110: 225-235.
https://doi.org/10.1016/j.fishres.2011.03.009

Lucchetti A. 2008. Comparison of diamond- and square-mesh codends in the hake (*Merluccius merluccius* L. 1758) trawl fishery of the Adriatic Sea (central Mediterranean). Sci. Mar. 72: 451-460.

O'Neill F.G., Kynoch R.J., Blackadder L., et al. 2016. The influence of twine tenacity, thickness and bending stiffness on codend selectivity. Fish. Res. 176: 94-99.
https://doi.org/10.1016/j.fishres.2015.12.012

Ordines F., Massutí E., Guijarro B., et al. 2006. Diamond vs. square-mesh codend in a multi-species trawl fishery of the western Mediterranean: effects on catch composition, yield, size selectivity and discards. Aquat. Living Resour. 19: 329-338.
https://doi.org/10.1051/alr:2007003

Özbilgin H., Tokaç A., Kaykaç M.H. 2012. Selectivity of commercial compared to larger mesh and square mesh trawl codends for four fish species in the Aegean Sea. J. Appl. Ichthyol. 28: 51-59.
https://doi.org/10.1111/j.1439-0426.2011.01916.x

Recasens L., Lombarte A., Morales-Nin B., et al. 1998. Spatiotemporal variations in the population structure of the European hake in the northwestern Mediterranean. J. Fish Biol. 53: 387-401.
https://doi.org/10.1111/j.1095-8649.1998.tb00988.x

Robertson J.H.B. 1986. Design and construction of square mesh cod-ends. Scottish Fish. Inf. Pamph. No. 12. Aberdeen. 10 pp.

Sala A., Lucchetti A. 2010. The effect of mesh configuration and codend circumference on selectivity in the Mediterranean trawl *Nephrops* fishery. Fish. Res. 103: 63-72.
https://doi.org/10.1016/j.fishres.2010.02.003

Sala A., Lucchetti A. 2011. Effect of mesh size and codend circumference on selectivity in the Mediterranean demersal trawl fisheries. Fish. Res. 110: 252-258.
https://doi.org/10.1016/j.fishres.2011.04.012

Sala A., Priour D., Herrmann B. 2006. Experimental and theoretical study of red mullet (*Mullus barbatus*) selection in codends of Mediterranean bottoms trawls. Aquat. Living Resour. 19: 317-327.
https://doi.org/10.1051/alr:2007002

Sala A., Lucchetti A., Buglioni G. 2007. The influence of twine thickness on the size selectivity of polyamide codends in a Mediterranean bottom trawl. Fish. Res. 83: 192-203.
https://doi.org/10.1016/j.fishres.2006.09.013

Sala A, Herrmann B, De Carlo F., et al. 2016. Effect of codend circumference on the size selection of square-mesh codends in trawl fisheries. PLoS One. 11: e0160354.
https://doi.org/10.1371/journal.pone.0160354

Sistiaga M., Herrmann B., Nielsen K.N., et al. 2011. Understanding limits tocod and haddock separation using size selectivity in a multi-species trawlfishery: an application of FISHSELECT. Can. J. Fish. Aquat. Sci. 68: 927-940.
https://doi.org/10.1139/f2011-017

Tokaç A., Özbilgin H., Kaykaç H. 2010. Selectivity of conventional and alternative codend design for five fish species in the Aegean Sea. J. Appl. Ichthyol. 26: 403-409.
https://doi.org/10.1111/j.1439-0426.2009.01379.x

Tokaç A., Herrmann B., Gökçe G., et al. 2016. Understanding the size selectivity of red mullet (*Mullus barbatu*s) in Mediterranean trawl codends: A study based on fish morphology. Fish. Res. 174: 81-93.
https://doi.org/10.1016/j.fishres.2015.09.002

Tosunoğlu Z., Aydın C., Özaydın O. 2008. Selectivity of a 50-mm diamond mesh knotless polyethylene codend for commercially important fish species in the Aegean Sea. J. Appl. Ichthyol. 24: 311-315.
https://doi.org/10.1111/j.1439-0426.2008.01067.x

Turkish Fisheries Regulation (TFR). 2016. Turkish Fisheries Regulation (TFR) No. 4/1-2016 concerning commercial fish catching regulations in 2016-2020 fishing period. Beyda Ofset. Ankara, 112 pp. (in Turkish).

Wileman D.A., Ferro R.S.T., Fonteyne R., et al. 1996. Manual of methods of measuring the selectivity of towed fishing gears. ICES Coop. Res. Rep. No. 215. 126 pp.