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GDYNIA, POLAND
MARCH 23-25, 1999

Fiskeriverket-National Board of Fisheries
Havsfiskelaboratoriet- Institute of Marine Research

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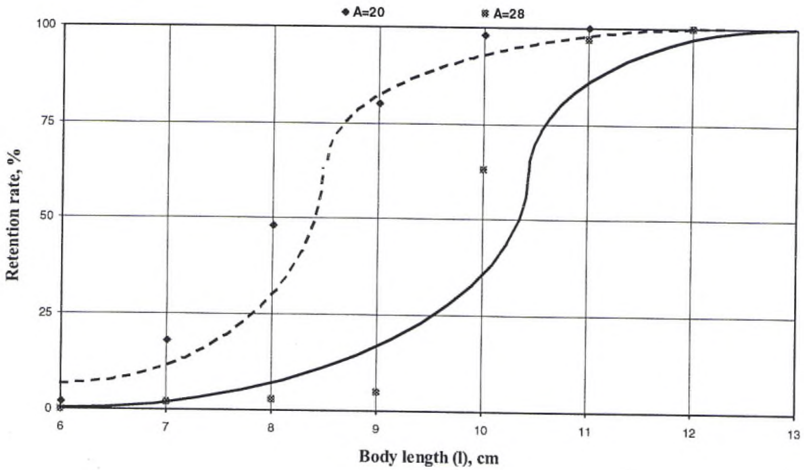

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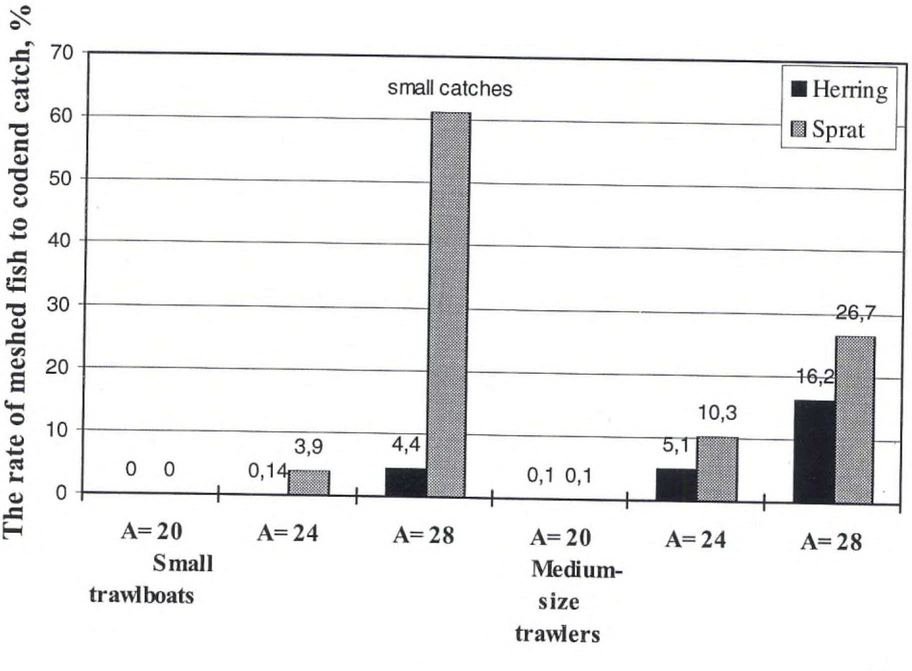

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and
Institute of Marine Research, Lysekil, Sweden

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Contents

Preface

The idea of young fish protection is not new in the Baltic area. One of the first known measures is from the city of Puck in Poland, where the lord major of Puck district, Mr. Ignacy Przebendowski, in 1767 introduced a minimum mesh size for the adjacent sea area. According to this rule "The fishermen are not allowed to use any nets with meshes smaller than one inch high and one inch wide". With the enforcement of this rule was also appointed a controller to supervise the net production and to control the mesh sizes during the use of the net.

Introduction of this protection rule over 200 years ago was probably connected with a concern for a fishery based mainly on juveniles. The waters adjacent to Puck can still be regarded as nursery grounds rather than feeding grounds for adult fish.

The number of exploited species inhabiting the Baltic Sea is not high but there are still problems with a proper management of these stocks, because the state of the stocks are not only dependent on the success of spawning but also on the amount of juveniles in the by-catches in the commercial fishery.

The present high fishing technology can affect the recruitment to a much higher degree than in the past. As good selectivity of gears is one of the most important protection measures for highly exploited stocks, extensive selectivity research has developed in the Baltic Sea area, starting in the early 1950s. The studies have mainly been directed on cod, flounder, salmon and herring but also on other commercial species.

With the aim to sum up the current knowledge on gear selectivity in the Baltic Sea area, this symposium was planned in co-operation between our two institutes. It was successfully held at the Sea Fisheries Institute in Gdynia, Poland, during March 23-25, 1999.

The participants presented interesting results on many stocks and fisheries and examples of new ideas how to further improve selectivity. The results also highlighted the need to combine improved selectivity with other measures, e.g. minimum landing size, closed seasons, effort restrictions and others, in a holistic management strategy to obtain an optimal exploitation of the fish resources.

We now convey to you the full papers of the majority of the presentations made at our symposium.

The conveners

Jan Netzel	P-O Larsson
Senior scientist	Senior scientist
MIR, Gdynia	IMR, Lysekil

A New Sound Source for Acoustic Fishing

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Abstract

A well-known method to increase the catch-per-unit effort in gill-net fisheries is to herd the fish into the net using a sound source. This is a traditional fishing method in the Baltic Sea coastal fishery for whitefish *(Coregonus lavaretus)*, pike *(Esox lucius)*and perch *(Perca fluviatilis)*. Traditional sound sources, such as a bucket on a rod or an outboard engine, are most likely only scaring fish at very close range. A new sound source was developed to scare the fish more efficiently. The sound source was tested on four whitefish *(C. lavaretus)* tagged with ultrasonic pingers in a 80x100 m net enclosure. Additional tests were made on four tagged perches *(P. fluviatilis)* in a 70x70 m bay. Instead of the expected scaring effect, the sound source was in some trials attracting both species. The possibilities of using this unpredicted attraction of fish to the sound source in coastal fishing operations are discussed.

***Key Words:** Acoustic attraction, sound production, fish telemetry*

Introduction

Whitefish *(Coregonus lavaretus)* is a target species for the coastal fishery in the Bothnian Bay. Both gill nets and trap nets are used (Toivonen *et al.* 1992). This fishery is facing very serious catch losses and gear damages by grey seals *(Halichoerus grypus)* (Westerberg *et al.* 1997). Therefore, it has become highly interesting to develop new fishing methods that are not as vulnerable to seals as the present ones but retain the favourable advantages in terms of high quality catches and low energy costs.

One solution to the problem is to speed up the catching process, giving seals less time to feed on the catch. The presently used traps seem very inefficient (Westerberg 1982) and therefore long soak times are needed. The catching process can be speeded up by using attraction or herding techniques. Such techniques may be based on different sensory cues. Most commonly, bait attractants are used. On the Swedish west coast, light is used in the winter sprat purse seining. Acoustic attraction is only known from traditional fishing techniques and scientific trials (reviewed by Wahlberg 1999*a)*. Fish herding techniques make use of acoustical cues or *brute force* (such as a beach seine).

In the Baltic Sea there is a traditional fishing method denoted 'plumsning' in Swedish (in German 'Plumpfischerei'; Wolff 1966) for scaring fish, notably perch, pike and whitefish, into a fishing net with a sound source. In Germany they use an acoustic fishery where pikeperch are believed to be attracted into nets by sound ('Klapperfischerei'; Wolff 1966). In Sweden, either a bucket on a rod or a motor engine is used to generate sound, and it is generally believed that the fish are scared away from the sound source. Little scientific work has been made to estimate how efficient acoustic herding and attraction is for increasing the catching efficiency. Although an extensive literature exists on fish hearing and fish behaviour in relation to various sound sources , the understanding of these topics is limited (Popper & Carlson 1998, Wahlberg 1999*a*). In the case of whitefish, there is, to our knowledge, no information in litterature. Although it is likely that whitefish hearing abilities can be generalised from Atlantic salmon *(Salmo salar)* studies, one should bear in mind that such an extrapolation may be erroneous when discussing the behaviour of whitefish confronted with a sound source.

The reaction of Atlantic salmon to sound has been extensively studied (Popper & Carlson 1998). The general consensus is that very intense infrasound, with a sound pressure level in the order of 160 dB re 1 μPa at a frequency of 10 Hz, is needed to consistently scare salmon away from a sound source (Knudsen *et al* 1992). Higher frequencies or lower source levels do not elicit a consistent response.

It will be shown that the traditionally used sound sources for acoustic herding of whitefish are far from optimal for the specified demands for scaring salmon. Again, the extrapolation between salmon and whitefish is probably not appropriate in the behavioural context, as there are vast behavioural state differences between river migrating salmons and foraging coastal whitefish. However, studies on other species do emphasize the need for intense low frequency sound to scare fish (Wahlberg 1999*a*). Therefore, we have tried to construct a new sound source to fulfil the required needs. The sound source is still under development and therefore the design described here is to be considered preliminary. The same holds for the studies on the reactions of fish being confronted with the sound source.

Materials and Methods

Theoretical considerations for constructing an infrasound source

Acoustic waves are generated through the compression of a small volume of the medium, resulting in a pressure wave propagating away from the source. One way to accomplish an efficient compression of the medium is to move a piston shielded within a cylinder (Figure 1a). The efficiency of acoustic transmission mainly depends on the relationship between transmitted wavelength (here measured in terms of the wave number $k=2\mathrm{p}f/c$ where f is the transmitted frequency and c is the sound velocity of the medium) and the size of the source (Michelsen 1983). For a piston of the radius a, the generated acoustic pressure at 1 m distance is given (for $ka<1$) by

$$p(f,a) = 2\pi^2\rho \cdot d(f,a)f^2a^2 \qquad (1)$$

where r is the density of the medium, $d(f,a)$ is the root-mean-square (rms) displacement of the piston, and f is the piston vibration frequency. The displacement of two pistons is given by

$$d(f,a) = \sqrt{\frac{P}{2M(a)}\frac{1}{(2\pi)^{3/2}}\frac{1}{f^{3/2}}} \qquad (2)$$

where P is the power of the engine moving the pistons and $M(a)$ is the virtual water mass that is moved by the pistons. The weight of the virtual mass depends on the ka product. For $ka<0.5$, which will be applicable in our case, the virtual mass for each piston is calculated (Beranek 1993) as

$$M(a) = 2.67a^3\rho \qquad (3)$$

In summary, the generated sound pressure is proportional to

$$p \propto \sqrt{Paf} \qquad (4)$$

so that the acoustic intensity I is proportional to

$$I \propto p^2 \propto Paf \qquad (5)$$

In this report the acoustic intensity is given in dB units of the sound pressure level, $SPL=20\,log(p/p_0)$, with $p_0=1\,\mu Pa$. The SPL will depend logarithmically on both piston radius and emitted frequency:

$$SPL \propto \log p \propto \log P + \log a + \log f \qquad (6)$$

Note that a higher acoustic intensity is generated for a larger radius of the piston at a given frequency, and by a higher frequency for a given piston radius.

Figure 1b summarizes these results for a hydraulic engine of 2 kW. For practical reasons a piston radius of 0.25 m was chosen, vibrating at a frequency of 17 Hz (1020 rpm). Ommitting losses due to friction it should be possible to generate a sound pressure level of almost 185 dB re 1 μPa @ 1 m. At the frequency given, the maximum possible peak-to-peak displacement amplitude was calculated from Equation (2) to about 1 cm.

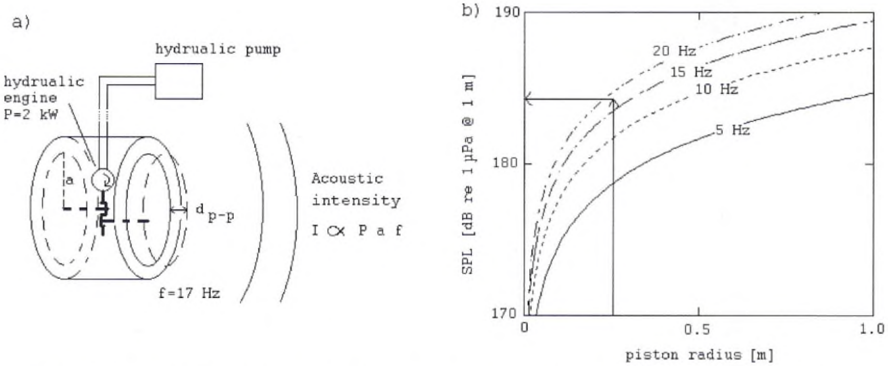


Figure 1. a) *Schematic drawing of the bass drum, consisting of two pistons moving in phase with a displacement* d *generating an acoustic pressure,* p. ***b)*** *The maximum obtainable acoustic sound pressure level at 1 meter distance from two shielded circular pistons for different rotation frequencies between 5 and 20 Hz. The pistons are powered with a 2 kW engine. Arrows indicate piston radius in this experiment.*

Design of the sound source

The new sound source (called the bass drum) consisted of two pistons with a radius of 25 cm in a 42 cm long aluminium cylinder with a diameter of 66 cm (Figure 1a). The pistons were coupled with connecting rods to a crank shaft which was rotated at 17 Hz by a 2 kW hydraulicengine, the pistons moving in phase with a peak-to-peak displacement of 1 cm. The engine was connected through 10 m long hydraulichoses to a 6 hp hydraulicpump. The pistons were sealed to the cylinder with a rubber ring (Figure 2). In this way the bass drum was made completely waterproof.

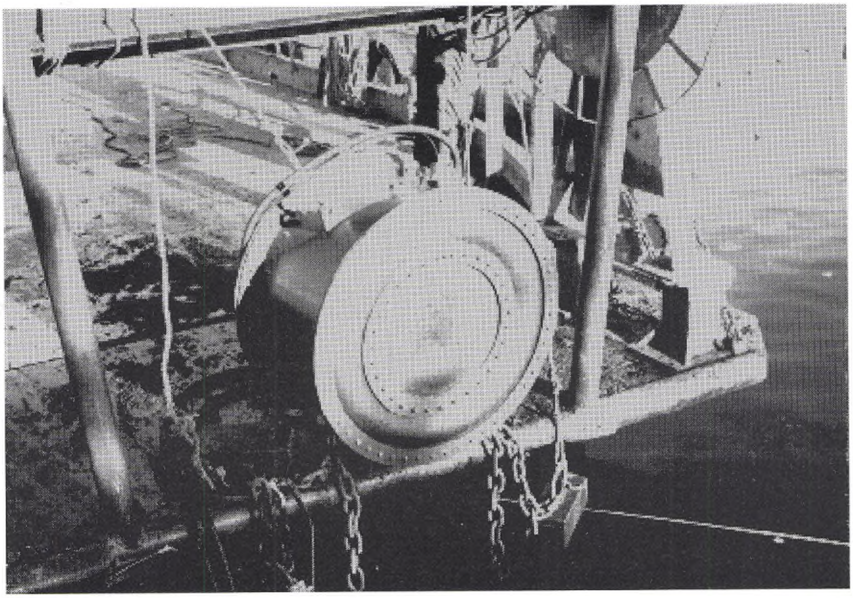


Figure 2. *The bass drum delivered to the experimental site. With a weight of 90 kg the drum is neutrally buoyant in the water.*

Acoustic recording techniques

The recordings of sound sources were made during the fall of 1998 with one or two B&K 8101 hydrophone(s) connected via a home-made amplifier to a Sony TCD-D7 DAT recorder (sampling frequency 48 kHz, $^{\pm}$3dB frequency response of the whole recording system 10-24000 Hz), calibrated with a B&K 4223 calibrator. The recordings were digitally transferred to a PC for frequency spectrum and sound pressure level estimation using the softwares CoolEdit 96 (Synthrillium) and Spectra Plus (Pineer Hill Software).

