Available online at www.sciencedirect.com
ScienceDirect
Fisheries Research 85 (2007) 142–147
FISHERIES RESEARCH
www.elsevier.com/locate/fishres

The selectivity of the gill-nets used to target hake (*Merluccius merluccius*) in the Cornish and Irish offshore fisheries

Andrew Revill [a,*], John Cotter [a], Mike Armstrong [a], Jon Ashworth [a], Rob Forster [a], Gus Caslake [b], Rene Holst [c]

[a] *CEFAS, Lowestoft Laboratory, Fishing Gear Technology, Fisheries Management Team, Pakefield Road, Lowestoft, Suffolk, NR33 0HT, UK*
[b] *SEAFISH, Seafish House, St Andrew's Dock, Hull HU3 4QE, UK*
[c] *DIFRES, Hirtshals, Denmark*

Received 10 July 2006; received in revised form 12 January 2007; accepted 20 January 2007

Abstract

The North European gill-net fishery targeting hake (*Merluccius merluccius*) is mostly prosecuted using gill-nets with a mesh size of 120 mm. Fishers from both the UK and Ireland are active in this fishery using this particular gear type.

A study was undertaken aboard a commercial gill-netter off the coast of Cornwall (UK) in 2005 to estimate the selectivity parameters of this particular fishing gear, as little published information was available. We found that the 120 mm gill-net caught mostly larger hake, catching few fish below 60 cm. The modal selectivity length for hake using gill-nets with this mesh size was close to 80 cm.

The study indicates that the 120 mm gill-fishery off Cornwall and Ireland is a highly size-selective component of the international fishery exploiting the northern hake stock, a stock in which international landings at length peaked at around 30 cm (2004).

Keywords: Gill-net; Selectivity; Hake; *Merluccius merluccius*; SELECT

1. Introduction

Cornish gill-net fishermen in the UK believe their gear (120 mm gill-net) to be selective for large hake (*Merluccius merluccius*), catching relatively few small hake in the process. The same nets are also used in the Irish gill-net fishery, but as we could find no published selectivity data on this type of gear, we conducted a series of trials to estimate the selectivity parameters. The hake gill-nets used by both the Cornish and Irish fishermen are typically made up from sheet monofilament netting of 120 mm mesh size and about 50 meshes deep. They are rigged onto a floated head-rope and lead-cored footrope (Cosgrove et al., 2005).

Hake off Cornwall and Ireland form part of the northern hake stock, a stock which is spread from the continental shelf from Norway to the Bay of Biscay. This hake stock is fished by international fleets using a wide variety of gears including trawls, gill-nets and long-lines. The spawning stock biomass of the northern hake reached a low level in the 1990s (ICES, 2006), and emergency measures were introduced in 2001 to conserve the stock (Council Regulations 1162/2001, 2602/2001 and 494/2002). This has been replaced by EC Regulation 811/2004 which implements measures for the recovery of the northern hake stock, with the objective of rebuilding the spawning stock biomass. Fishing gear selectivity is an important aspect for hake conservation, and the use of gears that have minimal catches of young, immature hake will assist stock recovery.

This paper presents the results from sea trials to determine the selectivity of the 120 mm hake gill-nets used by the Cornish and Irish fishermen. The sea trials were conducted aboard a commercial gill-netter during the periods 8–15 October, 22–29 October and 7–14 November 2005.

2. Method

2.1. Experimental design

The experiment was carried out on the hake fishing grounds off Cornwall (Fig. 1) aboard the FV Carol H (WY 379), a

* Corresponding author. Tel.: +44 1502 524531; fax: +44 1502 524546.
E-mail addresses: andrew.revill@cefas.co.uk, a.s.revill@cefas.co.uk (A. Revill).

