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CREELSELECT - a method for determining the optimal creel mesh: case study on Norway lobster (*Nephrops norvegicus*) fishery in the Mediterranean Sea

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Abstract

In the laboratory, we investigated which sizes of *Nephrops* (*Nephrops norvegicus*) could pass through the meshes of different size and shape to establish a predictive model for the creels size selectivity. Predictions agreed well with the results from experimental fishing, demonstrating the reliability of this simple method. *Nephrops* minimum target size is 20 mm carapace length in the Mediterranean creel fishery, with some areas having restrictions on the mesh size, minimum being 36 or 40 mm. The model predicts that *Nephrops* below 28 and 32 mm carapace length would escape from creels with respectively 36 and 40 mm mesh size, implying a suboptimal exploitation pattern. Our method provides easy and quick identification of optimal mesh size and shape without the exhaustive sea trials with various creel designs. It was predicted that a square mesh of 30 mm would better match the desired exploitation pattern. The method could easily be adopted to other species and different creel fisheries, helping to determine optimal mesh matching a prescribed exploitation pattern.

Introduction

In the Mediterranean Sea, *Nephrops* (*Nephrops norvegicus*) is harvested by bottom trawls and creels, with trawling being the dominant fishing technique. In Croatia, around 90-95% of *Nephrops* is caught by bottom trawls and 5-10% with creels (Data for 2013 – 2015, Croatian Ministry of Agriculture). Creel fishery delivers high quality product with small environmental cost (Eno et al. 2001; Morello et al. 2009), making it a good alternative to trawling. Croatian creel fishermen are, depending on the region, allowed to use either minimum 36 or 40 mm square mesh (Croatian Regulation NN 84/2015). However, in other Mediterranean regions creel fishermen do not have mesh size restrictions, but they are obliged not to land *Nephrops* below the minimum landing size (MLS) of 20 mm carapace length (Council Regulation (EC) No 1967/2006). The question is how to identify the optimal creel mesh, matching the desired exploitation pattern (one that retains all sizes above, and releases all sizes below the minimum landing size)? Traditionally this has been done by conducting a series of experimental sea trials, but, apart from being costly and time consuming, sea trials are limited by the amount of different meshes that can be tested. Due to this limitation, we used a different approach, where a predictive model for creel selectivity was obtained based on laboratory experiments using dead *Nephrops*. Our approach has some conceptual similarities with the method for investigating blue crab size selectivity described in Guillory (1998), but it was mostly inspired by a method previously applied for trawls (Herrmann et al. 2009; Frandsen et al. 2010; Krag et al. 2011; Herrmann et al. 2013; Tokaç et al. 2016) and demersal seine selectivity (Herrmann et al. 2016a; Herrmann et al. 2016b). However, this method has never been applied to predict the creel size selectivity and, in addition our approach is simpler and easier to use.

The main objectives of this study were to:

- determine how *Nephrops* escape through the creel meshes,
- establish a predictive model for creel size selectivity for *Nephrops* and
- use the model to predict creel mesh size and shape that would match specific desired exploitation pattern for *Nephrops*.

Key words: Norway lobster, *Nephrops norvegicus*, creel selectivity, pot selectivity

Material and methods

Determining how Nephrops is *escaping through the creel meshes*

Frandsen et al. (2010) investigated size selection of *Nephrops* in bottom trawls by measuring *Nephrops* morphology and using computer simulations. The method also included conducting so-called fall-through experiments by testing which sizes of dead *Nephrops* could pass through the meshes of different sizes and shapes under the pull of gravity alone. Frandsen et al. (2010) assumed that *Nephrops* potentially contacts meshes oriented or curled in different ways (so-called contact modes). The size selection in a specific mesh will therefore depend on the way *Nephrops* contacts the netting. From the eight initial contact modes considered, three were identified to mainly contribute to the trawl size selectivity. Unlike trawls, creels lie stationary on the seabed, providing *Nephrops* much more time to orientate themselves to escape from the creel if they attempt prior to the creel retrieval. The contribution of different contact modes for size selection of *Nephrops* in creels is therefore unknown and may be different from those in trawls. In the present study, the approach of Frandsen et al. (2010) was simplified by using only fall-through experiments for investigating creel size selectivity.

As a starting point, the same eight potential contact modes were used (Fig. 1) as Frandsen et al. (2010). It was identified first which mode(s) determine size selection of *Nephrops* in creels. To do this, a sample of *Nephrops* was collected using a commercial fishing vessel equipped with the typical Mediterranean bottom trawl in the central Adriatic Sea. Sampled *Nephrops* were kept on ice until they reached the laboratory, where they were frozen individually. Prior to the fall-through experiments, the individuals were defrosted and the carapace length (CL) of each individual was measured. According to Frandsen et al. (2010), freezing does not affect the cross-sectional shape of *Nephrops* nor its ability to pass through the meshes. The fall-through experiments were conducted for each potential contact mode using one specific mesh (square 40 mm) and a sample of *Nephrops*. The 40 mm square mesh was selected because it approximates experimental netting for which experimental creel size selection data was available.