A digital 1/3 octave band spectral analysis (FFT size 16384 points, Hanning window) was performed. Due to the limited FFT size, frequency bands below 20 Hz could not be resolved. The 1/3 octave band was chosen as a rough model of the critical bands in the auditory system of a fish (cf Hawkins & Johnstone 1978). To obtain sound pressure levels, the spectra were compared with the calibration signal fed through the entire recording system. The sound pressure level was adjusted to a standard 1 m distance from the source by compensating for the transmission loss (TL). The TL was estimated from a simultaneous recording of the bass drum at two different distances. The range dependence of the transmission loss in the study area was measured to TL=*13 log r*, where *r* is the range in meters from the sound source and TL is given in values of [dB]. To assess the sound level within a frequency band at the range *r*, the transmission loss *TL* should be calculated and subtracted from the sound level given in the spectra. A rough estimate of the noise level was made through 1/3 octave band filtering of ambient noise recorded before or after the sound source was turned on. The time segment used for spectral analysis ranged from one to ten seconds.

Fish behaviour recording method

The behavioural experiments on whitefish were made at Birkö Island on the Swedish Baltic Sea coast during late October, 1998. Four whitefish were caught in shallow water (depth less than 8 m) in the area using gill-nets. The fish were anaesthetised with 2-phenoxyethanol (concentration 0.1-0.2 mg/L, exposure time 3-4 minutes) and tagged with ultrasonic transducers (Vemco V16; transmission frequency ranging from 50 to 76.8 kHz) on the ventral side close to the pectoral fins. The surgury time ranged from 3 to 5 minutes. After recovery in a small water container, the fish were released in an 80x100 m net enclosure. The depth within the enclosure did not exceed 8 m. The fish were tracked with the VRAP telemetry system (Vemco Ltd, Canada). Inside the net enclosure the positioning accuracy was better than 1 m (Wahlberg 1999*b*).

The fish were left to recover after surgery for just 6 h prior to the first sound experiment, as the study had to be speeded up due to technical constraints. Each test session lasted 15 min, followed by a silent period of at least 15 min, usually around 4 h. The test session consisted of 1-3 minutes of stimulations with the bass drum followed by up to 2 minute-breaks in between stimulations.

Trials with 4 dorsally tagged perches were made in the warmwater outlet at the nuclear power plant of Oskarshamn, Sweden, during February and March 1999. In these trials, a recording of the bass drum was playbacked (Source level 145 dB re 1 µPa @ 1 m) with a 30 W underwater speaker. The impulse response of the playback system fell rapidly for frequencies below 150 Hz, therefore the stimulus in these trials was a highpass-filtered version of the bass drum sound. The tagging procedure and the experimental set-up were similar to those described above, except that the recovery time between tagging and sound trials was at least 14 days, and each experiment consisted of a single 3-5 min long stimulation followed by a control interval of at least 12 h.

Results

Recordings of traditional sound sources

Figure 3a-d shows the time series and power spectrum of two sound sources traditionally used for acoustic herding: a boat engine (Figure 3a-b) and a bucket on a rod (Figure 3c-d). The engine is characterized by a broadband signal with a frequency emphasis above 300 Hz. The time signal is made up by a series of transient-like sounds. The bucket on a rod is similar in its frequency characteristics, even though the signal is made up of a single transient created when splashing the bucket into the water.

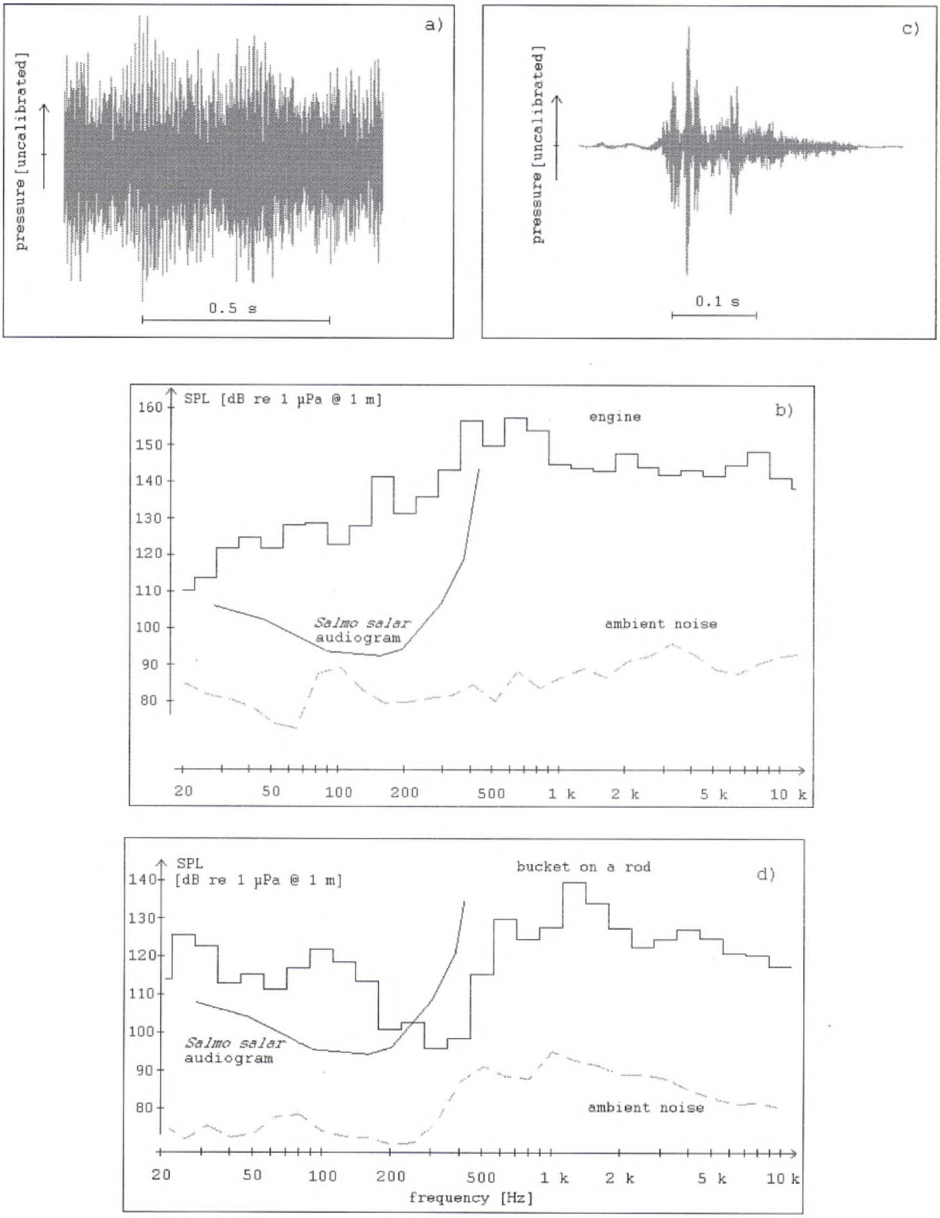


Figure 3. *Characteristics of sound sources used in traditional acoustic herding. The audiogram of the Atlantic salmon (from Hawkins & Johnstone 1978) is indicated.* ***a)*** *Oscillogram from a 10 hp outboard engine on an open 4 m boat at full speed.* ***b)*** *1/3 octave band power spectrum of the sound source in a).* ***c)*** *Oscillogram from a bucket on a rod hitting the water surface.* ***d)*** *1/3 octave band power spectrum of the sound source in c).*

Acoustic measurements of the bass drum

The bass drum was designed to generate a continuous 17 Hz tone, but the outcome was quite different. The bass drum generated a series of pulses with a 17 Hz repetition rate (Figure 4a). The power spectrum shows that the energy spreads over a very broad frequency band, decreasing rapidly below 100 Hz (Figure 4b). There was a 5-10 dB difference in the power spectrum for frequencies above 3 kHz as the bass drum was turned 90° (Figure 4b). The broadband source level was 160 dB re 1 μPa @ 1 m.

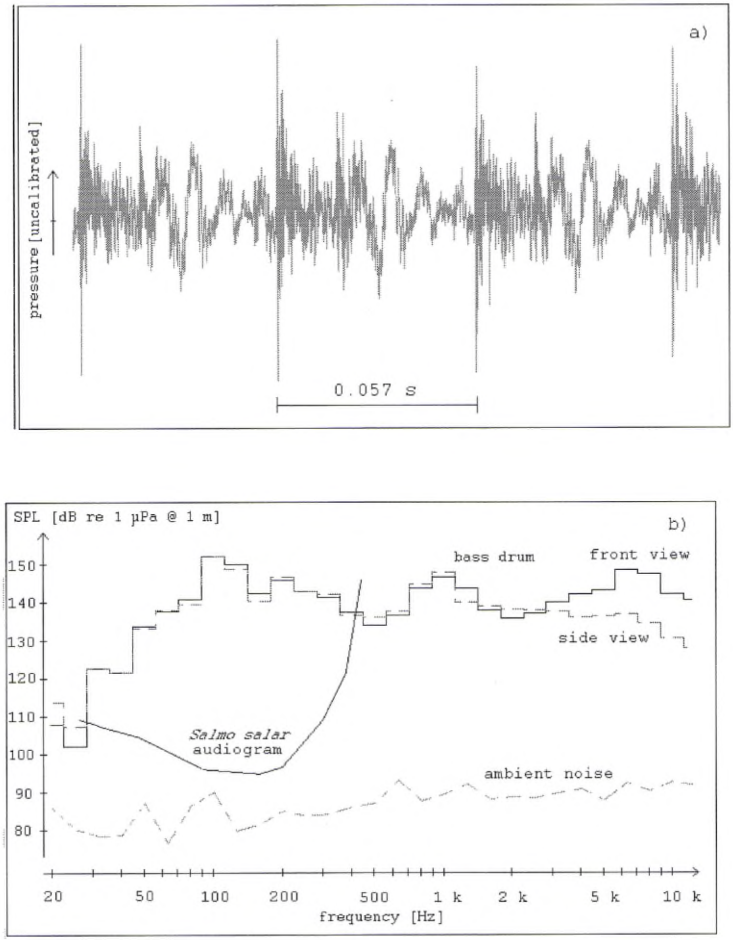


***Figure 4. a)** Oscillogram and **b)** 1/3 octave band power spectrum of the bass drum sound source. The audiogram of the Atlantic salmon (from Hawkins & Johnstone 1978) is indicated.*

Reactions of whitefish to sound from the bass drum

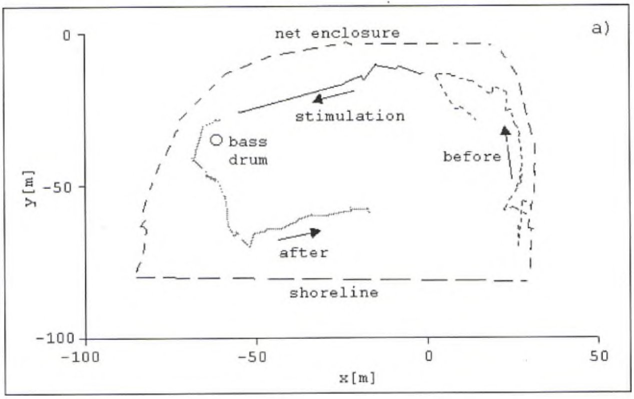
There seemed to be large individual variations in the behaviour of the whitefish to the sound from the bass drum (Table 1). No fish showed avoidance behaviour. Most fish were indifferent to the drum, but one was consistently attracted (Figure 5a). All successful trials were made with very short silent intervals (about 15 minutes) between the trials.

Reactions of perch to the sound playback

The reaction of perches to the playback of sounds from the bass drum also showed large variations (Table 1). Figure 5b shows an example of a perch turning towards the loud speaker in response to the sound. The fish was attracted to the sound source in 3 out of 14 trials. Only 2 of the 4 individuals were attracted. No avoidance reaction was observed. The fish could not be attracted during inactive (non-swimming) periods.

Table 1. *Results of a pilot study on attracting fish with sound. During a stimulation with sound, each fish is treated as a separate trial. The total number of fish attracted and not responding is indicated, and in parenthesis the number of different individuals involved is given. The distance between the fish and the sound source during the trials is shown.*

Fish species	No of fish	No of trials	Total no of fish attracted	Attraction distance [m]	Total no of fish not responding	No response distance [m]
Whitefish	**4**	**13**	**3 (1 ind.)**	**40-80**	**10 (4 ind.)**	**20-120**
Perch	**4**	**14**	**3 (2 ind.)**	**30-70**	**11 (4 ind.)**	**30-60**



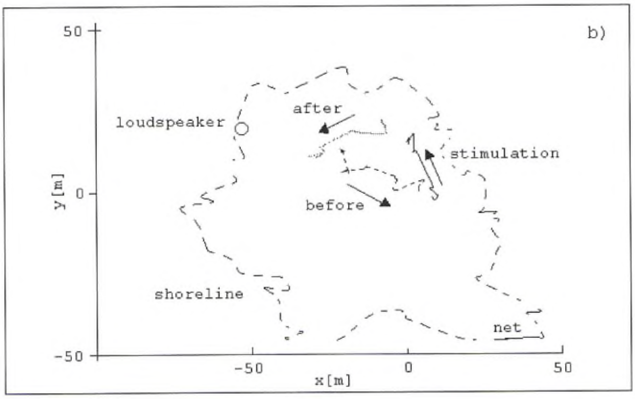


Figure 5. a) *Reaction of a whitefish to the bass drum sound.* ***b)*** *Reaction of a perch to playback of the bass drum sound.*

Discussion

The fact that the drum generates pulses instead of a continuous tone can be explained by the amplitude of the piston vibrations being larger than what is possible to sustain by the hydraulic engine. In this manner, a forced transient is generated every time the engine makes a revolution. New trials with a smaller amplitude is in progress. The sound pressure level is some 25 dB lower than the theoretically obtainable level. The difference is ascribed to friction losses in the engine and in the drum. The measured sound pressure level is probably loud enough to scare fish at very close range if the frequency content is lowered to infrasonic frequencies. The directional properties at higher frequencies (Figure 4b) are caused by the increased radius-to-wavelength ratio (Beranek 1993).

At the low frequencies of interest for scaring fish, the relevant stimulus to the fish inner ear is not pressure, but particle acceleration (Kalmijn 1988). The acoustic acceleration field within the near field around the sound source is difficult to estimate, especially in shallow water, but it is assumed that the acceleration will be larger than what is predicted from far-field theory. Therefore, the drum should be more efficient for generating stimuli to fish than what was indicated from the SPL measurements.