0165-7836/$ – see front matter.
doi:10.1016/j.fishres.2007.01.008

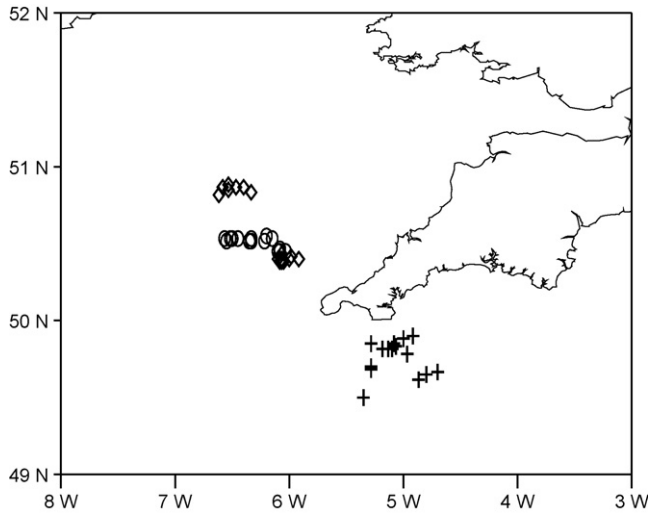

Fig. 1. Shooting positions of the gill-nets during the selectivity trials. Circles, trip 1 (8–15 October); crosses, trip 2 (22–29 October); diamonds, trip 3 (7–14 November).

steel-hulled netter of 17.5 m reg. length and with a 195 kW engine. Twenty-four gill-nets (bottom setting type) were constructed using materials which closely matched the type used commercially in the Cornish and Irish hake gill-net fisheries. The gill-nets were all newly made for the study and differed from each other only in terms of their mesh size. Four different mesh-sizes were used, with six gill-nets of each mesh-size (i.e. 80 mm, 100 mm, 120 mm and 140 mm (full stretched mesh length)). Each gill-net was 5.5 m high × 107 m long when set.

Gill-net mesh sizes, both smaller and slightly larger than the commercial mesh size of 120 mm were used in order to estimate the selectivity parameters of the commercial mesh size. Meshes larger than 140 mm were not considered because of the low expectations of any catches, and meshes smaller than 80 mm were not used because they were expected to become fouled with excessive amounts of weed, etc.

To allow a valid comparison of the catch rates and size compositions of the different mesh sizes, all nets were made with the same type and diameter (0.65 mm) monofilament nylon, and all the mesh sizes were fished at the same time and place and for the same soak time. (Intended soak times were 24 h but these had to be adjusted according to weather and other practical reasons.) The hanging ratios of all nets were set to 0.6 in all cases, and floats of 113 g buoyancy were set every 180 cm. The lead-line was 10 mm 3× strand heavy leaded.

Each day, all 24 gill-nets were retrieved after soak times which ranged between 12 and 36.5 h with an average of 23.3 h, which was close to the intended 24 h. On retrieval the catches were removed and each net was cleaned and redeployed. This process was repeated for 7 days, whereupon the vessel returned to port to land the catch. Three netting trips were made within a 6-week period in 2005: 8–15 October, 22–29 October, and 7–14 November. This provided repetition of the trials to assist the statistical analysis. Fig. 1 shows the positions where fleets were shot for each of the three trips. The first and third trips fished grounds to the North of Cornwall, whilst the second fished to the south of Cornwall.

It was commented by the skipper of the commercial vessel that new gill-nets do not fish as efficiently as older nets. We therefore deployed some extra older commercial 120 mm gill-nets (belonging to the vessel) in the vicinity of the selectivity experiments. The catches from these older commercial 120 mm nets were compared to the catch compositions from the new experimental 120 mm nets.

All fish species caught were measured to the cm below, and no sub-sampling of the catch took place. For hake, a record was kept of whether each fish was caught by the gills or by the teeth, as this may affect selectivity.