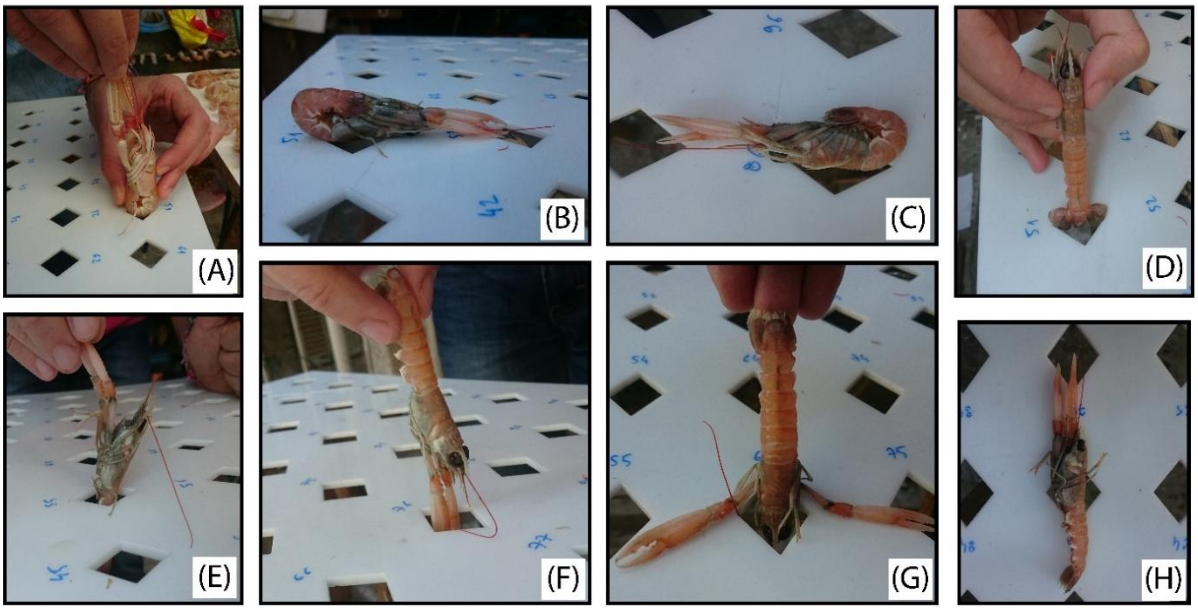

Fig. 1. Potential contact modes used to test *Nephrops* ability to penetrate the 40 mm square mesh.

The fall-through data were treated as a cover codend data (Wileman et al., 1996) for each contact mode separately, where each *Nephrops* that passed through the 40 mm square mesh was considered to escape and all others were considered to be retained. Hence, each dataset contained information on the number of successful and failed passes for each length class (1 mm wide carapace length). The following *logit* size selection model was then fitted to the fall-through dataset for each contact mode to obtain a size selectivity curve for each mode (further in text referred to as "fall-through size selection curve"):

$$r(l, L50, SR) = \frac{\exp((l - L50) \times \ln(9) / SR)}{1 + \exp((l - L50) \times \ln(9) / SR)} \quad (1)$$

where *l* represents carapace length, *L50* carapace length at which a *Nephrops* has 50% probability of being retained and *SR* = L75 - L25. By comparing each fall-through size selection curve with the experimental size selection curve, it was possible to judge whether each of these contact modes contributes to the *Nephrops* creel size selection or not. This was determined by inspecting if the 95% confidence intervals (CIs) of the curves overlap. All modes without any overlap between CIs were immediately excluded from further consideration. Fall-through size selectivity curves for remaining contact modes where then compared pairwise and those leading to identical or nearly identical size selection were represented by only one of the modes because they would predict similar size selection. Ideally, this procedure leads to only one contact mode for determining creel size selection of *Nephrops* and the following description is based on the presumption that this condition is fulfilled.

Establishing a predictive model for creel size selectivity

The contact mode identified to determine creel size selection (previous section), was applied to establish fall-through size selection data to obtain the predictive model. The creels applied to harvest *Nephrops* in Mediterranean waters typically use one specific type of netting stretched over a metal frame (Fig. 2). Typical diamond mesh netting with minimum 36 or 40 mm mesh size is mounted in a way to form square meshes and attain a mesh opening angle of approximately 90 degrees because this is required by the regulation for some areas (Croatian Regulation NN 84/2015). However, a deviation in the mesh opening angle from the square shape of ±10% is tolerated. Therefore, a predictive model should enable quantifying the effect of mesh opening angle, as well as mesh size, on the creel size selection of *Nephrops*.

Fig 2. *Nephrops* creel used in the Brčić et al. (2018).

Since the creel netting is stretched over a metal frame, the meshes have a fixed shape during fishing and it is unlikely that *Nephrops*, while attempting to escape through, would be able to distort the shape of the mesh. Therefore, we assume it is realistic to use stiff mesh templates in fall-through experiments to provide data for establishing a predictive model for creel size selection of *Nephrops*. A total of 110 different stiff ideal diamond mesh templates were produced and used for the data collection for the predictive model (Fig. 3). The meshes ranged from 30 to 50 mm in mesh size (MS) with opening angle (OA) ranging from 45° to 90°. This range of mesh sizes was chosen because we wanted to investigate the selectivity of creel meshes that were within ±10 mm of legally prescribed meshes.