It is important to consider the extent of the transmission loss as the sound is propagating from the source to the fish. In shallow waters, the far field transmission loss will fall between spherical (*TL=20 log r*) and cylindrical (*TL=10 log r*) spreading. Additional transmission loss will be created by a small water depth-to-wavelength ratio. Wavelengths longer than a quarter of the water depth cannot propagate according to normal mode propagation theory (Clay & Medwin 1977). This would seriously affect sound propagation at the wavelengths of interest (some hundreds of meters) for scaring fish in shallow water. However, the extent of the acoustic near field around the bass drum is in the order of some hundreds of meters, and within this range, propagation loss is not predictable from theory, but should be measured. In the Birkö Island study, the range-dependence of the transmission loss was measured to *TL=13 log r* for the lower 100 Hz part of the bass drum sound source within a range of 100 m. This means that the audible stimuli would be about 120-130 dB re 1 μPa at the site of the fish at the start of the trial shown in Figure 5a. This is well above the hearing threshold at the relevant frequencies, as depicted in Figure 4b.

The results from the studies on whitefish and perch indicate the opposite reaction to the bass drum of what was anticipated. This is actually good news, as it is easier to visualize a fishing application where fish are attracted than one where fish are scared. Both sound production and the implementation in fishing operations would be substantially facilitated. There is a vast 30-40 dB gap between the auditory threshold for salmon at infrasonic frequencies and the threshold for consistently scaring the fish. It is also possible that the low frequencies necessary to scare fish are not needed for attraction, again making sound production much easier. This is indicated by the fact that perch could be attracted to the high-pass filtered version of the sound source. These considerations are also important in applications of creating guiding structures for salmonids at hydroelectric power plants. Decades of efforts to scare the fish with sounds have only created modest results (cf Popper & Carlsen 1998). A different approach to this problem could be to attract the fish to the bypass instead of scaring it away from the turbine intakes.

It is difficult to explain why both whitefish and perch are attracted to such an unnatural sound source as the bass drum. Even though fish to some extent use sounds for intraspecific communication, an additional important function of the ear is for orientation (Lagardère *et al.* 1994). A preying fish may use acoustic cues, generated by prey as well as by foraging conspecifics, to find food (Montgomery & MacDonald 1987, Janssen 1990, Janssen & Corcoran 1993). The transient sounds from the drum may catch the interest of the fish as a possible feeding site. This has also been inferred in previous studies on acoustic fish attraction (reviewed by Wahlberg 1999*b*). Therefore the physiological state of the fish may be crucial for the success of the attraction trial, possibly explaining the variability of the responses presented in this study.

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An Experimental Study of Alternative Baits and Selectivity of Eel-pots, made under Semi-Natural Conditions in an Eel Population with a Known Size Distribution

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Abstract

A study of bait preference and size selectivity in eel-pots was made in a 100 m^2 salt-water basin stocked with approximately 179 yellow eels, individually length measured and tagged with passive interrogated transponders (PIT-tags). The size selectivity was estimated for three diameters of the pot ventilation holes - 9, 11 and 13 mm. The observed selection of the pots, measured as the minimum size of the caught eels, was at approximately 240, 280 and 330 mm eel length, which corresponds well with a simple model of maximum girth width of eel. The attraction of a number of different baits were studied, using frozen under-yearling herring as reference bait. It was found that cod roe and commercial eel-feed gave a similar attraction as the under-yearling herring bait. No statistically significant differences between the bait types could be demonstrated.

The number of recaptures of individual eels was not entirely random. It was found that a fraction of the eels seemed to avoid the pots after being captured once, while another fraction became "trap-happy" and were recaptured more often than expected by chance. There was also a clear aggregation effect to pots where eels already were present.

***Key Words**: Selectivity, Anguilla anguilla, bait, attraction*

Introduction

Fishing on yellow eel (*Anguilla anguilla* L.) was traditionally carried out with eel-pots along the Swedish coast. Nowadays, this method is largely abandoned in favour of small fyke-nets (Karlsson 1976). However, this fishing gear is unselective and by-catches of non-target demersal fish are regularly higher than the wanted eel catches. Steadily increasing damages by cormorants (*Phalacrocorax* sp) and common seals (*Phoca vitulina*) also threaten this fishery. A renewal of the eel-pot fishery has been considered as a possibility worth trying in order to handle both the discard and the predator interaction problems.

The scarcity of effective baits at low costs for most of the fishing season is the main obstacle in using eel-pots instead of fyke-nets. Fresh under-yearling herring, *Clupea harengus*, is the traditional bait, but shoals of young herring in littoral habitats occur only during three summer months and the abundance of juvenile herring has decreased in the Skagerrak following the collapse of the North Sea fishery in the 1960s. Because of these circumstances, eel-pots cannot be used for more than a limited part of the fishing season. However, alternative baits may be a way to make eel-pots more efficient and competitive compared to fyke-nets, such as blue mussels, slices of salted herring, commercial eel feed etc.

The modern eel-pot used in Sweden is made of aluminium and is perforated by holes (9 mm in diameter). These holes are important for the ventilation of the eel-pot and for the spread of attractive smell agents to the surrounding water mass, but also functions as escape openings. Hence, the objective of this study was also to study the effects of varying escape opening size on the selectivity of the eel-pot with respect to the size distribution of the caught eel.

Material and methods

A semi-natural environment was built up in an out-door basin (about 100 m^2) with a mean water depth of 0.8 m in the vicinity of Ringhals nuclear power station (57° 15´N 12° 10´E) on the Swedish west coast. The bottom was filled with a 10 cm thick layer of sand and gravel. A continuous renewal of seawater (salinity about 20 PSU) was kept throughout the experimental period in order to avoid oxygen deficiency and to keep a good water quality. Hiding places, such as piles of stones with seaweed or bricks, were arranged on the bottom. Yellow eels of different sizes, caught in the nearby fyke-net fishery, were stocked. Every eel was anaesthetised, measured in total length (cm) and surgically marked with PIT-tags (Passive Interrogated Transponders, Trovan AS, glass-encapsulated 2.1*11.5 mm) placed in the abdomen (Holmgren 1996).

After a few days of acclimatisation, experimental fishing commenced using baited eel-pots (Fig. 1). In total, six eel-pots were used at every fishing occasion, of which two pots each with hole diameter 9, 11 and 13 mm, respectively. One pot of each diameter were baited with deep-frozen under-yearling herring in order to get a reference material for every fishing occasion. The other three eel-pots were given alternative baits: sliced salted adult herring (Mohr 1963), crushed fresh blue mussels (*Mytilus edulis*), frozen cod roe, and commercial eel feed (Danex 25/50). A number of blank trials with empty eel-pots were made to test the attraction of the eel-pot itself. The experimental design concerning paired tests of baits are shown in Table 1. The eel-pots were set at dawn and examined the next morning. At examination, the eels were identified with a hand-held PIT-reader and restocked to the basin. The number of stocked fish was 179. The mortality rate was low, only 11 fish died (6.4 %) during the entire experimental period. Because essentially all the deaths occurred at the end of the experiment, the measurements on selectivity and recapture rate have not been corrected for the small change in size distribution.

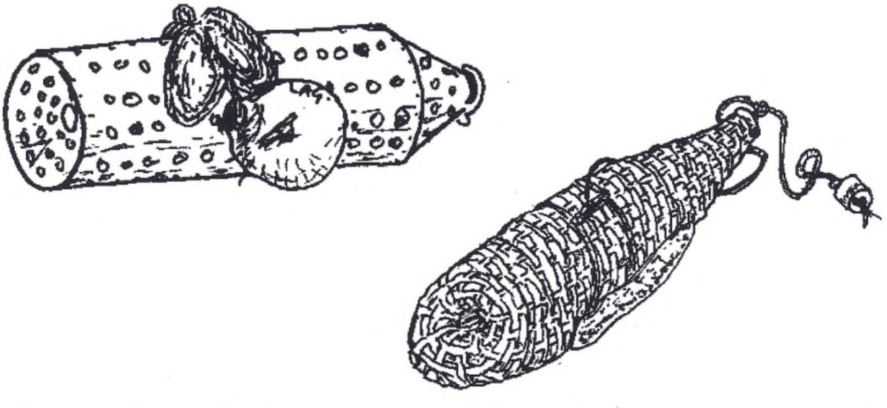

Figure 1. *Sketch of an aluminium eel-pot used in the experiments (above) and a traditional pot made from juniper basketwork (with courtesy from Ingvar Lagenfelt)*

The selectivity of the eel-pot was studied by varying the size of the ventilation/escape openings. In order to estimate the relationship between total length and the transversal diameter of the eel, it was assumed that the eel body has a uniform cylindrical shape and a density, rr, of 1 g/cm^3. A weight-length relationship of $\ln W = -7.41 + 3.21 * \ln L$, where W is the weight in gram and L is the length in mm, was used. This relation is based on measurements of 1924 eels from various sites on the Swedish west coast (Svedäng 1999). The mean transversal eel diameter (D) at a certain length was calculated using the relation

$$\mathbf{D = \sqrt{4W/\pi L\rho}} \qquad \text{(eq 1)}$$

The size of ventilation openings in commercial eel-pots is 9 mm in diameter. The selectivity was studied for hole sizes 9, 11 and 13 mm, corresponding to eel sizes of about 240, 280 and 330 mm in total length, respectively.

Experimental fishing in the field was also performed with those modified eel-pots, giving the opportunity of an evaluation of the selectivity of the eel-pot in a natural population of yellow eels. This test fishing was made in the Gullmarsfjorden (58° 17´ N, 11° 30´ E) on the Swedish west coast. Three chains of eel-pots were used, each containing five eel-pots with a certain size of the escape openings (i.e. 9, 11 and 13 mm in diameter). The fishing period from setting to examination lasted one night. All eel-pots were baited with under-yearling herring at every fishing occasion. The caught eels were measured in total length. The test fishing took place between 13 August and 3 September 1998. It was repeated 12 times with eel-pots whose escape openings measured 9 and 11 mm, whereas fishing with the link containing eel-pots with 13 mm escape openings was made 10 times only, because of scarcity of bait.

Results

Bait preferences

The experimental design and the number of fish caught at every fishing occasion are shown in Table 1. There was a strong variation in the number of caught fish (Fig. 2a). This variation was unrelated to the choice of bait as ame, quasi-cyclic, variation is seen in the CPUE in pots baited with under-yearling herring only (Fig. 2b). This catch variation seems to be related to the lunar cycle (Fig. 2a). Because of the high variability due to this effect, the level of CPUE can neither be compared between fishing occasions nor between different alternative baits (Table 2). However, paired comparisons can be made between the reference bait and test bait in pots with equal hole size, i.e. three paired observations per fishing occasion. No significant difference in attraction is found in any paired test of an alternative bait item and the reference (i.e. under-yearling herring). Nevertheless, a ranking of the attraction of different bait types can be indicated by comparing the ratio in grand mean values between alternative bait and reference (Table 2). It was found that the ratios between cod roe, eel feed, blue mussels, salted herring and the reference bait were 1,5; 1,2; 0.6 and 0.5 respectively. The catch in the empty pots was higher than with the reference bait, with a ratio of 1.2, mostly due to a very high number of eels aggregating in one of the empty pots.

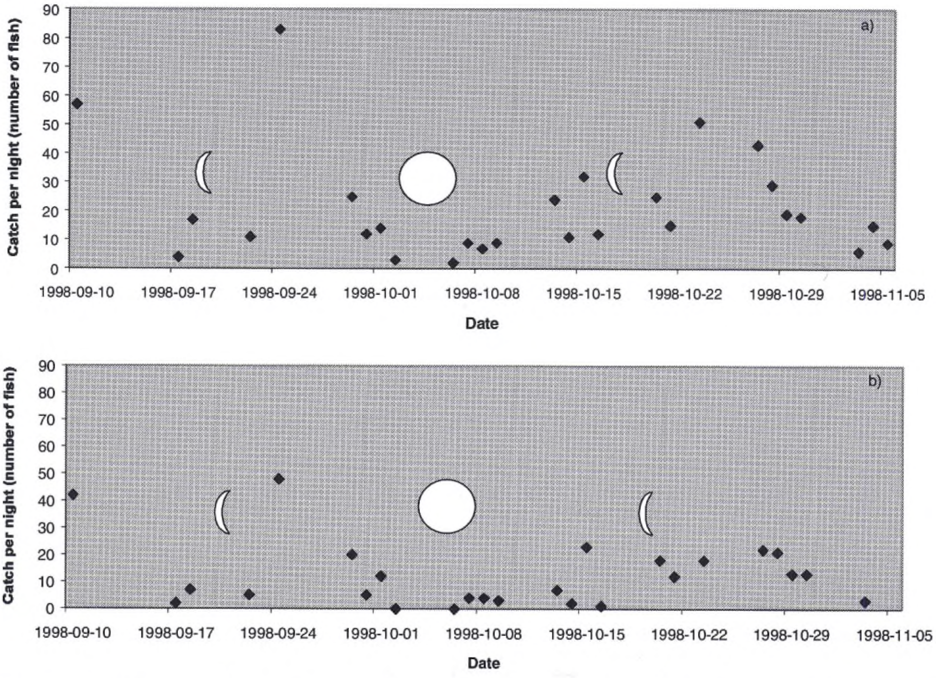

Figure 2. a) *Total number of caught eels at various fishing occasions between 10 September and 5 November 1998.* ***b)*** *The number of caught eels in eel-pots baited with under-yearling herring at various fishing occasions between 10 September and 5 November 1998. The moon quarter is also shown.*

Table 1*. Design of the experimental bait fishing and number of fish caught. Under-yearling herring was used as reference bait at all fishing occasions, except twice at the end of the experimental period, when cod roe was used as a reference bait.*

Date of examination	**Bait**						
	Under-yearling herring	Pieces of adult herring	Blue mussels	Cod roe	Eel pellets	Empty eel-pot	Total
10 Sep	42		15				57
17 Sep	2				2		4
18 Sep	7				10		17
22 Sep	5	6					11
24 Sep	48		35				83
29 Sep	20	5					25
30 Sep	5		7				12
1 Oct	12	2					14
2 Oct	0				3		3
6 Oct	0					2	2
7 Oct	4		5				9
8 Oct	4				3		7
9 Oct	3			6			9
13 Oct	7					17	24
14 Oct	2			9			11
15 Oct	23	9					32
16 Oct	1				11		12
20 Oct	18				7		25
21 Oct	12			3			15
23 Oct	18			33			51
27 Oct	22			21			43
28 Oct	21		8				29
29 Oct	13					6	19
30 Oct	13			5			18
3 Nov	3			3			6
4 Nov			3	12			15
5 Nov			3	6			9
No. of examinations	25	4	7	9	6	3	27
No. of fish caught	305	22	76	98	36	25	562

***Table 2.** Number of fish caught in paired tests with under-yearling herring and alternative baits. Since three eel-pots with different size of the escape openings were used at every fishing occasion (9, 11 and 13 mm in diameter) for each type of bait, the number of fish caught are presented per eel-pot and size of the openings of the eel-pot.*

	Reference bait material				Alternative bait			
	"9"	"11"	"13"	Total number	9"	11"	"13"	Total number
Under-yearling herring					*Empty eel-pots*			
Total catch	7	9	4	20	17	7	1	25
Mean ± SD	2.3±2.5	3.0±2.6	1.3±2.3		5.7±4.7	2.3±3.2	0.33±0.6	
Grand mean ± SD		2.2±0.8			2.8±2.7			
Under-yearling herring					*Salted herring*			
Total catch	29	8	8	45	7	7	8	22
Mean ± SD	7.2±6.9	2.0±1.8	2±1.8		1.7±1.7	1.7±1.3	2.0±1.4	
Grand mean ± SD		3.8±3.0			1.8±0.14			
Under-yearling herring					*Eel-feed*			
Total catch	8	19	6	33	8	19	6	33
Mean ± SD	2.2±3.3	2.4±3.9	1.0±0.7		1.6±1.3	3.8±4.7	1.2±0.8	
Grand mean ± SD		1.9±0.8			2.2±1.4			
Under-yearling herring					*Blue-mussels*			
Total catch	41	29	49	119	16	19	34	69
Mean ± SD	8.2±13	5.8±4.4	9.8±11		3.2±3.1	3.8±2.4	6.8±8.0	
Grand mean ± SD		8.0±2.0			4.6±1.9			
Under-yearling herring					*Cod roe*			
Total catch	14	28	16	58	28	15	31	74
Mean ± SD	2.3±2.5	4.7±5.1	2.7±2.7		5.6±6.5	3.8±2.2	5.2±5.9	
Grand mean ± SD		3.2±1.3			4.8±1.0			

Size selectivity

The mode of the length distribution of the stocked, total eel population was located in the length class 375-400 mm and ranged in total length from 225 to 700 mm (Fig. 3). The length distribution in the eel catches of the three types of eel-pots were fairly similar to the total population structure and to each other, regardless of the escape opening size (Table 3). As the experimental eels originated from catches with fyke-nets, the number of eels in the size-classes below 350 mm is small, which conceals the selectivity. If the catch per size class is normalised with the proportion of eels in this size class in the basin population the selection becomes more evident (Fig. 4). It is seen that the observed length distribution is cut off at successively larger sizes with increasing hole diameter, and the observed selection length follows the theoretically predicted length according to equation 1. The eel catch-per-unit-effort (CPUE) also decreased with increasing size of the escape opening (Table 4). These differences in CPUE were, however, not significant (one-sided t-test).