2.2. Data analysis using the SELECT method

Millar and Holst (1997) demonstrated how the SELECT method model reduces to a log-linear model for a range of (uni-modal) selectivity curves. This facilitates easy estimation with most statistical software packages. Uni-modal curves have however often appeared inadequate for modelling the selectivity. Fish are often caught in gill-nets by more than a single mechanism. A typical pattern is a dominant mechanism, e.g. gilling, which accounts for the majority of the catch and span a relatively narrow length interval for a given mesh size, whereas other catch mechanisms (e.g. entangling, or caught by the teeth) act on a wider length range. If the selectivity curve corresponding to each catch process is described by a Gaussian-shaped curve, the resulting selectivity curve describing the total selectivity will be a mixture of these with the individual components scaled according to relative efficiency of the corresponding catch mechanism. In practice it is however often not possible to identify more than two components. These can then be referred to a main process and secondary processes accounted for by a single component. Such curves are commonly denoted 'bi-modal' curves, but it may be more appropriate to call them 'mixture-curves', since they do not necessarily show more than a single mode. Estimation of such curves requires a general purpose optimiser to maximise the log-likelihood function or customised software such as the Gill-Net program (ConStat, Denmark). In general the selectivity curves are estimated by maximising the log-likelihood function:

$$L(\theta|n) = \sum_{\ell}\sum_{j} n_{\ell,j} \cdot \log(\phi(\ell, m_j; \theta))$$

A given choice of the selectivity curve function is incorporated in the expression of ϕ. See Millar and Holst (1997) for the parameterisation of four uni-modal curves. These are all two-parameter curves whereas the bi-modal curve uses five-parameters and is given by

$$\phi(\ell, m; \theta) = \varphi(\ell, m; a_1, a_2) + \omega \cdot \varphi(\ell, m; b_1, b_2)$$

$$= \exp\left(-\frac{(\ell - a_1 \cdot m)^2}{2(a_2 \cdot m)^2}\right)$$

$$+ \omega \cdot \exp\left(-\frac{(\ell - b_1 \cdot m)^2}{2(b_2 \cdot m)^2}\right)$$

The curve is a (weighted) mixture of two normal scale curves. Selectivity curves for all mesh sizes detailed in this paper are summarised by parameters a_1 and a_2. The mode and spread for each given mesh size m is given by $a_1 m$ and $a_2 m$, respectively.

Estimates from individual hauls can be assumed to be normally distributed if 'sufficient' numbers of fish are observed in a 'sufficient' number of length classes and in a 'sufficient' number of mesh sizes (Fryer, 1991). While it is difficult to rigidly define 'sufficient', each fit must be assessed by a general goodness-of-fit measurement in every individual case. The asymptotic normality of the estimator permits the use of Fryer's model of between-haul variation for estimating mean selectivity (Fryer, 1991). This two-stage approach is best known from selectivity analysis of data from towed gear experiments but has also been applied to gill-net data analysis (see for example, Madsen et al., 1999 and Holst et al., 2002).

3. Results

3.1. Stations fished and soak times

The soak times shown in Fig. 1 for each fishing location are indicated by the height of the symbol marking its position. No systematic differences of soak times with region or trip are evident, implying that soak time is not a factor to take into account when comparing results across regions and trips. The numbers of hake caught, plotted against soak times for each trip are depicted in Fig. 2. There is no indication of a consistent relationship over the range of times observed. For these reasons, catches reported here are all 'per immersion'. Standardisation to a 'per hour' basis was not thought to be useful for interpretation. Hake, haddock, cod, ling and pollack made up the bulk of the commercial species taken in the 120 mm mesh experimental net (Table 1).

Table 1
Total numbers of fish taken in the experimental nets during the trials

Species	Mesh size			
	80 mm	100 mm	120 mm	140 mm
Hake (*Merluccius merluccius*)	269	349	299	94
Haddock (*Melanogrammus aeglefinus*)	95	166	184	39
Cod (*Gadus morhua*)	26	49	122	74
Bib (*Trisopterus luscus*)	485	455	91	18
Ling (*Molva molva*)	215	169	79	29
Pollack (*Pollachius pollachius*)	43	55	74	77
Whiting (*Merlangius merlangus*)	337	116	51	39
Megrim (*Lepidorhombus whiffiagonis*)	4	7	11	12
Saithe (*Pollachius virens*)	8	9	8	3
Monk (*Lophius piscatorius*)	0	0	3	6

3.2. Length frequencies of hake in commercial and experimental 120 mm mesh nets

The total length frequency for hake recorded from the experimental and additional commercial 120 mm mesh nets fished at each location were very similar, and showed that few hake less than approximately 60 cm in length were either gilled or entangled by their teeth (Figs. 3 and 4). The majority of hake caught in this mesh size were 70–85 cm long. In contrast, the length frequency of hake from the northern stock landed by all international fleets in 2004 was dominated by hake smaller than 70 cm long (ICES, 2006; Fig. 5). Data in ICES (2006) also indicate that discarding of hake by sampled international fleets is mainly of fish <25 cm long (not shown on Fig. 5). If the data are typical of hake catches taken by UK gill-netters off the SW coast throughout the year, they indicate that the fishery is a highly selective component of the international fishery exploiting the northern hake stock.

