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Size selection of Antarctic krill (*Euphausia superba*) in a commercial codend and trawl body

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ABSTRACT

During fishing, many fish species are able to avoid the net walls of the trawl body and so the majority of size selection occurs in the codend of the net. Antarctic krill (*Euphausia superba*) are regarded as true planktonic organisms passively drifting with currents, but they also display self-locomotion by active swimming. There is a lack of knowledge regarding the behavior of krill during the fishing process, and extrapolating results obtained for other species to krill is of limited value. In the case of krill, it is largely unknown to what extent the codend versus the trawl body contributes to the size selection process. The current study aims to quantify the size selection of krill in a commercially applied codend during experimental fishing. Combining these results with a model for full trawl size selectivity it was possible to provide an insight to the size selection process in the trawl body. Specifically, the study applied a two-step approach by first estimating the size selectivity of a commercial codend and second used the codend size selectivity obtained in this study to estimate the trawl body size selectivity of a commercial trawl based on entire trawl-selectivity obtained in a previous study. The results of this two-step analysis revealed that the trawl body contributes significantly to the total size selection process, demonstrating that size selectivity of Antarctic krill in commercial trawls is affected by both the trawl body and the codend.

1. Introduction

Several fish species avoid the netting of trawls during capture (Wardle, 1993) and so the majority of size selection for those species occurs in the codend of the trawl (Wileman et al., 1996). Other species, such as smaller invertebrates, may display a different pattern of behavior. For example, prawns tend to display a more limited response to trawl stimuli (Lochhead, 1961; Newland and Chapman, 1989) and size selection resembles more of a sieving process in which individuals may meet the trawl netting frequently and with a more random orientation. Polet (2000) found that it was mainly the rounded lateral part of the net belly that was responsible for size selectivity for Crangon shrimps (*Crangon crangon*). Antarctic krill (*Euphausia superba*) are generally regarded as true planktonic organisms that drift with the currents, however they also display the ability to move horizontally and vertically in the water column, by swimming at higher speeds for limited periods of time (Marr, 1962; Kanda et al., 1982). Krag et al. (2014) speculated if size selection may occur throughout the entire trawl body when harvesting Antarctic krill.

Size selectivity results and underwater video recordings indicate that Antarctic krill escape through the mesh head first, at an angle perpendicular to the netting wall (Krag et al., 2014). This suggests that individual krill are either able to orientate themselves optimally in relation to the net mesh to facilitate their escape or, alternatively, their escape is a random process, where frequent contact with the trawl netting will result in some krill meeting the netting at an optimal orientation for escape by chance. Recent trawl designs in the fishing industry also support these mechanisms: Traditional net designs in the krill fishery comprised midwater trawls (Budzinski et al., 1985) with large openings (e.g. 60 × 50 m) and large meshes near the mouth of the net with a successive reduction in size towards the small meshed codend. More recent designs comprise small mouthed (20 × 20 m), low-tapered trawls with small meshes throughout the length of the trawl body (Bakketeig et al., 2017). Detailed knowledge of the selection processes operating in fishing gear is important both in terms of understanding catch efficiency and gaining a better insight into ecosystem based management practices (Krafft et al., 2016).

Krag et al. (2014) assessed the selectivity of a full commercial trawl.

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However, it is unknown whether their results represented size selection over the full trawl body, with krill having multiple random contacts with the mesh in the trawl body, eventually resulting in escape, or they were due to the fact that krill are very effective at orientating themselves towards the meshes at an angle that facilitates escape in the codend. Therefore, it is unknown to what extent trawl body and codend each contribute to the size selection in the trawl. If the majority of size selection occurs in the codend, management of size selection in the krill fishery would only require changes in codend design. However, if the trawl body is important, adjusting the gear selectivity would require changes to other parts of the trawl. Therefore, it is important to quantify size selection in commercial codends and trawl bodies. The current study aimed to provide data to bridge this knowledge gap. Specifically, the main objectives were:

- To quantify size selection in a commercial krill trawl codend.
- To investigate to what extent size selection of krill in commercial trawls is attributed to the codend and the main trawl body.

2. Materials and methods

To obtain the objects described above, the study applied a two-step approach: i) estimating the size selectivity of a commercial codend (Sections 2.1 and 2.2); and ii) used the codend size selectivity obtained in this study to estimate the trawl body size selectivity of a commercial trawl based on entire trawl-selectivity obtained in a previous study under the assumption that the codend selectivity in both studies is similar (Sections 2.2 and 2.3).