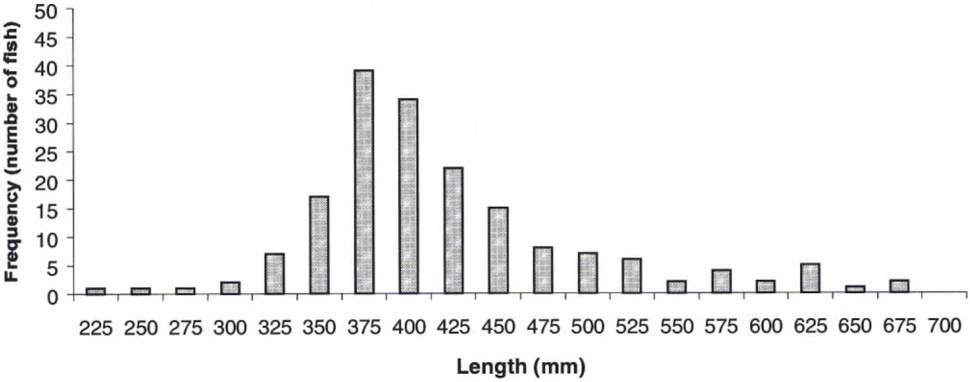

***Figure 3**. The initial length distribution of the eel population stocked in a basin at Ringhals.*

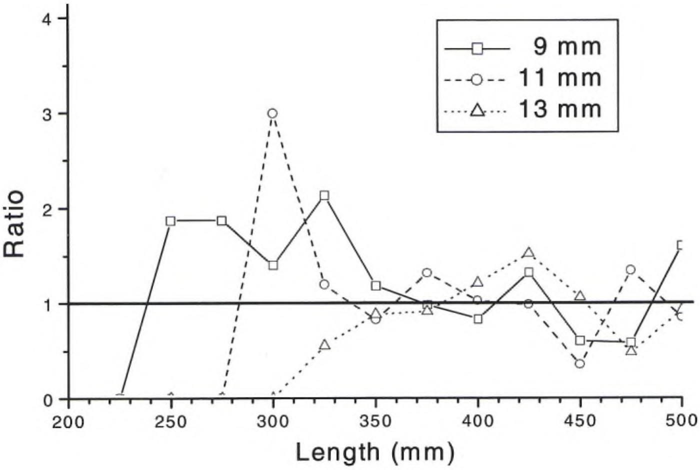

***Figure 4.** The ratio between length frequency of caught eels, using pots of different hole diameter, and the length frequency of the total stocked eel population. The line indicate equality between the length frequency of caught eels and the total stocked eel population.*

Table 3. *The number of fishing occasions, mean total length, standard deviation and number of eels caught in an experimental fishing with eel-pots with various escape opening sizes (9, 11 and 13 mm in diameter). The experimental fishing was performed in a basin at Ringhals on the Swedish west coast from September to November 1998. Parameter values are given for total stocked eel population (*^{1} *- the number stocked eel). Differences in mean length of eels caught in eel-pots with various escape openings sizes are shown (Student t-test: NS- not significant, *-p<0.05, **-p<0.01, ***-p<0.001)*

	Total eel population	Eel-pots with different size of the escape openings 9 mm	11 mm	13 mm
Number of fishing occasions	-	26	26	26
Number of fish caught	184[1]	197	154	143
Mean total length	409	398	402	414
Standard deviation	78	74	72	77
t-test (9 mm eel-pots vs 11 mm eel-pots)		NS		
t-test (11 mm eel-pots vs 13 mm eel-pots)		NS		
t-test (9 mm eel-pots vs 13 mm eel-pots)		*		

Table 4. *The eel catch-per-unit-effort (CPUE) in experimental fishing with eel-pots with various escape opening sizes (9, 11 and 13 mm in diameter). The experiment was performed in a locked basin with stocked eels at Ringhals on the Swedish west coast from September to November 1998. Differences in CPUE in eel-pots with various escape openings sizes are shown (Student t-test: NS- not significant, *-p<0.05, **-p<0.01, ***-p<0.001)*

	Eel-pots with different size of the escape openings		
	9 mm	11 mm	13 mm
Number of fishing Occasions	26	26	26
CPUE Mean value	7.5	5.9	5.4
Standard deviation	8.4	4.7	7.5
t-test (9 mm eel-pots vs 11 mm eel-pots)	NS		
t-test (11 mm eel-pots vs 13 mm eel-pots)	NS		
t-test (9 mm eel-pots vs 13 mm eel-pots)	NS		

The experimental fishing in the Gullmarsfjorden gave length distributions that were fairly similar, regardless of the size of the escape openings. The mode of the length distributions were located at about 350 mm and the ranges in total length were similar (Fig. 5a-c). However, the mean length of eels caught in eel-pots with 9 mm openings was significantly smaller than the mean length of those caught in eel-pots with larger openings (including all fishing occasions; one-sided t-test, p<0.001), whereas the mean length of the eels caught in eel-pots with 11 and 13 mm were similar (Table 5). Also, the length frequency distribution of the eels caught in eel-pots with 9 mm holes was significantly different from the length distributions observed in eel-pots with large holes (K-S, p<0.05). In accordance to the basin experiment, CPUE seemed to decrease with increasing size of the escape opening (Table 6). These differences in CPUE were, however, not significant (one-sided t-test).

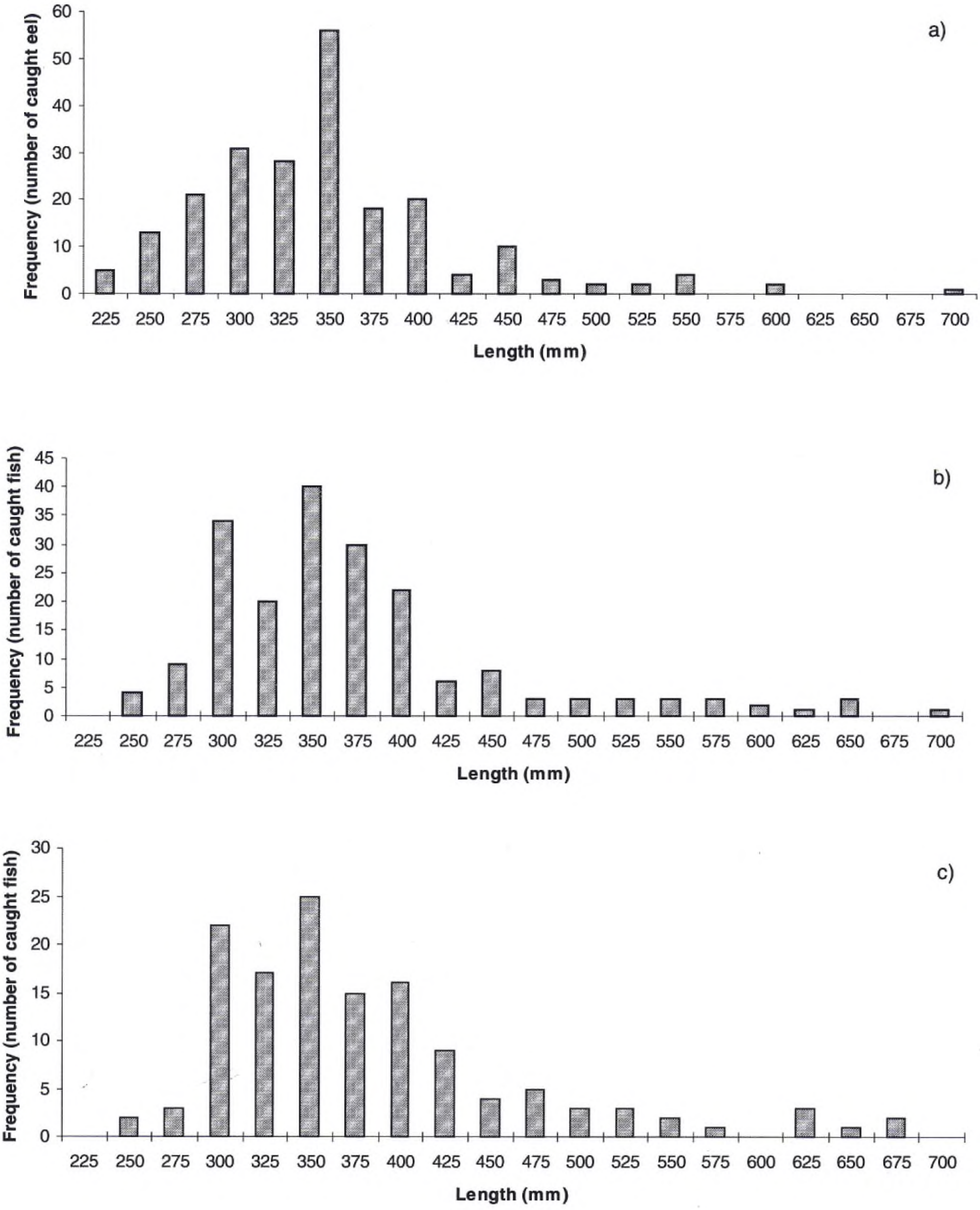

***Figure 5.** Length distribution of caught fish in eel-pots with various escape opening sizes in the Gullmarsfjorden on the Swedish west coast in August and September 1998. a) Escape opening size equal to 9 mm in diameter, b) 11 mm in diameter c) 13 mm in diameter. Note the different scales on the y-axis.*

Table 5. *The mean total length, standard deviation and number of eels caught in test fishing with eel-pots with various escape opening sizes (9, 11 and 13 mm in diameter). The fishing was performed in the Gullmarsfjorden on the Swedish west coast in August and September 1998. Differences in mean length of eels caught in eel-pots with various escape openings sizes are shown (Student t-test: NS- not significant, *-p<0.05, **-p<0.01, ***-p<0.001)*

	Eel-pots with different size of the escape openings		
	9 mm	11 mm	13 mm
Number of fishing Occasions	12	12	10
Number of fish Caught	220	195	133
Mean total length	337	363	372
Standard deviation	73	83	86
t-test (9 mm eel-pots vs 11 mm eel-pots)	***		
t-test (11 mm eel-pots vs 13 mm eel-pots)	NS		

Table 6. *The eel catch-per-unit-effort (CPUE) in test fishing with eel-pots with various escape opening sizes (9, 11 and 13 mm in diameter). The fishing was performed in the Gullmarsfjorden on the Swedish west coast in August and September 1998. Differences in mean length of eels caught in eel-pots with various escape openings sizes are shown (Student t-test: NS- not significant, *-p<0.05, **-p<0.01, ***-p<0.001).*

	Eel-pots with different size of the escape openings		
	9 mm	11 mm	13 mm
Number of fishing Occasions	12	12	10
CPUE Mean value	3.7	3.2	2.7
Standard deviation	2.9	1.8	2.6
t-test (9 mm eel-pots vs 11 mm eel-pots)	NS		
t-test (11 mm eel-pots vs 13 mm eel-pots)	NS		
t-test (9 mm eel-pots vs 13 mm eel-pots)	NS		

Recapture rate

Because all eels were individually marked with PIT-tags, the number of recaptures can be counted for each fish (Fig. 6). The mean recapture rate was fairly low, 2.8 (SD: ±± 2.2) out of 26 fishing occasions. About 5.6 % of all stocked eel were never recaptured. Because of the over-all low incidence of recaptures it can be expected that the number of recaptures should follow a Poisson distribution (Sokal & Rohlf, 1981). In comparison with the expected frequency according to such a distribution, it can be observed that the number of fish recaptured at a single time were over-represented. On the other hand the number of fish visiting the eel-pots more than 6 times were also over-represented, which indicates both a learned avoidance in some of the eel and a trap-happiness in others.

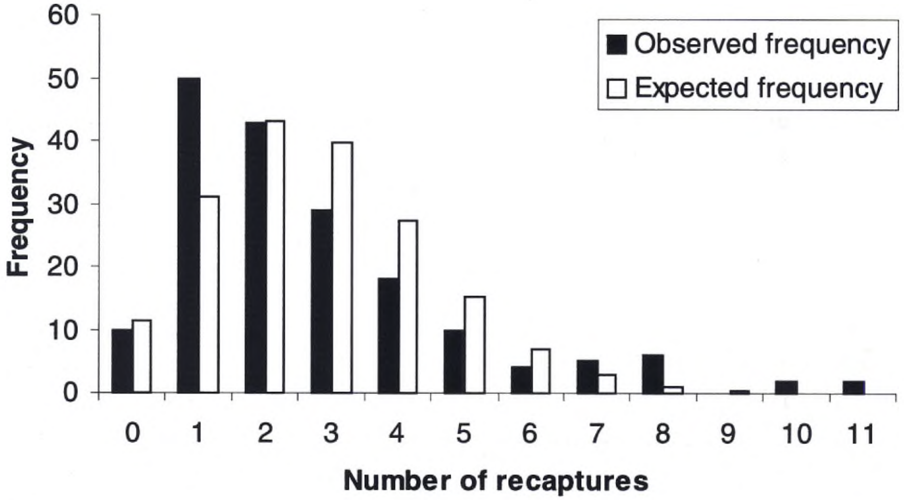

Figure 6. The frequency (number of fish) regarding the number of recaptures. The total number of stocked and surviving fish was equal to 179.