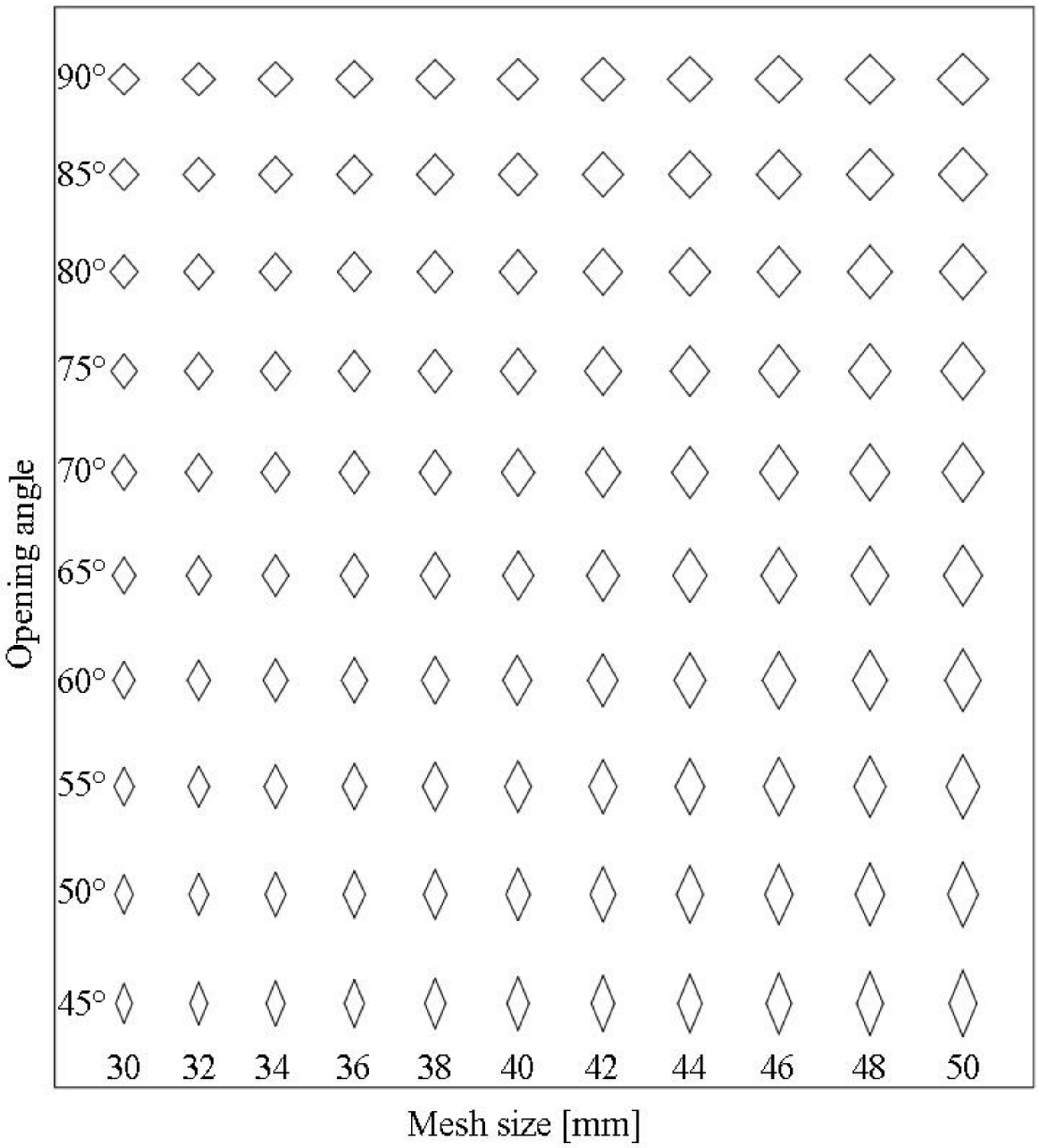

Fig. 3. Mesh templates used for the fall-through experiments. Mesh size ranges from 30 to 50 mm and opening angle range from 45° to 90°.

The same sample of *Nephrops* was used in testing of each mesh template to obtain fall-through selectivity data for each identified contact mode. The resulting 110 fall-through datasets were then treated as a size selectivity data and analysed using the software tool SELNET (Wienbeck et al. 2011; Sala et al. 2016a; 2016b), following the methodology described by Fryer (1991). First a *logit* curve (1) was fitted to each fall-through dataset. Then using the obtained *L50* and *SR* values from each analysed dataset, their covariance matrix and the values for mesh size (*MS*) and mesh opening angle (*OA*), the following predictive size selection model was established:

$$\begin{aligned} L50 &= \alpha_1 \times MS \times OA + \alpha_2 \times MS \times OA^2 + \alpha_3 \times MS \times OA^3 \\ SR &= \beta_1 \times MS \times OA + \beta_2 \times MS \times OA^2 + \beta_3 \times MS \times OA^3 \end{aligned} \tag{2}$$

where $\alpha_1, \alpha_2, \alpha_3$ and $\beta_1, \beta_2, \beta_3$ are the coefficients to be estimated. Using model (2) as a starting point, all possible simpler sub-models obtained by leaving out one or more parameters at the time were also considered for predicting *L50* and *SR* following the procedure described by Sala et al. (2016b). Based on this procedure, a total of 64 models were considered, and the one with the lowest AIC value (Akaike 1974) was selected as predictive model.

To check the self-consistency of the model, the obtained *L50* and *SR* values for individual fall-through datasets and their 95 % CI were plotted against mesh size and mesh opening angle, together with predictions based on the established model.