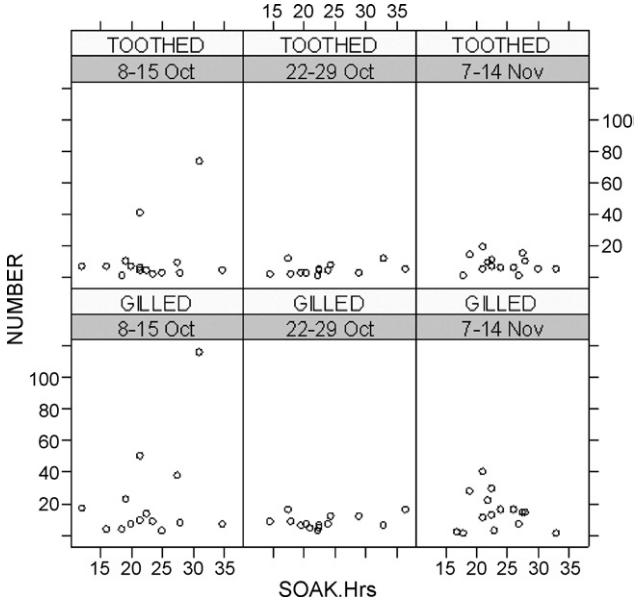

Fig. 2. The effect of trip date and soak time on numbers of hake caught during each of the three trips.

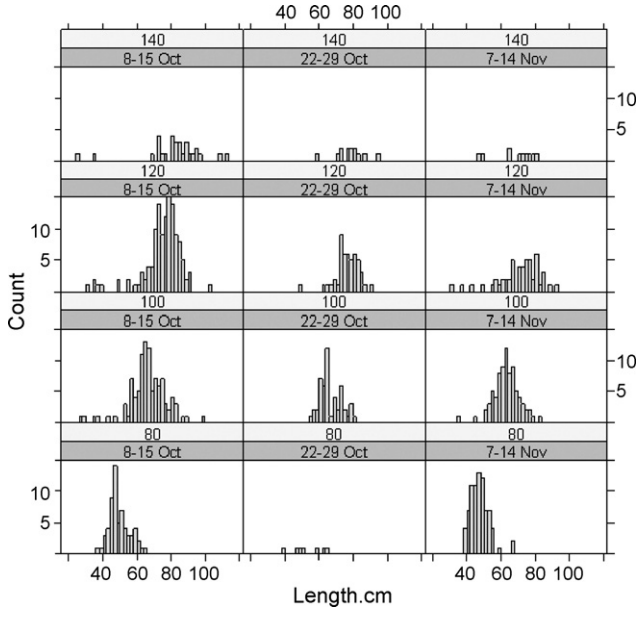

Fig. 3. The length frequency of hake caught per trip and at each mesh size, which were enmeshed at or near the *gills*.