Aggregation

For each fishing occasion there was a triplet of herring baited pots. If eels enter the pots at random, the catch distribution between the three pots will follow the hypergeometric probability distribution. This predicted distribution is calculated for the case of three pots and a total catch of 12 eels and is shown in Figure 7 as open bars. The shaded bars show the observed distribution in the experiment based on 36 emptyings with a total catch of at least 12 eels. Evidently there was a tendency to aggregate in one or two of the pots.

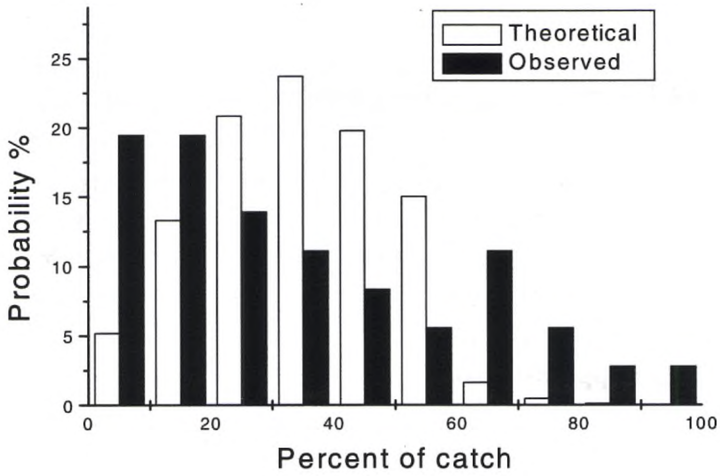

Figure 7. *The observed distribution of the total catch in individual pots observed at 36 emptying occasions when the mean CPUE was 4 or larger. The white bars show the expected theoretical distribution if the pots were chosen at random.*

Discussion

The preference of yellow eels to different bait is little studied. The variation of bait that is used in the German eel fishery is large (Tesch 1973), ranging from fish, preferably smelt (*Osmerus eperlanus*) to crustaceans as *Crangon crangon* or *Neomysis vulgaris* or molluscs as *Mytilus mytilus* or *Buccinum undatum*, the choice depending on the time of year. Eel, like many other fish species, seems to specialise on a certain prey in periods which coincide with the peak abundance of the prey.

In the present study there was a large variation in CPUE, probably related to the lunar cycle, which makes results from different fishing occasions difficult to compare over time. Each test bait can, however, be compared to the reference bait, i.e. juvenile herring. The fact that the eels that were recaptured several times tended to have chosen many different baits, indicated that prey specialisation may be not so important in eels.

Modifications of the ventilation/escape openings of the eel-pot showed a size selectivity which was in accordance to the predicted eel sizes. The range of hole diameters that were tested is however small, and it is not evident that the results can be extrapolated to the size that will be necessary in order to achieve a minimum size of say 400 mm (corresponding to 17 mm diameter). A selection, at least at this size, is probably needed to optimise the use of the eel resource (c.f. Svedäng 1999). More experiments should be made to find a practical system with escape openings - the number of holes necessary, placement and diameter.

The average catch during one night fishing in the basin was 12 % of the total number of eels present, so the capacity of the fishing was not saturated. No extra feeding was made in the basin during the experiment, but it is possible that the supply of bait was so large that the eels were satiated most of the time. The aggregation of the catch in one or a few of the pots instead of a random spreading is very clearly demonstrated by the observations. The reason to this is not so clear. It may partly be an effect of the placement of the pots. Another explanation is an attraction of eels to other eels. This may also explain the high catch in some unbaited pots. An occasional entry of an eel can induce social aggregation. Similar effects have been previously observed in unbaited fish traps (Furevik 1994).

Acknowledgements

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Experimental Adjustments of the Escape Window Position in Trawl Codends - Implications for Baltic Sea Cod Fishery

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Abstract

A selectivity experiment was conducted from a commercial Danish vessel fishing cod in the Baltic Sea. The main objective of the trials was to determine the optimal location for square mesh windows in Baltic cod trawl codends, which would maximise the escape of cod under minimum landing size. The catches of two codends, each fitted with windows of equal total area but different location, were compared directly when fished alongside each other in a twin trawl rig. A significant reduction of cod under the Danish minimum landing size of 35 cm was found when the "Danish" window was moved backwards from the positioning of 2.1 m from the codline to a positioning 0.4 m from the codline. A significant reduction of cod over MLS was also found. When a codend with a single large window in the upper panel was tested against a codend with "Danish" windows moved to a position 0.4 m from the codline, statistical analyses showed that it caught significantly less cod under the minimum landing size. Catches were however so low during the experiment and in particular so very few undersized cod were caught that this result should be regarded with caution. On the other hand, comparing cod under 45 cm, where higher catches were obtained, suggested that the single large window caught significantly fewer small cod.

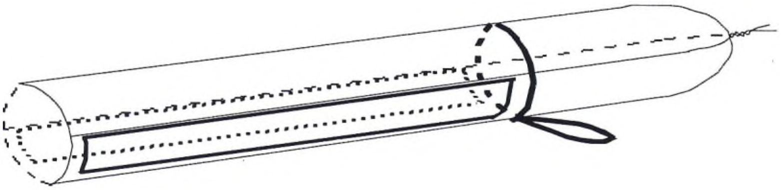
Keywords: *Selectivity; Cod; Baltic Sea; Trawl; Escape windows; Gadus morhua*

Introduction

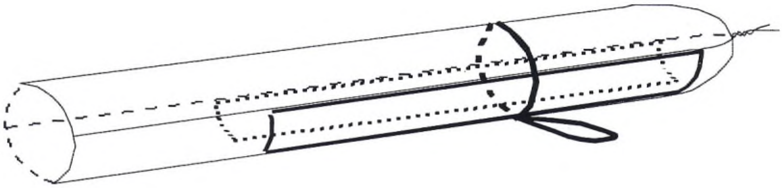
According to Bagge et al. (1994) the fishing mortality was estimated at 1.37 in 1991, which was more than five times the F_{max} of 0.25. This high fishing mortality is not sustainable on a low stock, so there is a serious need for the use of more selective gears in the cod fishery. An ad hoc working group established by the International Baltic Sea Fisheries Commission (IBSFC) recommended "an increase in mesh size from 105 mm to 120 mm, or the use of alternative gear which can be demonstrated to have similar improved selection characteristics". Swedish (see Tschernij et al., 1996) and Danish (Lowry et al., 1995) selectivity experiments indicated that this target could be reached using two different designs of windows with meshes of wide open or square configuration inserted in standard 105 mm mesh size codends. Both window design options were adopted into the fisheries legislation from 1^{st} of June 1995, by the European Communities [EC council regulation No. 3362/94, 20 December 1994] and for the whole Baltic Sea by the IBSFC. The minimum mesh size stipulated for the windows was 105 mm for both designs.

An illustration of the location of the windows is shown in Figure 1 where codend 1 illustrates the "Danish" codend. The "Swedish" codend is shown at the bottom. In Denmark most vessels in the fleet use codends with the "Danish" window. An ICES working group (Anon, 1996) estimated the selection factor (SF = L50/window mesh size) of these "Danish" window codends to be only 3.06 (giving a L50 of 32 cm at 105 mm window mesh size) and that of "Swedish" windows to be much higher, 3.52 (giving a L50 of 37 cm at 105 mm window mesh size) based on all available data sets from the Baltic Sea area. The selection range was estimated to be marginally lower for the "Swedish" window, 8.2 cm compared to 8.6 cm for the "Danish" window. A Danish experiment comparing catches from two identical trawls, one fitted with "Swedish" and one with "Danish" window codends, fished at the same time in a twin trawl rig, also indicated that the "Danish" codend was less selective retaining significantly more fish under 50 cm (Moth-Poulsen et al., 1995). The results of this experiment are shown in Figure 2.

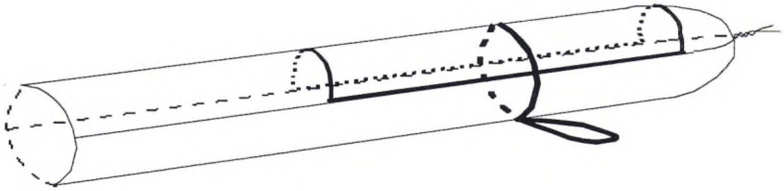
Codend 1 ("Danish codend")



Codend 2 (Modified "Danish codend")



Codend 3 (Single top window)



"Swedish codend"

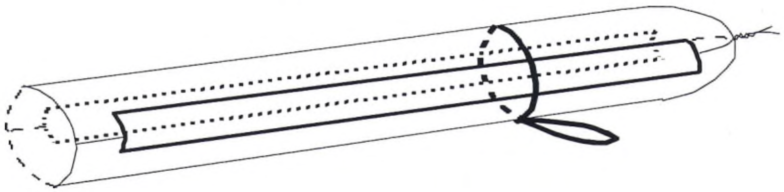


Figure 1. *Codend constructions used in first and second experiment and the "Swedish" type codend.*

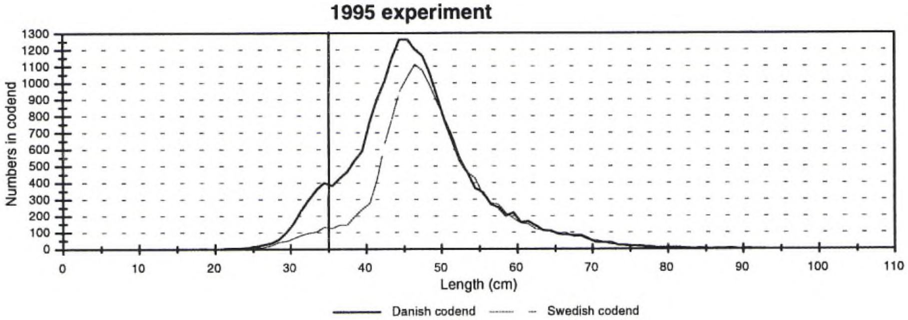


Figure 2. Comparisons of codend catches of Danish and Swedish codend tested during experiments in 1995. The vertical line indicates MLS.

There are some main technical differences between the two window types used by the commercial fleet. The net material in the "Swedish" window is patented stiff plastic coated knotted single twine netting hung such that the meshes maintain the conventional fore-aft orientation but have a wide opening. The net-material in the "Danish" codend is conventional netting turned 45 degrees to form square meshes. The regulations do not specify use of single or double twine and double twine is most commonly used. According to the regulations the "Swedish" windows must be 80% of the length of the codend and end only 40-50 cm from the codline. The windows are 50 cm wide but are inserted in an opening of 15-20 cm, giving the window an out bending bulbous shape. The "Danish" windows end 2-2.5 m from the codline and should be 57-62 square meshes (bars) long giving a total length of about 3.5 m. The "Danish" window must be 8 square meshes wide giving a width of about 50 cm.

The main objective of the trials described in this paper was to compare different locations for square mesh windows in Baltic cod trawl codends, which would maximise the escape of cod under minimum landing size. The validity of experiments with codend covers has often been questioned by both fishermen and scientists (Robertson et al., 1995; O'Neill and Kynoch, 1996) therefore an experimental design was used where the catches of two codends, each fitted with windows of equal total area but different location, were compared directly when fished alongside each other in a twin trawl rig

Methods

Fishing vessel and area

The vessel chosen for the sea trials was a 290 HP commercial stern trawler R86 named Lis-Hansa built in 1978 having an overall length of 19.98 m and GRT of 49.98. This trawler had been found in previous trials to be well suited for experiments with twin trawls. Both experiments were conducted on fishing grounds around Bornholm (ICES subdivision 24 and 25) in May and June 1997. The hauling duration was about 8 hours for the first sea trials and due to poor catches about 4 hours for the second sea trials.

Trawls

Two identical typical commercial Baltic Sea cod trawls with a mesh size of 110 mm full mesh throughout and a circumference of 300 meshes were fished at the same time in a twin trawl rig. Headlines had thirteen 8" floats. Warp length used varied from 319 to 364 m. The otterboards were Thyborøn 72", sweeps 109 m and bridles 10 m throughout both trials. The headline heights of the trawls were measured with Scanmar equipment to be about 2 m and the wing spreads 11-13 m at three knots towing speed. The spread between the otterboards was measured to be about 130 m at three knots speed.

Codends and windows

Three conventional 6 m long codends were made by a local Bornholm net manufacturer Nexø Trawl using 4 mm green PET double twine netting. This material is usually used by the commercial Danish Baltic Sea fleet for codends with or without windows. The same piece of netting was used for the construction of all three codends.

To overcome problems with the net performance, which might affect the selectivity and hence the results in an unpredictable way, it was decided to use the Japanese produced single twine knot-less Ultra Cross netting for the windows inserted in the three codends. In this netting the twine threads are continuous in the all bars direction making it very strong and of stable mesh configuration when used as square mesh netting. The netting used was black 4.9-mm PET twine, which has a breaking strength of 330 kg. The commercial Danish fleet uses the same net material for windows as that used for codends. It is thought that this material is not well suited to windows because the double twines tend to separate, reducing the opening of the meshes and not giving fish an optimal chance of escape. Another problem with using conventional netting in square mesh windows is knot slippage, which leads to a high degree of uneven mesh sizes and shapes.

Codend 1 was the "Danish" window design (Fig. 1). The codend had two windows, one inserted in each side immediately below the selvedges, ending 30 cm in front of the lifting strop which is 2.1 m from the codline. One square mesh was attached to one diamond mesh at each end of the windows. The window was 3.42 m long (57 open meshes) and 0.48 m wide (8 open meshes). Codend 2 (Fig. 1) had the same window size as codend 1 but the window positioning was moved backwards giving an end position 40 cm from the codline. This end position was similar to that of the "Swedish" window codend (Fig. 1). Codend 3 (Fig. 1) had a single window inserted in the upper panel. The window was 2.40 m long (40 open meshes) and 1.38 m wide (23 open meshes). For practical reasons it was decided to place the window between the selvedges. This window is easier to fit than the "Danish" and "Swedish" windows and more readily inspected. This window type is successfully used in other fisheries, principally in *Nephrops* trawling (Robertson 1993, Madsen and Moth-Poulsen 1994), to reduce bycatches of immature individuals of gadoid species. The total window area was almost the same as for the two other codends. One square mesh was attached to two diamond meshes at the ends of the window as specified in the fisheries legislation for windows of this type. Codend 1 and codend 2 were compared in the first experiment. During the second experiment codend 3 was tested against codend 2.

Codends were regularly interchanged during the sea trials. It was decided not to change the codends after each haul in order to avoid having possible problems with one codend always fishing on the same side at a given time of day (morning or evening haul). The codends were interchanged 10 times at the first sea trials and 9 times during the second sea trials.

Recordings

All fish were length measured to nearest centimetre below. In the further analyses 0.5 cm was added to all lengths.

Inside mesh sizes (mesh openings) were measured 60 times for the window and 100 times for the codend with a 4-kg ICES gauge in the first experiment. Measurements were conducted on dry meshes before the sea trials, in wet condition after haul 9, and after the last haul in wet condition. In the second experiment, measurements were taken in the wet condition before the trials, after haul 8 and after the last haul. These were later converted to approximate legal equivalents (as would have been obtained if using the wedge gauge with 5 kg hanging weight specified in the fisheries regulations) by adding 4% (Ferro and Xu, 1996).