Finally, the predictive model was checked against the experimental creel selectivity obtained by Brčić et al. (2018) for the creel with the nominal 40 mm square mesh. To make this comparison as accurate as possible, actual mean mesh size and opening angle was acquired for one of the experimental creels used by Brčić et al. (2018). In total, 28 meshes were scanned, and by using the image analysis facilities of the FISHSELECT software (Herrmann et al., 2013), mesh sizes and opening angles were obtained by fitting an ideal diamond shape to each image. Mean mesh size and mean mesh opening values were then calculated based on these individual values. Subsequently, these mean values were applied to predict the experimental creel size selectivity.

Predicting creel size selectivity

The established model was subsequently applied to predict size selection for creels with other mesh sizes and mesh opening angles. The results were visualized in so-called design guides - plots showing predicted L50 and SR values as isocurves for a relevant range of mesh sizes versus mesh opening angels (Herrmann et al., 2009). These plots provide information to assist determination of the creel mesh design to obtain a specific exploitation pattern.

Results

Selecting mode of contact to predict creel size selection

A total of 86 *Nephrops* ranging from 15 to 43 mm CL were used in the experiment with the 40 mm square mesh. Of the eight tested contact modes (Fig. 1) only modes E and F led to fall-through size selection curves with CI's overlapping with the CI's for the size selection curve obtained experimentally by Brčić et al. (2018) (Fig. 4). Therefore, only these contact modes were considered further for the prediction of creel size selection. Modes B, C, D, G and H were clearly not realistic. For mode A the discrepancy between the fall through size selection curve and the one from fishing trials is smaller. However, the fall through curve is significantly biased towards smaller sizes of *Nephrops* and given that modes F and E better describe the experimental size selection curve, it is considered unlikely that mode A is important for *Nephrops* escapement from creels.

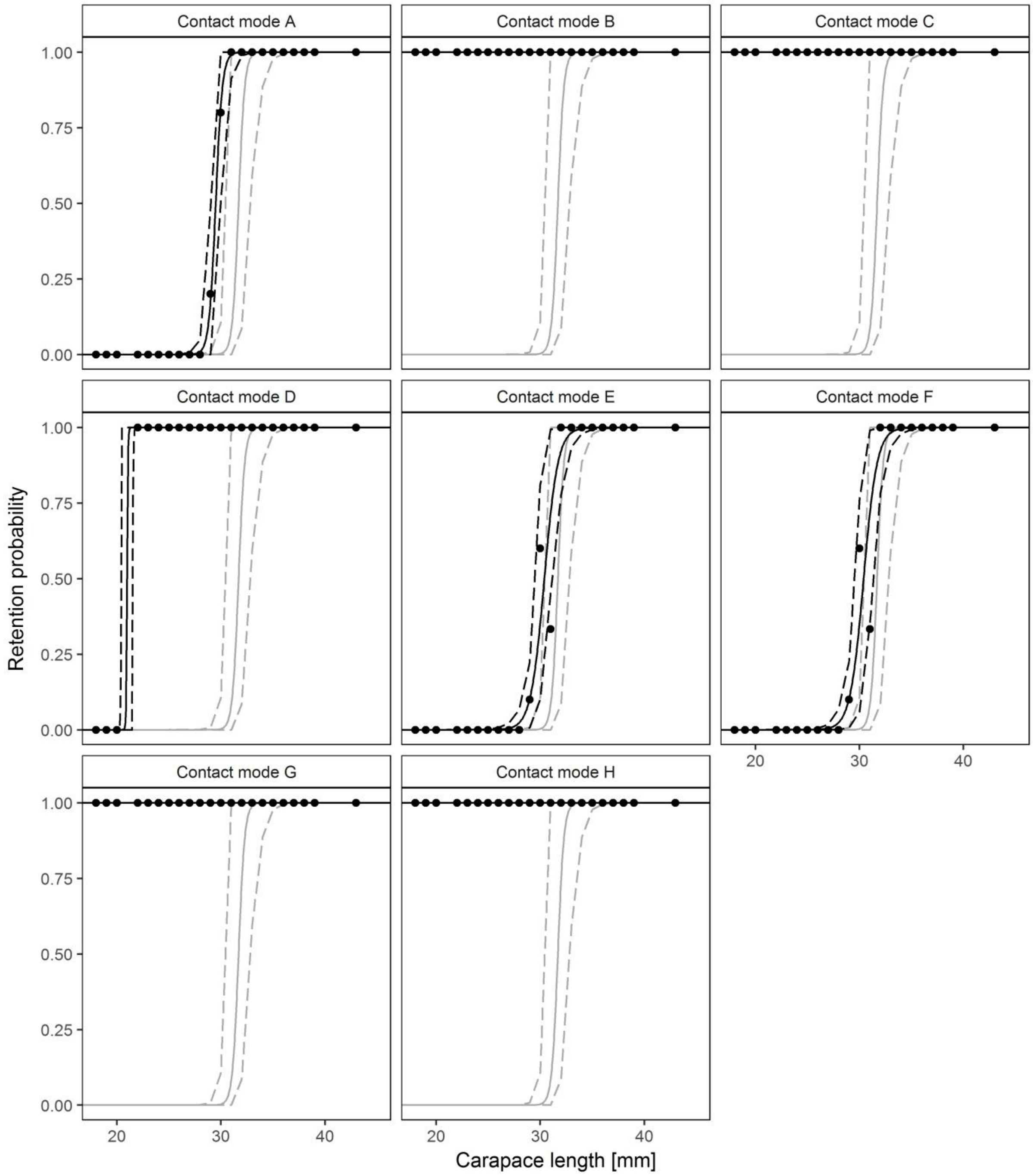

Fig. 4. Comparison between the retention probabilities of eight different potential modes of escapement (black) and experimentally obtained size selection data from Brčić et al. (2018)

(grey) for 40 mm square mesh (Opening Angle=90°); Black symbols represent the experimental fall through probability; A, B, C, D, E, F, G, H: different contact modes (detailed in the Fig. 1).