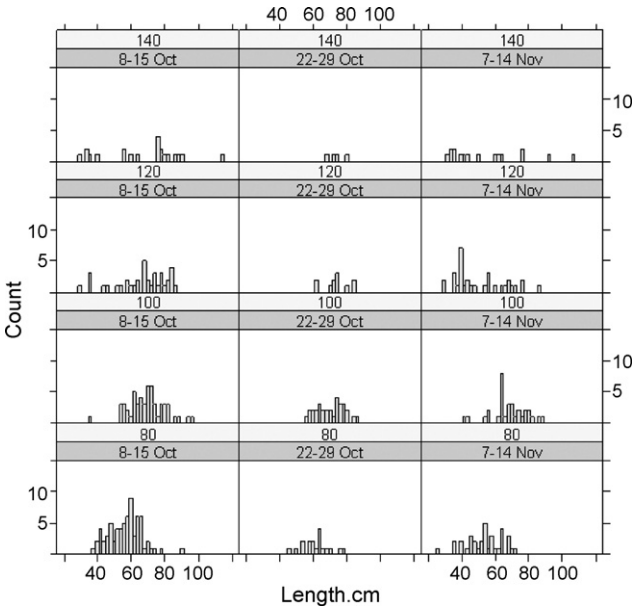

Fig. 4. The length frequency of hake caught per trip and at each mesh size, which were enmeshed by their *teeth*.

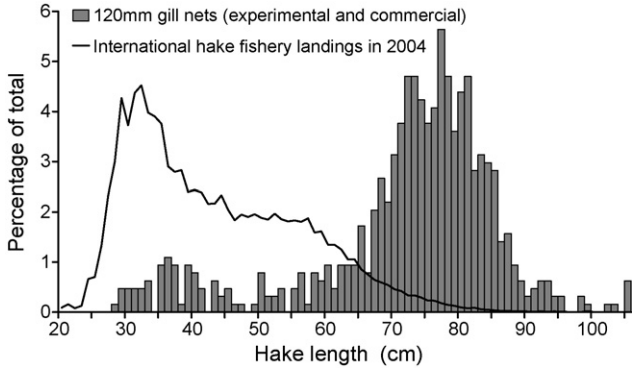

Fig. 5. Length frequency of hake caught by 120 mm mesh gill-nets (both experimental and commercial) during the trials, compared with the length frequency of international landings of Northern hake in 2004 (from ICES, 2006).

3.3. Catch and size composition of hake

Few hake less than 60 cm in length were either gilled or toothed by the 120 mm mesh sized nets (Figs. 3 and 4). Catches of hake <60 cm long in the 80 mm mesh nets during two of the trips show that small hake were present at the study sites, but these fish were caught in only small numbers in the larger mesh gill-nets. The majority of hake caught were meshed by their gills. For 80–120 mm mesh nets, the average length of gilled hake tended to increase with increasing mesh size, whereas there was no clear relationship between mesh size and fish size when the fish were snagged by their teeth. This is to be expected because gilling depends on the girth of the fish and is more likely to be a length-related process than toothing. The mesh size of 120 mm provides good catch rates of hake in the 60–90 cm length range, and low catch rates of smaller hake due to mesh selection. Catches of gilled hake in the 140 mm net were much lower than in the 120 mm net.

3.4. Estimation of the selectivity parameters

3.4.1. The SELECT method

A first exploratory analysis of the data consisted of fitting selectivity curves to data pooled over hauls for each trip is shown in Table 2. In trip one, all of the uni-modal curves showed over-dispersion and the bi-modal curves did not converge. In trip two, the curves showed acceptable fits with the bi-modal curves giving the best fit in terms of having the smallest 'deviance-to-degrees of freedom' ratio. In trip three, the uni-modal curves showed over-dispersion, whereas the bi-modal curve provided a good fit.

A subsequent analysis by trips combined (stacked) across hauls but within trips indicated that all curves provided acceptable fits for all trips (Table 3). The bi-modal curves showed the best fit for all three trips, but only slightly better than the normal scale curves. This type of curve represents a more parsimonious model and was consequently preferred.

The two-stage analyses consist of fitting curves to individual hauls followed by estimation of a mean curve using Fryer's model of between-haul variation. Contrary to the initial analysis, the normal scale curve appeared to provide good fits for almost all hauls. It did thus not make sense to fit a more complicated model (e.g. a bi-modal curve). The normal scale curve is defined by two parameters a_1 and a_2 and is given by the expression below. It is important to note that both the mesh size and fish length are expressed in cm units of length:

$$\phi(\ell, m; \theta) = \exp\left(-\frac{(\ell - a_1 \cdot m)^2}{2(a_2 \cdot m)^2}\right)$$