Data analysis

Catch weights of cod were estimated using the following formula: $W = K * l^3$, where W is the weight in g of a cod in length class l cm and K is the condition factor. K was set to 0.0110 for the first sea trials in May and to 0.0109 for the second sea trials in June from estimates produced by Bagge and Steffensen (1991).

In order to evaluate the fishing performance of the two codends paired *t*-tests (two-tailed) were performed. The assumptions for the test are that each pair of measurements is independent of other pairs and that differences are normally distributed. The test is, however, parametric and is fairly robust to deviations from the normal distribution. The tests were performed on all haul by haul paired observations of cod catch numbers or catch weights in chosen groups of length classes. The groupings used were all cod, those less than minimum landing size (35 cm), those above minimum landing size and those under and above 45 cm. The last category was chosen because the results indicated that selection took place up to about 45 cm. The data analysis was performed using routines in the S-PLUS software package.

Results

Mesh size measurements

The ICES gauge measurements are presented in Table 1. The first measurements were made on dry meshes before use. The window mesh size was about 109 mm (113 mm with legal wedge gauge) for this measurement but decreased to about 105 mm (109 mm with legal wedge gauge) for the following wet measurements. There were only small differences in the mesh sizes of the two codends used during the first experiment (approximately 101 mm with the ICES gauge corresponding to the legal minimum mesh size of 105 mm with a wedge gauge).

Table 1. *Mesh measurements made before use, midway and after the last haul.*

Sea Trials	Codend	Window mesh size (mm) ± SD			Codend mesh size (mm) ± SD		
		Before	Midway	After	Before	Midway	After
First	Codend 1	108.9 ± 0.8	105.3 ± 0.9	105.0 ± 0.6	102.4 ± 3.0	101.7 ± 3.0	101.2 ± 3.0
	Codend 2	109.0 ± 0.7	105.0 ± 1.3	104.6 ± 0.8	102.3 ± 2.7	101.1 ± 3.0	101.0 ± 3.1
Second	Codend 2	104.6 ± 0.8	103.3 ± 0.9	103.9 ± 0.8	101.0 ± 3.1	100.9 ± 3.0	101.1 ± 3.1
	Codend 3	105.6 ± 1.1	103.6 ± 0.8	104.1 ± 0.7	101.8 ± 2.9	100.6 ± 3.5	101.0 ± 3.2

Prior to the second sea trials there was 1 mm difference in the window mesh sizes (measured wet) for codend 2 and codend 3. This difference was probably due to codend 3 being new whereas codend 2 was used in experiment 1. In the remaining measurements there were only very small differences in the mesh sizes of the two codends

The standard deviations of the window mesh sizes were relatively small compared to those of the codend measurements and measurements of windows made of 4 mm double PET in previous experiments (Moth-Poulsen et al., 1995; Madsen et al., 1997).

Catch comparisons for the first experiment

Towing times were relatively long in the first experiment conducted in May and there were relatively good catches. A total of 19 hauls (all valid) were conducted. There was a relatively high bycatch mainly consisting of flounder (*Platichthys flesus*).

Catches of each haul are shown in Appendix 1 and the pooled results of the cod catches are presented in Table 2. There was a 53% reduction in the number of fish under the Danish minimum landing size (MLS), which is 35 cm, when comparing codend 2 to codend 1. The reduction of cod numbers over MLS was 12% and the total reduction over all length classes was 14%.

These differences were found to be highly significant when using the paired t-test. The length frequency distributions of the pooled catches are shown in Figure 3. A marked difference in catches of cod up to about 45 cm was indicated. For fish longer than 45 cm the catches in the two codends are relatively equal. Comparing lengths below 45 cm, there was a 24% significant reduction whereas there was a non-significant 4% increase of cod above 45 cm.

Table 2. *Number and weight of pooled cod catches in the first experiment with two types of codends*

	Codend 1	Codend 2	Difference	Significance
No. < 35 cm	468	222	- 53 %	(P < 0.001)
No. = 35 cm	8506	7462	- 12 %	(P < 0.001)
No. < 45 cm	5926	4520	- 24 %	(P < 0.001)
No. = 45 cm	3048	3164	4 %	NS
No. total	8974	7684	- 14 %	(P < 0.001)
Weight (kg) < 35 cm	176	81	- 54 %	(P < 0.001)
Weight (kg) = 35 cm	8858	8369	- 6 %	(P < 0.05)
Weight (kg) < 45 cm	4280	3417	- 20 %	(P < 0.001)
Weight (kg) = 45 cm	4753	5032	6 %	NS*
Weight total (kg)	9034	8450	- 6 %	(P < 0.01)

*Significant at 10 % level (P < 0.1)

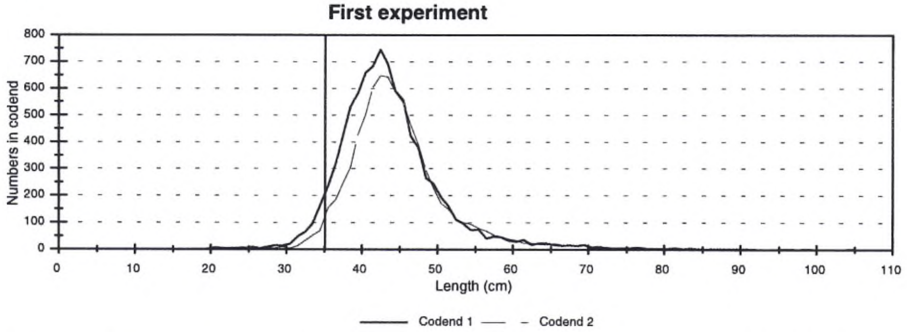


Figure 3. *Comparisons of pooled codend catches (numbers) of codend 1 and 2 tested in the first experiment. The vertical line indicates minimum landing size (MLS).*

When a "Danish" and a "Swedish" codend were compared in 1995 (Fig. 2) the results showed similar tendencies as in this experiment, but in this case the differences between the two codends were larger. Figure 4 shows the difference in cod numbers under MLS for single hauls. Except for the two first hauls there were large reductions in the numbers of undersized cod for codend 2.

The reductions in catch weight for codend 2 were 54% for cod under MLS, 6% for cod over MLS and 6% in total. All these differences were statistically significant. Figure 5 shows the differences in catch weight between the two codends by length classes. The differences are marked up to about 45 cm. Dividing catches by 45 cm showed a significant 20% decrease of cods under 45 cm, but a 6% increase for cod over 45 cm (only significant at the 10% level). However, as shown in figure 4, there was in fact a loss of marketable cod over MLS in numbers and weight for codend 2 in most hauls. Codend 2 caught less cod under 45 cm in all hauls except haul 1.

Differences in selectivity of the two codends may also be illustrated by calculating the number of cod under MLS caught per kg cod over MLS. This gives 0.053 for codend 1 and 0.027 for codend 2. Then the reduction is 49% in codend 2 when compared to codend 1. If differences, comparing codend 2 to codend 1, were calculated as the average difference per haul, weighting all hauls equal, the reduction in numbers under MLS was 49%, 16% in numbers and 10% in weight for cod over MLS, similar to the results of the pooled data (Tab. 2).

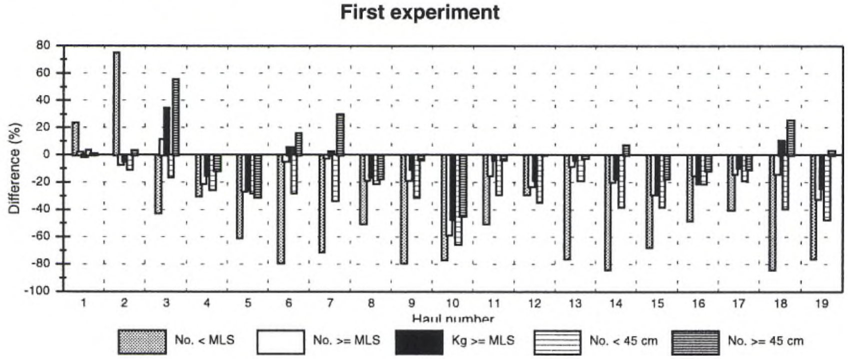


Figure 4. *Differences (%) in cod catches by haul between codend 1 and 2 in the first experiment.*

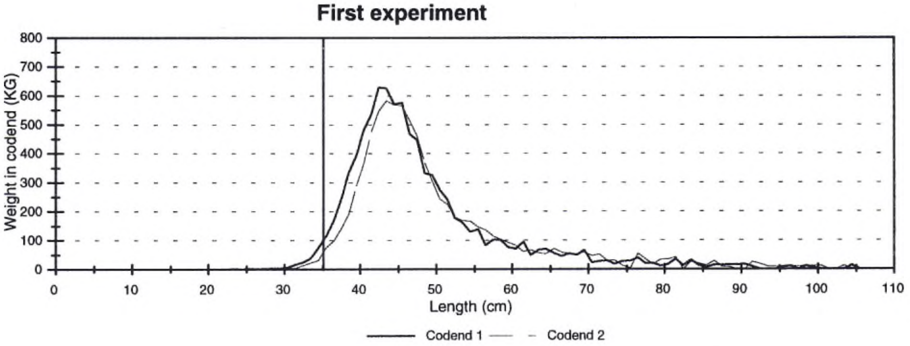


__Figure 5.__ Comparisons of pooled catches (kg) of codend 1 and 2 tested in the first experiment. The vertical line indicates MLS.

Catch comparisons for the second experiment

Catches, catch rates and towing times were lower in the second experiment in June. A total of 20 hauls were completed. Three hauls were discarded because of irregular gear performance (holes in the net etc.). In haul 17 codend 3 had a very large bulk catch of more than twice as many fish as codend 2 (937 and 411 cod respectively). Compared to all other hauls this gave clearly outlying results. Even though there was no evidence of irregular performance of either trawl, it was decided to exclude this haul because it would have a dramatic influence on the conclusions.

Catches of single hauls are shown in Appendix 2 and pooled results for catches of cod are presented in Table 3. Although a significant reduction of cod under MLS comparing codend 3 to codend 2, but as a whole, very few cod under MLS were caught (approximately one per haul with codend 3 and three per haul with codend 2, Figure 6). There was a 3% decrease in the number of cod over MLS but a 3% increase in weight. The pooled catch numbers and catch weights by length class are showing that codend 3 caught less cod up to about 42 cm (Figures 7 and 8). Codend 3 had a tendency to catch more large cod between 43 cm and 55 cm. When the catches were divided at 45 cm, the reduction 16% of cod under 45 cm was significant whereas the 8% increase in numbers and 9% in weight above 45 cm were not significant. If the catches of cod in numbers over 50 cm were compared the 16% increase in codend 3 was significant ($P < 0.05$), whereas the 13% increase in weight was not significant.

Differences between the codends in catch numbers or total weight of cod over MLS were not significant. Figure 6 shows that codend 3 caught more large fish in several hauls.

Table 3. *Number and weight of pooled cod catches in the second experiment, comparing codend 3 with codend 2.*

	Codend 2	Codend 3	Difference	Significance
No. < 35 cm	54	20	- 63 %	(P < 0.001)
No. = 35 cm	1627	1585	- 3 %	(NS)
No. < 45 cm	866	725	- 16 %	(P < 0.01)
No. = 45 cm	815	880	8 %	(NS)
No. total	1681	1605	- 5 %	(NS)
Weight (kg) < 35 cm	15	6	- 60 %	(P < 0.01)
Weight (kg) = 35 cm	1956	2006	3 %	(NS)
Weight < 45 cm	655	578	-12 %	(NS)*
Weight = 45 cm	1317	1434	9 %	(NS)
Weight total (kg)	1972	2012	2 %	(NS)

*Significant at 10 % level (P < 0.1)

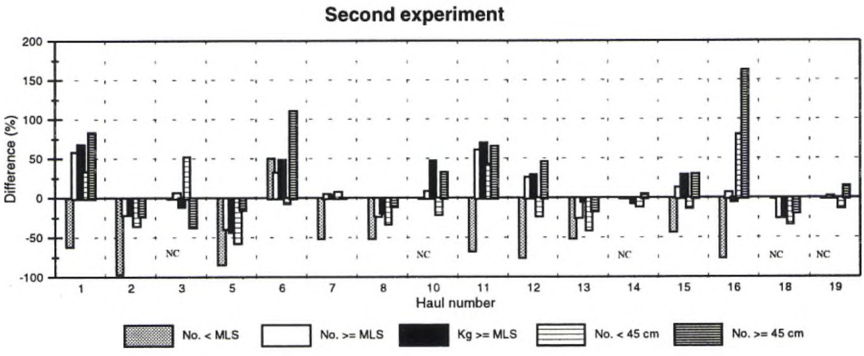


Figure 6. *Differences (%) in cod catches by haul between codend 3 and 2 in the second experiment. Catches are divided by MLS. NC indicates no comparisons of cod under MLS because there were no catches in one or both codends.*

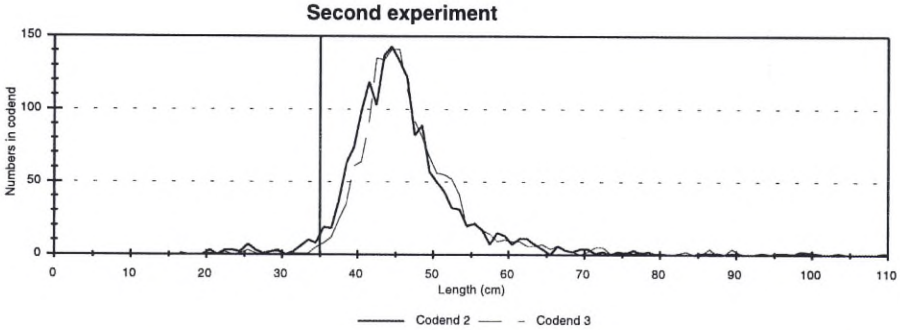


Figure 7. Comparisons of pooled catches of codend 2 and 3 tested in the second experiment. The vertical line indicates MLS.

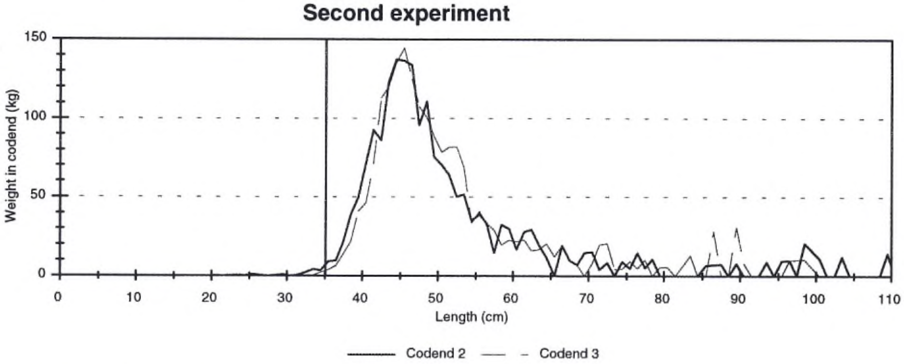


Figure 8. Comparisons of pooled catches (kg) of codend 2 and 3 tested in the second experiment. The vertical line indicates MLS.