Pairwise comparison of the E and F mode showed a total overlap between curves meaning that for prediction of creel size selection either one of them can be used (Fig 5). Therefore, only the contact mode E was considered for the additional steps in the experiment.

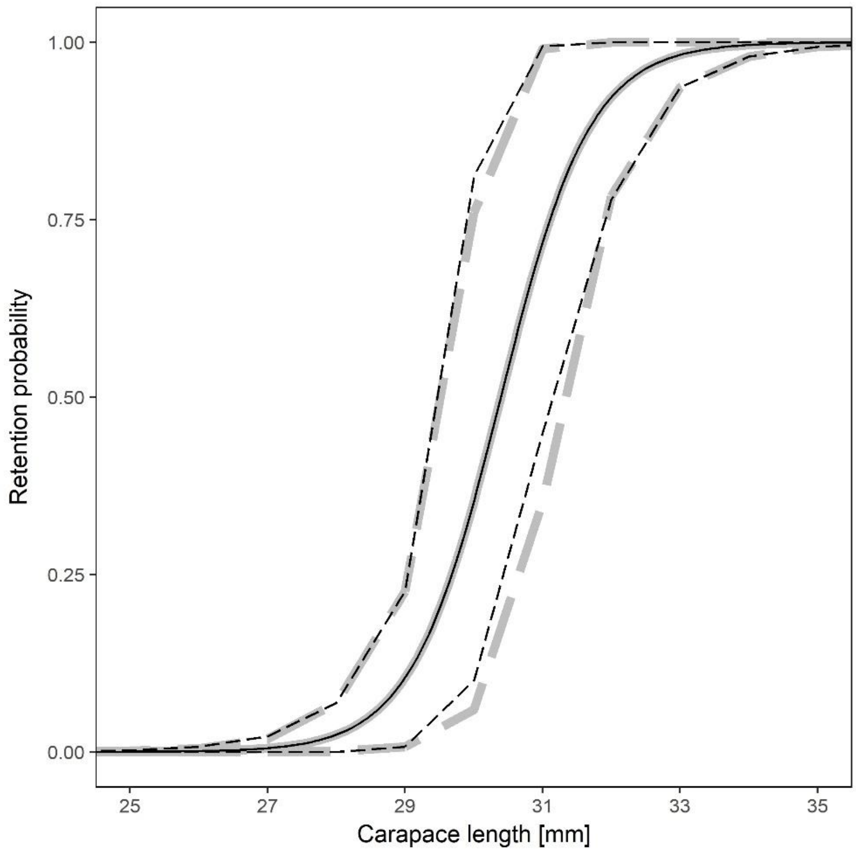

Fig. 5. Comparison between the fall-through size selectivity curves for contact modes E (black solid curve) and F (grey solid tick curve) mode. Dashed lines represent 95% confidence intervals.

Predictive model for creel size selectivity for Nephrops

All 86 *Nephrops* used in the fall-through experiment with the 40 mm square mesh were also used in the fall-through experiments with the 110 mesh templates, leading to a total of 9460 fall-through results for the contact mode E. The resulting 110 fall-through size selectivity datasets formed the basis for constructing the predictive model for creel size selection. Among 64 competing models, the model with the lowest AIC (Table 1) was found to be:

$$\begin{aligned} L50 &= \alpha_1 \times MS \times OA + \alpha_2 \times MS \times OA^2 \\ SR &= \beta_1 \times MS \times OA + \beta_2 \times MS \times OA^2 \end{aligned} \tag{3}$$

Table 1. Results for fitting model (3) to the fall-through size selectivity data. 95% C.I.: 95% confidence intervals;

			95% C.I.		
Parameter	**Factor**	**Value**	**low**	**high**	**p-value**
L50 [mm]	α_1	1.8323E-02	1.8116E-02	1.8531E-02	<0.0001
	α_2	-1.0771E-04	-1.1046E-04	-1.0495E-04	<0.0001
SR [mm]	β_1	8.4598E-04	5.5312E-04	1.1388E-03	<0.0001
	β_2	-4.0627E-06	-8.1104E-06	-1.5100E-08	0.0499

Plotting the estimated L50 and SR values and their 95% confidence intervals from the 110 individual fall-through datasets, against mesh size and mesh opening angle, together with the model prediction, revealed that the model represented the trends in the fall through data well (Figs. A1-A4 in the Appendix). This allowed the use of the model (3) to predict *Nephrops* creel size selectivity for the range of mesh sizes and mesh openings used in the fall-through experiments.

To accurately compare the predictions made with the model (3) with the existing experimental size selectivity curve obtained by Brčić et al. (2018), one typical creel that was considered to be representative of the creels used in Brčić et al. (2018) was selected and the exact measurements of 28 creel meshes (Table 2) were obtained.