2.1. Sea trials and gear specifications

To quantify the size selection process that occur in the codend, a survey trawl with a codend of commercial mesh size was used. The codend was surrounded by a small-meshed cover to collect codend escapees. The trawling was carried out off the coast of the South Orkney Islands (60∘35´S, 45∘30´W) in January and February 2014 and 2015, using the Norwegian commercial ramp trawlers FV *Saga Sea* (96 m, 6000 hp) in 2014, and the FV *Juvel* (99.5 m, 8158 hp) in 2015. A 30 m long small mesh survey trawl ('Macroplankton trawl') was used (see Krafft et al., 2010, 2016; Krafft and Krag, 2015), with a 6 × 6 m mouth and 7 mm netting from the trawl mouth to the end of the last tapered section. The trawl body and cover were supported by an outer 200 mm protection net (single 3 mm PE twine). The codend was 5 m long (stretched) with four similar panels joined into four selvedges. Each codend panel was 270 meshes wide forward and 96 meshes wide at the codline following a 3N2B cutting rate. The codend was about 440 meshes in circumference where the codend was closed and made of 16 mm (nominal; 15.4 mm measured) diamond mesh PA netting. The actual mesh size was obtained by placing a small sample of the codend netting on a flatbed scanner with no tension in the netting together with a measuring unit to determine the precise mesh size. Individual meshes in the picture were analysed in FISHSELECT software tool (Herrmann et al., 2009) using the built-in image analysis function, and mesh size was assessed following the procedures described in Sistiaga et al. (2011). Standard mesh measuring methods using the OMEGA measuring gauge, which are applied for larger mesh sizes, could not be used in this study because the measuring jaws are too large for the small mesh sizes used in the krill fishery.

A 26.5 m long cover comprised of 7 mm mesh was mounted to the codend to collect escaping individuals. To prevent the cover net from masking the codend, two aluminium hoops (4 m diameter) were used (Fig. 1). The cover had a zipper to facilitate easy access to the codend catch. The trawl was towed at speeds of approximately 2.5 knots as used in the commercial fishery.

When a trawl was landed on deck, a random subsample of krill from both the codend and the cover was taken. The length of the krill in the subsamples were measured from the anterior margin of the eye to the tip of the telson excluding the setae, following Marr (1962). The catch data was sorted into 1 mm wide length classes with count numbers quantifying the number of krill belonging to each length class from the codend and cover catch, respectively. The total catch and the subsample were weighed for both cover and codend in all hauls.

2.2. Analysis of data from sea trials to estimate codend size selectivity

Data was pooled from different hauls in order to estimate average size selection over hauls $r_{av}(l,\boldsymbol{v})$ (Herrmann et al., 2012), where $\boldsymbol{v}$ is a vector consisting of the parameters of the size selectivity model and l is the length of the krill. The purpose of this analysis is to estimate the values of the parameters $\boldsymbol{v}$ that make the experimental data (averaged over hauls) most likely to be observed, assuming that the selectivity model is able to describe the data sufficiently well. Therefore, expression (1) was minimized with respect to parameters $\boldsymbol{v}$, which is equivalent to maximizing the likelihood for the observed data in form of the length-dependent number of krill retained in the codend (nR_{jl}) versus those escaping to the cover (nE_{jl}):

$$-\sum_{j=1}^{k}\sum_{l}\left\{\frac{nR_{jl}}{qR_j}\times ln(r_{av}(l,\boldsymbol{v}))+\frac{nE_{jl}}{qE_j}\times ln(1.0-r_{av}(l,\boldsymbol{v}))\right\} \tag{1}$$

The outer summation in (1) is over k hauls conducted and the inner summation is over length classes l. qR_j and qE_j are the sampling factors for the fraction of krill length measured in the codend and cover, respectively.

Four different models were chosen as basic candidates to describe $r_{av}(l,\boldsymbol{v})$: Logit, Probit, Gompertz and Richard (Wileman et al., 1996). The first three models are fully described by the two selection parameters L50 (length of krill with 50% probability of being retained) and SR (difference in length between krill with 25% and 75% probability of being retained, respectively). The Richard model requires one additional parameter ($1/\delta$) that describes the asymmetry of the curve. The formulas for the four selection models, together with additional information, can be found in Wileman et al. (1996). In addition to the four classical size selection models (Logit, Probit, Gompertz, Richard), which assume that all individual krill entering the codend are subject to the same size selection process, we also considered one additional model that we refer to as the double logistic model DLogit (Herrmann et al., 2016). The Dlogit model is constructed by assuming that a fraction C_1 of krill entering the codend will be subject to one logistic size selection process with parameters $L50_1$ and SR_1 while the remaining fraction ($1.0 - C_1$) will be subject to an additional logistic size selection process but with parameters $L50_2$ and SR_2. The rationale behind considering the DLogit model for the codend size selection of krill is the expectation that the selection process may constitute more than one process. Therefore, a total of five models were considered for $r_{av}(l,\boldsymbol{v})$:

$$r_{av}(l,\boldsymbol{v})=\begin{cases}Logit(l, L50, SR)\\ Probit(l, L50, SR)\\ Gompertz(l, L50, SR)\\ Richard(l, L50, SR, 1/\delta)\\ DLogit(l, C_1, L50_1, SR_1, L50_2, SR_2)\\ \quad = C_1\times Logit(l, L50_1, SR_1)+(1.0-C_1)\\ \quad \times Logit(l, L50_2, SR_2)\end{cases} \tag{2}$$

Each of the five models were fitted in (1). Selection of the best model of the five considered in (2) was carried out by comparing the AIC values for the model fit in (1). The selected model is the one with the lowest AIC value (Akaike, 1974). Evaluating the ability of a model to describe the data sufficiently is based on calculating the corresponding p-value, which expresses the likelihood of obtaining at least as big a discrepancy