Discussion

First experiment

Relatively good catches were obtained during the first experiment. A statistically significant reduction by number of 63% of cod under MLS was found when the "Danish" windows were moved from the position currently specified where they terminate just in front of the lifting bucket to one where they terminate just in front of the codline. There was, however, also a statistically significant 6% loss of cod catch weight over MLS. This reduction would force the fisherman to fish longer in order to catch a given quota. A better way to compare the results is therefore to calculate the reduction as numbers of cod under MLS per kg cod over MLS landed, showing that the reduction in number of cod under MLS for codend 2 was 49% lower than codend 1. The results therefore suggest that the selectivity of the conventional "Danish" window codend could be significantly improved if the window was moved aft to the end of the codend. However, the strength of the codend is likely to be weakened when lifting the catch on board, if part of the window was situated behind the lifting strop and conventional netting materials were used in the window as it is at present. The netting used for the "Swedish" windows is probably far stronger being in the conventional mesh orientation and specially treated. Special materials such as the Ultra-cross netting used in this project would be required for square mesh windows extending aft of the lifting strop.

The results of this experiment showed similar trends to the results of a previous experiment conducted in 1995, where a "Swedish" and a "Danish" window codend were compared (Moth-Pousen, et al., 1995). The differences were however larger in the previous experiment. The larger difference could be due to design differences between the "Swedish" window codend and codend 2 or to differences in the cod populations fished as more small cod were caught in the 1995 experiment. There are many basic geometrical design differences between the "Swedish" windows and those used in codend 3. In addition, the window of the "Danish" codend tested in the previous experiment was made of double thread, which it is thought to effectively reduce the open area inside a mesh, whereas the "Swedish" exit window was made of single thread. Consequently, the mesh size of the "Danish" windows was 1 to 3% smaller than that of the "Swedish" windows.

It could be speculated that cod are more seriously damaged by the codend catch, or even dead, when escaping from windows located in the aft part as opposed to the forward part of the codend. Experiments on survival of Baltic cod escaping from "Swedish" exit windows have, however, indicated that such mortality is negligible (Suuronen et al., 1996).

Second experiment

However, the results must be considered with care as relatively few cod were caught during the second experiment. The codends might behave in another way with larger catches. Very few cod under the Danish minimum landing size were caught. If catches of cod under 45 cm were compared the data set was reasonably large and still suggesting that codend 3 caught less small cod.

The top panel window codend caught significantly larger numbers of cod over 50 cm. This difference could be a result of better flow through the codend reducing the chance of large cod with better swimming performances from swimming forwards out of the codend. Experiments in the Skagerak area testing a selective flatfish trawl, with large meshes in the top panel and a square mesh section in the codend, against a standard trawl showed that significantly more large cod (over 50 cm) were caught in the selective trawl (Madsen et al., 1997). These results suggest that catches of larger cod might benefit from the use of more selective fishing gear reducing the economic loss to fishermen by allowing more small cod just above MLS to escape.

Locating a window in the upper panel of a codend is a more practical solution because it is more easily inserted and there are no possible problems with it being covered by attachments such as chafers. Also damages of the window caused by contact with the bottom will be reduced. Such windows have been successfully used to reduce gadoid bycatches in other areas (Robertson, 1993; Madsen and Moth-Poulsen, 1994) and are to be specified in EU legislation. The top window makes it possible to standardise legislation between fishing areas with regard to gear specification and inspection.

These results suggest that when the size of the window area is increased in the aftermost part of the codend the escape of smaller cod is improved. A problem with the window designs tested in these experiments could be that the accumulating codend catch would cover the window when catches are very large. Increasing the length of the window further could easily solve such a problem.

Conclusions

First experiment

A significant reduction of cod under the Danish MLS of 35 cm was found when the "Danish" window was moved backwards from the positioning of 2.1 m from the codline to a positioning 0.4 m from the codline. A significant reduction of cod over MLS was also found. In total, the mean numbers of cod under MLS per kg of cod over MLS was reduced by 49%.

Second experiment

When a codend with a single large window in the upper panel was tested against a codend with "Danish" windows moved to a position 0.4 m from the codline, statistical analyses showed that it caught significantly less cod below MLS. Catches were, however, so low during the experiment and in particular so very few undersized cod were caught that this result must be regarded with caution. Nevertheless, if catches of cod less than 45cm in total length were compared (thus including fish also above MLS) where catches were better, it is suggested that codend 3 with a single large window in upper panel caught significantly less small cod, whereas this codend caught significantly more cod above 50cm in terms of numbers.

Acknowledgements

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This article does not necessarily reflect the views of the European Commission and in no way anticipates any future opinion of the Commission.

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Appendix 1. *Catches of codend 1 and codend 2 in the first experiments.*

	Codend 1				Codend 2			
Haul	No cod < MLS	No cod = MLS	Total cod (kg)	Bycatch (kg)	No cod < MLS	No cod = MLS	Total cod (kg)	Bycatch (kg)
1	17	626	686	75	21	638	684	125
2	12	523	545	30	21	487	524	35
3	57	1081	1184	70	33	1203	1574	90
4	31	828	849	80	22	664	724	110
5	40	619	645	50	16	457	479	60
6	33	244	256	20	7	234	259	25
7	10	400	474	10	3	391	482	8
8	32	539	527	80	16	444	439	100
9	23	507	527	75	5	415	467	90
10	21	138	131	2	5	59	68	1
11	4	60	67	4	2	51	65	5
12	14	351	379	10	10	274	309	15
13	28	453	489	14	7	419	465	15
14	6	432	487	12	1	349	406	15
15	18	446	479	10	6	320	349	10
16	21	295	349	10	11	252	276	10
17	40	561	570	60	24	484	516	50
18	41	252	241	27	7	218	253	25
19	20	151	150	17	5	103	111	20

Appendix 2. Catches of codend 2 and codend 3 in the experiment.

	Codend 2				Codend 3			
Haul	No cod < MLS	No cod = MLS	Total cod (kg)	Bycatch (kg)	No cod < MLS	No cod = MLS	Total cod (kg)	Bycatch (kg)
1	5	67	80	5	2	106	133	7
2	16	99	106	11	1	79	82	9
3	0	44	49	12	3	47	46	8
4*	-	-	-	-	-	-	-	-
5	6	170	210	7	1	105	122	4
6	2	84	97	1	3	111	143	2
7	2	101	118	4	1	106	122	5
8	2	71	74	4	1	56	61	3
9*	-	-	-	-	-	-	-	-
10	0	70	79	2	1	76	117	2
11	3	54	68	0	1	87	115	0
12	4	23	28	0	1	29	35	0
13	2	242	324	0	1	184	313	0
14	0	92	129	0	0	92	121	0
15	7	77	88	0	4	87	113	0
16	3	58	68	2	0	62	65	1
17**	4	411	556	0	1	937	1277	0
18	0	94	121	4	0	71	92	5
19	2	281	331	0	0	287	330	0
20*	-	-	-	-	-	-	-	

* No records due to irregular performance of the trawls.

** Haul discarded for further analysis because of bulk catch in codend 3.

Selective Properties of Polyamide (PA) Cod Trawl Codends Made of Meshes Turned 90°

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Abstract

From 1996 to 1998 the Sea Fisheries Institute carried out investigations on characteristics of selective codends with meshes turned 90° (*a Polish selective codend*). The idea of such a codend was first presented in 1993 at the Annual Science Conference ICES in Dublin (Moderhak 1993a) and then published (Moderhak 1993b).

The results obtained have revealed that the codends with meshes turned 90°, may capture fewer undersized fish, have better selective properties and ensure better fish condition. Application of this type of codend in commercial fishing may help to restore fish resources in the Baltic Sea.

Key words: *trawls, codends, cod (Gadus morhua), turned mesh*

Introduction

The decrease of living resources of some particular fish species requires firm activities in order to stop the adverse tendency. Otherwise the tendency may lead to the limitation of commercial fishing and creation of significant socio-economical problems. The main technological direction, in order to protect young fish, is the increase of selectivity of fishing tools, especially of trawl bellies and codends. The influence of the codend on the selectivity is significant; since caught fish spend much more time in the codend than in the belly.

Most technical regulations of trawl fisheries so far have been based on the assumption that a proper increase of the mesh size in the codend is sufficient to increase protection of certain fish species. In the first half of the 1990s it appeared that perhaps simple increasing of the mesh size in the codend was not sufficient and that the mesh size should not only be increased, but also, and perhaps mote important, the meshes should maintain wide open during the whole towing process (e.g. Moderhak 1994).

The technical solutions which were proposed secured means for an increase of mesh opening in two different ways; first, natural, employing mechanic and hydromechanic phenomena (which occur in codends during towing) and second, artificial by mechanically widened mesh openings and then e.g. using some chemicals to sustain those openings. The natural solution involves increase of water flow through the codend (Moderhak 1994, Ziembo 1995). The investigations and technical analyses of this problem revealed that in order to obtain the assumed effect in a natural way, significant changes in constructions would be necessary, especially of the belly end as well as changes of proportions or shape of traditionally used codends and trawls (Moderhak 1994, Ziembo 1995). A different solution (based on an artificial way), in practice an easier and faster way, is based on replacement of traditional netting (with diamond meshes) in some codend areas, with different oriented netting or specially stiffened netting with wide open meshes (selective windows).

Investigations of codends with meshes turned 90° were aimed at determination of their selective properties, usefulness in commercial fisheries and choice of a mesh size, that would secure commercial catch rates (with proper selectivity) not lower than the currently obtained and is approved by international protection regulations. Results of investigations of such codends are universal. The general conclusions about selective properties may be applied in working out technical protection means of other fish species through application of codends with meshes turned 90° and with appropriate mesh size for a particular species.

This presentation gives a summary of results of investigations of polyamide cod trawl codends with various mesh sizes, which are based on the idea of netting with meshes turned 90°.

Material and methods

During three years codends with meshes turned 90° with mesh sizes of 120 mm (Moderhak 1997), 105 mm, 90 mm (Moderhak 1999a) and 85 mm (unpublished) were tested. They were all made of polyamide (PA) twine, 3.5 mm in diameter. The codend circumferences were about 6.7 m. First three codends (i.e. with mesh sizes 120 mm, 105 mm and 90 mm) had the same length of about 7.2 m. The codend with mesh size 85 mm was made as a commercial codend and its total length was about 22 m (codend and extension - both made from turned meshes), which was required by the fishing arrangement of the B-403 type cutter.

First three codends were made without any additional reinforcement, while the commercial codend with mesh size 85 mm (according to the owner's wish) was longitudinally reinforced (on both sides), which did not interfere with natural, characteristic for meshes turned 90°, mesh opening. All codends were one panel, without selvages and directly joined to the trawl belly.

In the production of all codends, standard polyamide netting was used; the same as in codends (with diamond meshes) which are used in Polish fisheries. They were produced at Olsztynskie Zaklady Sieci Rybackich (The Olsztyn Fishing Net Factory) in Korsze. The technology of the production was typical for this factory and identical for all codends. Production of cod netting with meshes turned 90° does not require changes in machinery and production technology in fishing net factories.

In order to describe the properties of netting with meshes turned 90° in comparison with identical, standard netting, two models of codends were made on the scale of 1:3. Both had the identical number of meshes in circumference (15 meshes with mesh bar length 20 mm and twine diameter 1.15 mm) and length (30 meshes). They were stretched on hoops with 17 cm in diameter and suspended vertically. In such a position, the gravity forces, which affect particular rows of meshes, imitate the force of hydrodynamic resistance during towing. Typical shapes of standard mesh and mesh turned 90° are shown in Figure 1. The shape of the codend model with meshes turned 90° significantly differs from the shape of the codend model with diamond meshes. The first one had the shape of a very long pear, with slightly increasing cross-sections towards the rear wall. This model as a whole is more rigid in the transverse direction (it is more difficult to bend it transversally) than the standard codend model. In longitudinal direction the codend with meshes turned 90° is more flexible, i.e. it requires less force to shorten it than in the case of the standard codend. This indicates that the "turned" codend should be more stable (it should preserve its shape without side movement perpendicularly to the direction of motion) with easy change of mesh opening (e.g. as a result of trawling speed change). The last feature reveals the need of smaller force to open the mesh wider, e.g. fish squeezing through „turned" meshes, than in case of the diamond meshes.

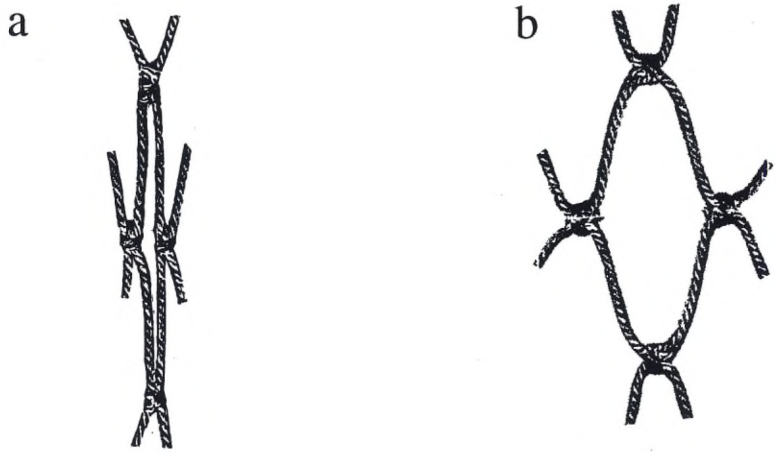

Figure 1. *Mesh shapes: a - standard, b - turned 90^0*

Codends with meshes turned 90° (in natural scale - 1:1) were tested using various methods in order to determine the selective properties. A hooped cover (codend mesh size 120 mm), alternate haul method (codends - 105 mm and 90 mm) and direct comparison of length composition of cod caught in commercial fishing (85-mm meshes turned 90° and standard, with mesh size of 120 mm) were tested. The first three codends were investigated on board the RV Baltica and the fourth one (85 mm) on a commercial cutter B-403 type. The cover used during the study was made accordingly to ICES recommendation and had the mesh size 40 mm, the total length about 15 m and the circumference about 10.5 m (both in the stretched state). The cover was fastened on two hoops 2.1 m in diameter.

The cod that were caught were measured to nearest whole centimeter below. In commercial catches, in cases of large numbers of fish, only about 50% of fish mass were measured (by dividing the catch on two equal parts).

All tests were carried out during the years 1996 to 1998 in the eastern fishing grounds of the Polish economical zone - in the area of the Gulf of Gdansk and Wladyslawowo fishing grounds. Test codends with mesh sizes 120 mm, 105 mm and 90 mm were mounted each time to the WD-20/25 bottom trawl, while the commercial codends were mounted to the pelagic trawl WP-53/64 ^{x}4 for semi pelagic fishing. The trawling speed varied from

1.5 to 1.75 m/s (3 to 3.5 knots) and catches were made at depths from 60 to 100 m. Calculation of the selectivity parameters were made by „CC-Selectivity" computer program and for alternate hauls method, by computer program elaborated in the Sea Fisheries Institute, Gdynia (Ziembo and Zaucha 1997).