The mean mesh size was calculated to be 41.04 ± 0.72 mm (± SD) and mesh opening angle 82.46 ± 4.35° (± SD).

Table 2. Mesh size (MS) and mesh opening angle (OA) obtained from the scanned images of creels meshes for one creel used in Brčić et al. (2018).

Mesh ID	MS [mm]	OA[°]	R^2
M1	41.37	82.04	0.9769
M2	40.68	80.48	0.9759
M3	41.50	79.92	0.9857
M4	41.82	78.77	0.9758
M5	40.70	77.83	0.9808
M6	41.70	79.90	0.9752
M7	40.82	77.67	0.9695
M8	40.47	79.62	0.9919
M9	41.32	78.56	0.9847
M10	40.23	81.13	0.9466
M11	41.38	79.23	0.9703
M12	39.73	82.94	0.9625
M13	39.94	83.13	0.9560
M14	40.56	79.36	0.9540
M15	40.80	78.42	0.9601
M16	40.17	84.60	0.9651
M17	40.23	82.42	0.9719
M18	40.73	83.53	0.9739
M19	41.06	86.10	0.9598
M20	41.05	86.62	0.9708
M21	40.75	86.81	0.9832
M22	40.93	84.36	0.9543
M23	41.49	85.27	0.9501
M24	41.66	83.42	0.9598
M25	41.15	92.45	0.9448
M26	41.84	81.78	0.9791
M27	43.06	77.01	0.9781
M28	41.99	95.72	0.9439
Mean (SD)	**41.04 (0.72)**	**82.47 (4.35)**	**0.9679 (0.0133)**

The mean mesh size and mesh opening angle were then applied in the model (3) to make prediction that can be compared with the experimentally available results obtained by Brčić et al. (2018) (Fig. 6).

Fig. 6 shows that the predicted curve overlaps with the experimentally obtained curve, and it is completely positioned inside the experimentally obtained 95% confidence intervals. Therefore, we see that experimentally obtained *Nephrops* creel size selectivity can be accurately reproduced using the model (3).