The subsequent estimation of REML mean curves resulted in the parameter estimates given in Table 4. The parameters a_1 and a_2 have a natural interpretation in terms of location and spread,

Table 2
Goodness-of-fit statistics for curves fitted to data pooled over hauls within trips (best fits are marked in bold)

	Trip 1			Trip 2			Trip 3		
Model	Deviance	d.f.	Deviance/d.f. ratio	Deviance	d.f.	Deviance/d.f. ratio	Deviance	d.f.	Deviance/d.f. ratio
Normal scale	**337.6**	**214**	**1.58**	112.3	121	0.93	280.5	184	1.52
Normal location	415.4	214	1.94	113.1	121	0.93	334.7	184	1.82
Gamma	409.4	214	1.91	110.4	121	0.91	323.6	184	1.76
Log-normal	453.1	214	2.12	111	121	0.92	343.5	184	1.87
Bi-modal	–	–	–	**104.1**	**118**	**0.88**	**201.2**	**181**	**1.11**

Table 3
Goodness-of-fit statistics for curves fitted to data stacked over hauls within trips (best fits are marked in bold)

	Trip 1			Trip 2			Trip 3		
Model	Deviance	d.f.	Deviance/d.f. ratio	Deviance	d.f.	Deviance/d.f. ratio	Deviance	d.f.	Deviance/d.f. ratio
Normal scale	694.3	769	0.90	337.5	442	0.76	594.1	682	0.87
Normal location	772.1	769	1.00	338.2	442	0.77	648.4	682	0.95
Gamma	766.1	769	1.00	335.5	442	0.76	637.2	682	0.93
Log-normal	809.9	769	1.05	336.1	442	0.76	657.1	682	0.96
Bi-modal	**647.2**	**766**	**0.84**	**329.2**	**439**	**0.75**	**520.2**	**679**	**0.77**

Table 4
The REML mean parameter estimates with standard errors, using the normal-scale selection curve

Model	Trip 1		Trip 2		Trip 3	
	Estimate	S.E.	Estimate	S.E.	Estimate	S.E.
a1	6.777	0.09661	6.847	0.07185	6.662	0.1254
a2	1.034	0.1116	0.7022	0.06394	1.151	0.0827

respectively, for a unit mesh size. In terms of modal value and spread for a 120 mm net the parameter estimates translate to the values given in Table 5. There appears to be good agreement on the estimated modal values for the three trips, but some variation in the spread (Fig. 6). The mean REML-derived selection curves from each trip indicate a modal point for all three trips close to a hake length of 80 cm (Fig. 6).

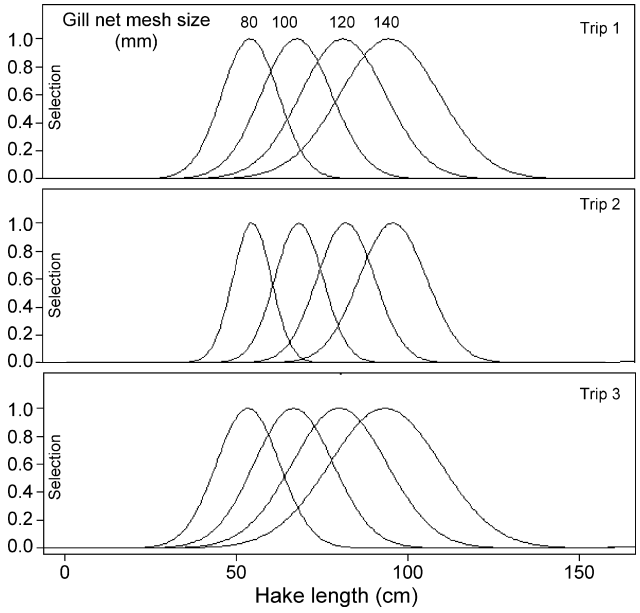

Fig. 6. REML mean selectivity curves for the three trips.