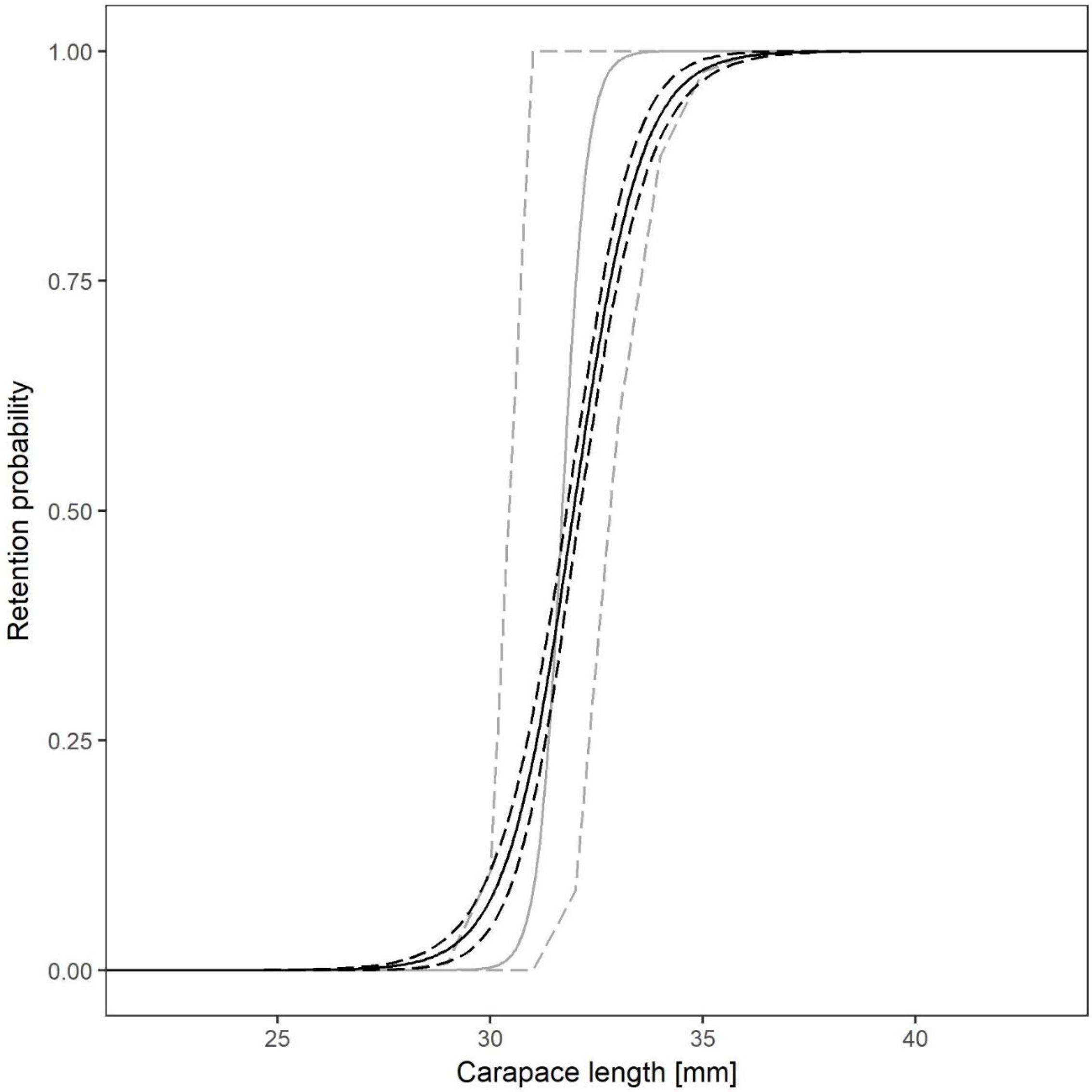

Fig. 6. Experimental vs. predicted creel size selection curve for *Nephrops*. The solid grey line represents experimentally obtained creel size selection curve for Nephrops from the literature (Brčić et al. 2018); The solid black line represents mean creel size selectivity curve predicted from the model (3) using the average mesh size and mesh opening angle for the experimental creel. Dashed grey and black lines represent 95% confidence intervals.

Design guides and predicted creel exploitation pattern

Based on the predictive model (3), design guides for L50 and SR were constructed showing the effect of mesh size and mesh opening angle (Fig 7). Fig. 7 shows that decreasing the mesh opening angel from 90° (square shape) to ~70° has negligible effect on L50. As the opening angel gets lower, the influence on L50 increases, leading to a lower value. Similar trend is observed for SR, although less pronounced.

The model predicts that creel with 36 and 40 mm square meshes (OA = 90°) would release significant number of *Nephrops* above MLS (= 20 mm CL) (Fig. 7), implying a suboptimal exploitation pattern. We predict that 30 mm square mesh (OA = 90°), or 30 mm diamond mesh with opening angle fixed at 55 degrees, would better match the desired exploitation pattern (Fig. 7).

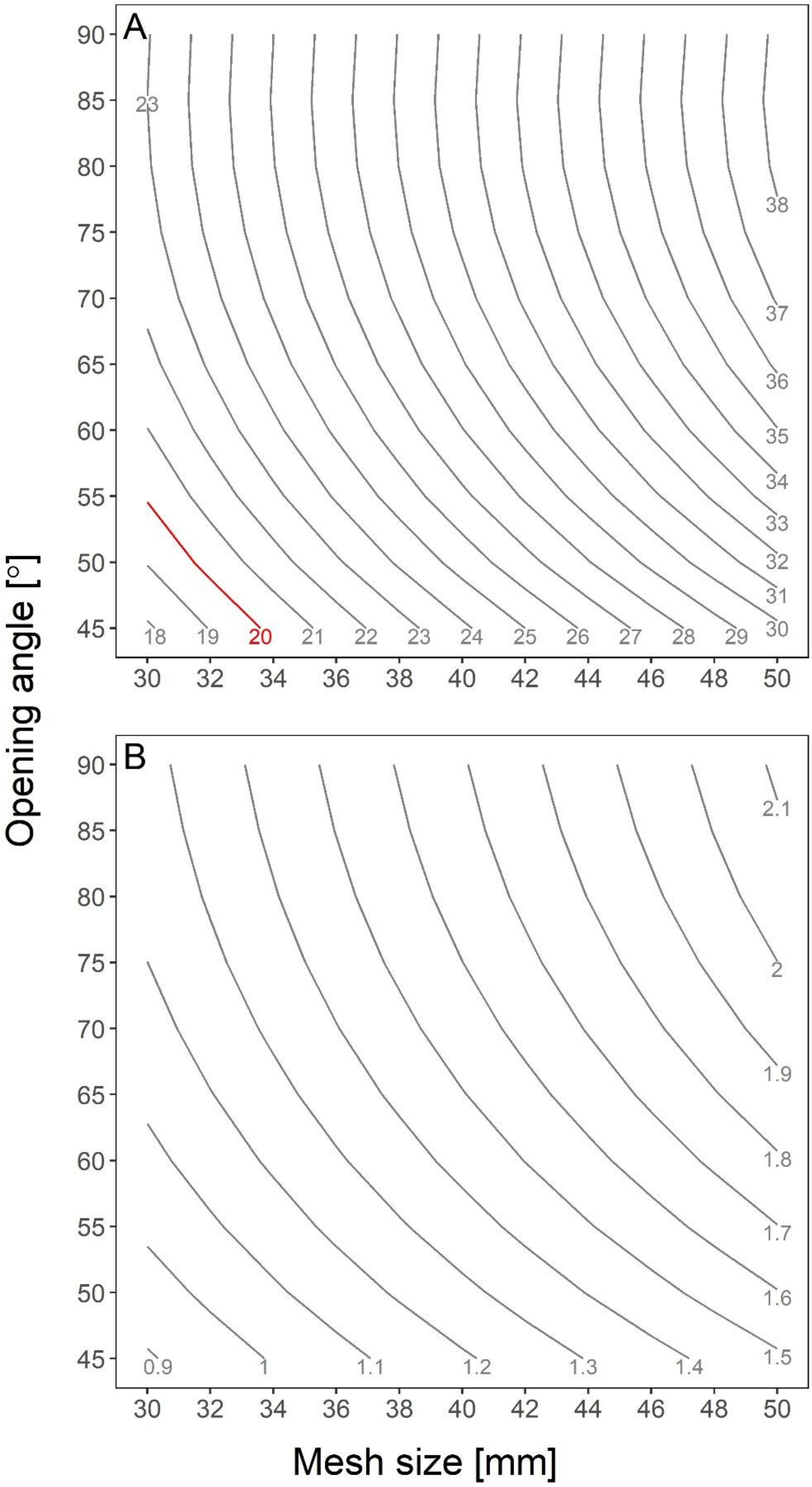

Fig. 7. Design guides for *Nephrops* creel size selectivity. Grey iso-cruves represent L50 (A) and SR (B) values predicted for different mesh sizes and mesh opening angles. Red line highlights isoline where L50 = MLS.

Discussion

A simple approach with fall-through experiments was used in the study to develop a predictive model for size selection of *Nephrops* in creels. The results showed that both tail first (Fig 2E) and claws first (Fig 2F) contact modes could potentially determine the selection. However, for establishing a predictive model it was not necessary to discriminate between these modes as they both lead to predict identical size selection within the investigated mesh configurations. Both contact modes can be regarded as optimal as they permit the biggest *Nephrops* to escape through a given mesh. The obtained results therefore imply that creel size selectivity for *Nephrops* is solely defined by the optimal modes for escapement, at least when creels are fished as in Brčić et al. (2018). Size selectivity defined solely by the optimal mode implies that *Nephrops* had sufficient time to orientate optimally for escapement from the creels. Considering that the creel haul-back phase is very short, about 1 minute in the trials performed by Brčić et al. (2018), the size selection process probably occurs prior to the retrieval phase. This is probably also the reason for the very small SR value for the obtained size selection, contrary to the ones obtained for trawls as reported by Frandsen et al. (2010).

A new method to establish a model to make predictions for size selection of *Nephrops* in creels with diamond or square mesh netting was used in the study, however, the method is also applicable to other mesh types like hexagonal, but it would require set of mesh templates different from those applied in our experiment and a model different from (2), because other mesh types would require other parameters to describe shape and size of the meshes (Herrmann et al., 2009). The method can also be easily adopted to other creel fisheries to determine the optimal creel mesh, especially if the fishery is in the developing phase e.g.

snow crab creel fishery in the Barents Sea (Sundet and Bakanev, 2014). This particular fishery is expected to increase significantly in volume and commercial importance in the next decade (personal communication, second author). However, little is known about the size selection of snow crab in this fishery, and the fishing sector is still experimenting with different creel designs to optimize the size selection. The method developed and reported in this study could potentially be applied to find the optimal creel mesh in this fishery.

The method used in the study can be seen as a simpler version of the FISHSELECT methodology (Herrmann et al., 2009). The more complex FISHSELECT methodology includes quantifying the external cross-sectional morphological shape of the investigated species and identifying the positions along the length axis that are expected to affect its ability to penetrate the meshes. In FISHSELECT methodology, transverse cross-sectional shapes are acquired with a mechanical sensing tool MorphoMeter (Herrmann et al. 2009). The methodology used in this study does not require the use of the MorphoMeter and neither a complex parametric cross-section shape modelling. This makes the approach more simple and quicker to use. All that is required for this method is a stiff mesh template and a reasonable number of individuals of different sizes for the fall-through experiments. This allows the method to be used during the experimental cruises which is very useful when fish size selectivity is investigated, because working with the fresh fish samples during the cruise is easier and doesn't require its transport to the laboratory facilities.

Before the investigation started we were not certain that the fall through experiments with dead animals would be able to reproduce the size selectivity results obtained during creel fishing for *Nephrops*. Fall through experiments, provided that relevant contact modes are chosen, should be able to reproduce the morphological component of fishing gear size selection, but not necessary a behavioural component (Herrmann et al., 2009). However, the similarity in the size selectivity curves between the one based on the sea trials and the one based on the fall through results for contact mode E (Fig. 6), demonstrates that at least under the fishing conditions described in Brčić et al. (2018), it is sufficient to only consider the morphological component to reproduce the size selection curve for *Nephrops* in this specific creel fishery.

The biggest advantage of using this method is its cost effectiveness and non-destructiveness. Experimental fishing can be very expensive and it only delivers a point estimate, while this method allows predictions for many different meshes. It enables creating the design guides which can be used by the fishermen and fisheries managers to identify the range of mesh sizes and mesh shapes needed to match the creel size selectivity with desired exploitation pattern. However, unlike FISHSELECT approach, where computer simulations can be used to provide prediction for mesh types not tested in the fall-through experiments, our approach does not allow extrapolating outside the mesh sizes and shapes used in the fall-through experiments. Further, our method also needs one experimental result from fishing to assist selecting contact mode for the fall through trials. This method will especially be relevant in situations where extrapolation is not needed.

Rudershausen et al. (2016) presented another simple approach based on measuring body depth to predict size selectivity of the Black sea bass in the trap fishery. However, it is doubtful if the approach of Rudershausen et al. (2016) could be applied as generally as our method, especially for species with irregular body shapes like *Nephrops*, where the condition for mesh penetration depends on mesh shape and cannot be determined on body depth alone. Such limitation does not exist for the fall through based method as long as trials are conducted with the mesh shapes of interest.

We have demonstrated that a simple and cost-effective method can be used to predict *Nephrops* creel size selectivity for a wide range of mesh sizes and mesh opening angles.

Based on the results obtained in our study we predicted that square mesh of 30 mm or 30 mm diamond mesh with opening angle of 55° would better match the desired exploitation pattern since it would release less individuals above MLS then the currently used meshes.

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