4. Discussion

This study demonstrated that the 120 mm mesh gill-nets used to target hake by both the fishermen off the SW of England and Ireland are highly selective and catch few hake less than 60 cm long compared with the international fishery as a whole. This is a result of the selectivity characteristics of the nets rather than the absence of small hake on the grounds. The majority of hake taken using 120 mm mesh during the study were 70–85 cm long, and the mean selection length was around 80 cm. Nets made from 140 mm mesh caught relatively few hake, indicating that there were insufficient numbers of large hake in the vicinity of the experiment to compensate for the increased escapement of smaller fish with this larger mesh size.

A similar study on the selectivity on the hake gill-nets in the fishery off Portugal provided mean selection lengths of 44–49 cm for 80 mm mesh (Santos et al., 2003) using the SELECT statistical method, but excluded hake entangled by their teeth. The results from the present study for gilled hake were 53–55 cm for 80 mm mesh (Table 5). The results of the two studies are therefore in reasonable agreement considering the different locations and times of the studies, and the different materials and field conditions used to generate the selectivity curves.

The percentage length frequencies of hake in the commercial and experimental 120 mm mesh nets were closely comparable (Fig. 7) and it can therefore be concluded that the selection curves derived in this paper are representative of those gears used in the UK and Irish commercial hake gill-net fishery.

Table 5
Modal lengths and spreads (cm) for hake selectivity as estimated from the REML mean normal scale fits

Gill-net mesh size (mm)	Trip 1		Trip 2		Trip 3	
	Modal (cm)	Spread (cm)	Modal (cm)	Spread (cm)	Modal (cm)	Spread (cm)
80	54	8	55	6	53	9
100	68	10	69	7	67	12
120	81	12	82	8	80	14
140	95	15	96	10	93	16

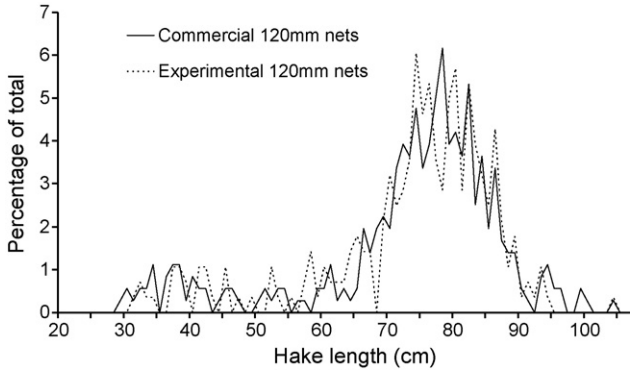

Fig. 7. Length frequency of hake caught by the experimental 120 mm gill-nets and the vessel's own commercial 120 mm gill-nets shot at the same time.

Acknowledgements

John Dann (CEFAS), Skipper Mitchell and the crew of the *Carol H* are warmly thanked for their enthusiastic co-operation throughout this project. The project was funded by Defra as part of the Fisheries Science Partnership 2005–2006.

References

Cosgrove, R., Browne, D., Robson, S., 2005. An assessment of acoustic deterrent devices in Irish gill-net and tangle net fisheries. Marine Technical Report No. 05MT07. Published by BIM (Irish Sea Fisheries Board), Galway, Ireland.

Fryer, R., 1991. A model of the between-haul variation in selectivity. ICES J. Mar. Sci. 48, 281–290.

Holst, R., Wileman, D., Madsen, N., 2002. The effect of twine thickness on the size selectivity and fishing power of Baltic cod gill-nets. Fish. Res. 56 (3), 303–312.

ICES, 2006. Report of the Working Group on the assessment of hake, monk and megrim (WGHMM). ICES CM 2006/ACFM 01.

Madsen, N., Holst, R., Wileman, D., Moth-Poulsen, T., 1999. Size selectivity of sole gill-nets fished in the North Sea fisheries research. Fish. Res. 44 (1), 59–73.

Millar, R.B., Holst, R., 1997. Estimation of gill-net and hook selectivity using log-linear models. ICES J. Mar. Sci. 54 (3), 471–477.

Santos, M.N., Gaspar, M., Monteiro, C.C., Erzini, K., 2003. Gill-net selectivity for European hake *Merluccius merluccius* from southern Portugal: implications for fishery management. Fish. Sci. 69, 873–882.