Results

Table 1 presents main catch data obtained during the experimental fishing and the selectivity parameters are presented in Table 2 - except of the codend of 105 mm mesh size for which were conducted only 3 hauls and caught a few number of cod. For most codends only a few hauls were conducted but the data obtained can be accepted as indicative. That assumption could be made because most hauls were made with methods that are commonly accepted in selectivity studies. Hence, obtained values are a bit less probable than the obtained ones from higher number of hauls. Tables 1 and 2 present differences in calculated parameters for the codends. They show that codends made of meshes turned 90° seem to have caught bigger cod than the standard ones while the outcome was similar to that with windows. „Turned" codends generally had better selective properties and retained less undersized, juvenile cod also in comparison with window codend.

Table 1. Basic data from the research on cod polyamide codends

Type of codend	Mesh size [mm] real/ nominal	Number of hauls	Total duration of hauls [h]	Total weight of fish in codend [kg]	Total number of fish in codend	Total number of fish in cover	Mean weight of single fish in codend [kg]/±SD[1]	Study method
Standard	– /120	5	53,5	6009*/4288	– /3897	–	1,10/0.07	commercial fishing
With meshes turned 90^0	86.6/85	5	48	5679*/2537	– /2066	–	1,23/0,13	commercial fishing
	91.4/90	10	19	610	403	–	1,51/0,53	alternate haul
	123.6/120	6	12	429	276	576	1,55/0,38	hooped cover
With windows	105.6/105	3	6	137	74	40	1,85/0,63	hooped cover

** Values for all hauls, including those for which only about 50% of fish were measured*

[1] Standard deviation

Table 2. *Selective properties of the codends tested*

Type of codend	Mesh size [mm] real/ nominal	Selectivity parameters			Number of cod up to 35 cm present in codend [%]*	Study method
		L_{50}	S_R	S_F		
Standard	–/120	–	–	–	8,8	commercial fishing
With meshes turned 90°	86.6/85	–	–	–	2,4	commercial fishing
	91.4/90	39,4	7,26	4,31	5,0	alternate haul
	123.6/120	47,2	5,89	3,84	1,5	hooped cover
With windows	105.6/105	42,8	9,4	4,0	8,9	hooped cover

** Calculated as a percent of cod up to 35 cm in length retained in codend in relation to the total number of cod caught in codend*

Studies conducted on commercial cutter indicated that codend with meshes turned 90° assure better living conditions inside the codend because most of the cod were still alive after very long commercial towing (6 to 15 hours) which was in contrast with the standard codend.

Comparison of selectivity of codends with meshes turned 90° made of the polyamide netting with twine diameter 3.5 mm and mesh sizes 120 mm and 90 mm, are presented in Figure 2 and retention properties of commercial codends (85 mm and 120 mm) are presented in Figure 3. Figure 2 shows that both selective curves have similar shape but they are differently situated, about 8 cm apart. Figure 3 indicate good protection properties for juvenile cod of „turned" codend with 85 mm mesh size in comparison to standard codend with 120 mm mesh size. „Turned" codend have retained about 2,4 % juvenile cod (up to 35 cm of length) while the standard codend retained about 9 % of the total catch in the codend. Regarding cod from 36 cm to about 50 cm, the codend with „turned" meshes with 85 mm mesh size caught more cod than the standard one and over that length class both codends have retained cod in the same degree (see frequency distribution - Fig. 3).

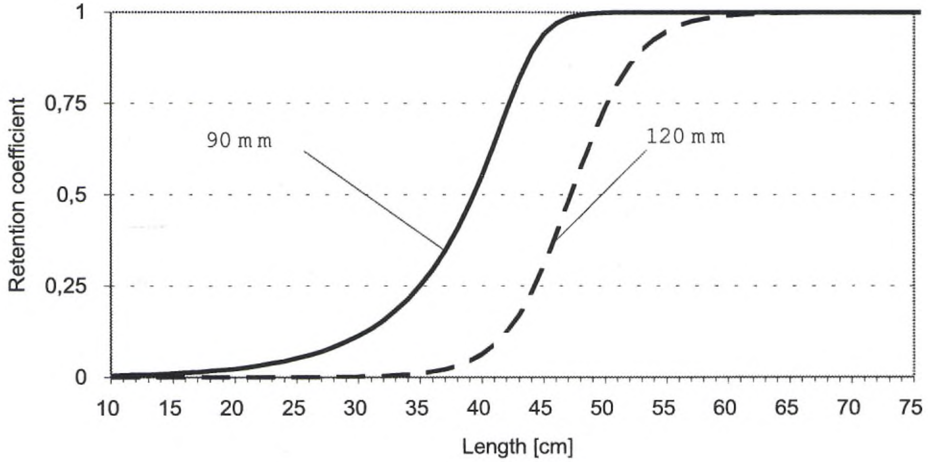

Figure 2. *Selection curves for two different „turned" codends.*

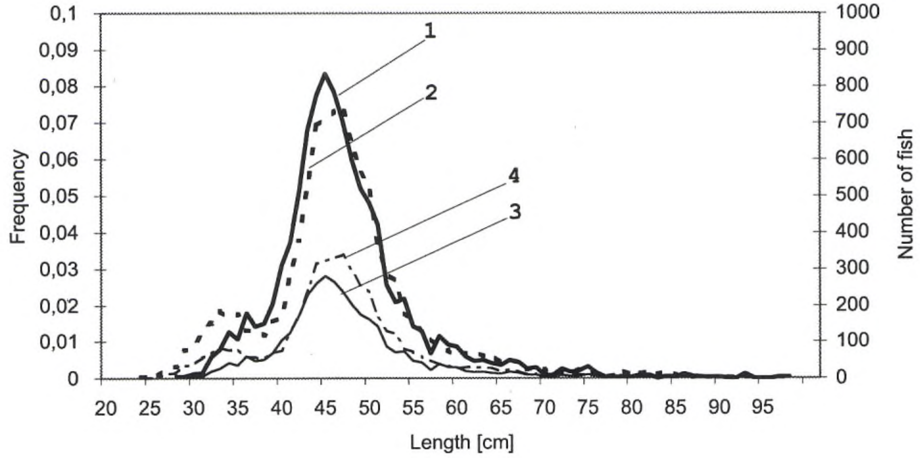

Figure 3. *Selective properties of „turned" and standard codends during commercial fishing; frequency of cod caught: 1 - turned, 85 mm, 2 - standard, 120 mm, number of cod caught: 3 - turned, 85 mm, 4 - standard 120 mm.*

Discussion

The results indicate that codends with meshes turned 90° may introduce new quality in protection of young fish (Moderhak 1999b). The results of the sea tests show that codends of such types may capture fewer young fish and create better conditions for fish, which may result in better survival rates. The results also indicate that codends with meshes turned 90° have better and more stable parameters of selectivity. Compared to the window codend, a narrower selection range was obtained. However, with the window codend only three hauls were made and only 74 (in the codend) and 40 (in the cover) cods were caught, why the difference was not significant. The results, although not significant, are comparable to the best L_{50} values of other codends (Zaucha *et al.* 1997, Zaucha *et al.* 1999). This is probably due to the oval shape of the mesh turned 90°, which better fits the cross-section cod shape and therefore it is easier for fish to go through the mesh (easier to open for fish).

Commercial tests of the polyamide codend with meshes turned 90° and mesh size 85 mm made of 3.5 mm diameter twine, allow to assume that its selective properties are comparable to those of the standard codend (with diamond meshes) with mesh size 120 mm, but ensures better protection of young fish (catches fewer cod of length smaller than 35 cm - see Fig. 3). Introduction of codends with meshes turned 90° may increase protection of young fish and cause gradual restoration of the Baltic cod stocks.

Since up to present, not sufficient data has been collected, it is necessary to conduct a much broader study of the codends with meshes turned 90° and single „turned" meshes to obtain data describing all properties (selective and mechanical) which could be used for increasing protection abilities of codends for different species of fish.

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The Selectivity of Polyethylene Codends with Diamond Meshes and Selective Windows in Cod Trawls

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Abstract

In this paper, the results of the selectivity research of three polyethylene codends are presented. Two of them had selective windows, while the third one had a standard codend with a mesh size of 120 mm.

The selective properties of codends with selective windows, which are produced of net elements with square meshes and hard, stiffened meshes, are higher than the selective parameters of codends made from diamond meshes. The selectivity of codends with square meshes depends on its construction, the location of the windows and the material used for it production. Diameter of twine used and type of codend netting significantly influence selective properties.

Key words: *codends, selective windows, trawl selectivity, cod protection.*

Introduction

In terms of cod protection in Poland, regulations issued by the Polish Maritime Authority in Slupsk on 1 June 1995 are obligatory (Anon.1995). These regulations require that fishermen use codends in trawls, pair trawls and Danish seine netting with mesh size not smaller than 120 mm (diamond mesh system) or codends of the commonly used mesh size equipped with 105 mm mesh size selective windows.

Since 1995, the Sea Fisheries Institute in Gdynia, Poland has conducted tests, on a large scale, of various codend constructions with diamond meshes and with selective windows, mounted in various places in codends. In total twelve various codend constructions have been tested. (Blady *et al.* 1995, Blady *et al.* 1996, Zaucha *et al.* 1997, Blady and Zaucha 1999). This presentation shows the selective properties of three codend constructions made of polyethylene twine netting.

Aims

The aim of the study was to determine the best construction of the polyethylene codend with focus on selectivity and potential for use in Polish fisheries.

The influence of polyethylene twine diameter and mesh opening of the netting on codend selectivity properties were tested. Polyethylene netting, being relatively cheap and at the same time very durable in terms of use in fishing, is becoming more and more common in fishing equipment in Polish Baltic fisheries. This was an additional motivation for undertaking the tests.

Materials and methods

The following three types of polyethylene codends were tested:

1. Standard codend with diamond mesh set and 120 mm mesh size, made of double twine 4.0 mm in diameter;
2. Codend with two selective windows and construction that complies with regulations, i.e. 105 mm mesh size. Both the codend and the selective windows are made of the same double-twined polyethylene, 4.0 mm in diameter. The codend construction is presented in Figure 1.
3. Codend with two selective windows; the same construction as codend no. 2; however, made of single twine (3.5 mm diameter) material.

The study was carried out during three research cruises in the autumn seasons between 1995-1996 to the fishing grounds of southern Baltic. This area showed the greatest catch rates at the time in the Polish economic zone (ICES Subdivisions 25-26).

We used a 24 m side cutter equipped with a cod trawl WD-28 + 29/46, the latter being made entirely of polyethylene.

Average time of hauls was relatively long and varied from 6 to 8 hours, at average trawling speed of 2.8 to 3.5 knots. The cutter worked in the commercial regime, i.e. trawling for 24 hours.

Data on mesh opening and twine diameter in the different codends are presented in Table 1 {Blady and Zaucha 1973}.

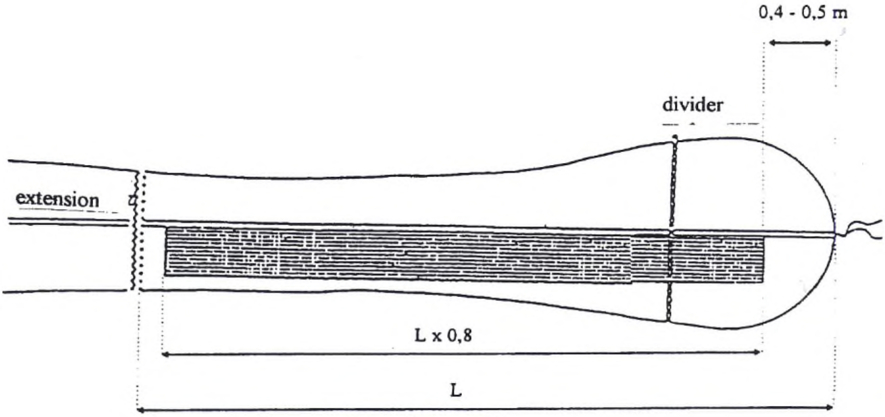

Figure 1. *Construction (according to the Polish Maritime Authority) of the codend with two selective windows*

Table 1. *Mesh size and thickness of netting material in tested codends*

Type of polyethylene codend	**Size of a wet mesh (mm)**		**Type and diameter of twine in the material (mm)**	
	selective window	**codend**	**selective window**	**codend**
Standard, with diamond mesh set and mesh size 120 mm	-	118,1	-	Double twisted 4,0
With two selective windows	107,0	107,6	Double twisted 4,0	Double twisted 4,0
With two selective windows	105,4	107,8	Single braided 3,5	Single braided 3,5

The determination of codend selectivity was carried out by means of the alternate haul method. This method requires an additional codend with a fine meshed insert for determination of the fish composition of the particular fishing ground. Each haul (see Table 2) with the test codend was followed by a haul (usually out and back) with the same type of codend but with a small-sized 20 mm codend insert.

This operation yielded subsequent pairs for comparison, and the catch composition in the codend reflected the composition of the fishing ground. It seems that among all methods which avoid construction changes of the trawling setup through application of selective covers, the alternate haul method is the most useful {Blady and Zaucha 1999}.

Application of a special computer program {Zaucha and Ziembo 1997} to the series of haul pairs enables calculation of all basic parameters of codend selectivity and selection curves to be drawn.

The results obtained enable characterization of the selectivity of the codend by the following parameters:

- L_{50} - protected cod length [cm], defined as the length at which 50% of the cod escape and 50% of the cod are retained during the haul;

- **selection range SR**, described by the difference: $SR = L_{75} - L_{25}$ [cm]

where:

L_{75} and L_{25} - are determined as for L_{50} above, but at the respective escape rates of 75% and 25%.

- **selection factor SF**, as ratio:

$$F = \frac{L_{50}}{A}$$

where:

A – mesh size of exit window or, if no window is used, of codend determined during tests [mm].

- **factor of selectivity quality (W)** of fish transfer, described by the equation:

$$W = \frac{N_S - N_t}{N_s} \cdot 100\ \%$$

where:

N_s and N_t - number of retained fish having lengths within a protection range in codend with insert [N_S] and the tested codend [N_t].

Results and Discussion

The data collected during the tests are presented in Table 2. The data reveal that the number of fish measured and used for evaluation of selective properties of tested codends was large; 5,000, 10,000 and 15,000, respectively.

Table 2. *Catch data and number of analysed hauls in tests with three types of polyethylene codends*

Type of polyethylene **codend**	**Total number of fish in:**		**Number of hauls**		**Total number of caught fish (specimens)**			
					up to 35 cm		**up to 38 cm**	
	tested codend	codend with insert	tested codend	codend with insert	codend	codend with insert	codend	codend with insert
Standard with diamond mesh set and mesh size 120 mm	2.668	6.891	8	10	174	450	313	674
With two selective windows made of double twine 4,0 mm in diameter	2.450	2.514	5	3	253	515	522	714
With two selective windows made of single twine 3,5 mm in diameter	4.790	10.095	9	8	651	4.281	1.029	5.154

1. Standard codend with 120-mm mesh size, made of double twine, 4.0 mm in diameter.

The basic selective parameters of this codend were as follows: L_{50} - 32.6 cm, L_{25} - 24.0 cm and L_{75} -38.0 cm, selection range - 14.0 cm. The values of basic parameters prove that application of this codend did not yield required selectivity parameters. Therefore, the evaluation of this codend must be negative; especially regarding L_{50}, which was 6.9% lower than the required value of 35 cm. Additionally, the selection range was great, 14.0 cm. Factors of selectivity quality [W] were not too high - 62.3% and 53.6% for cod of lengths 35 and 38 cm, respectively.

2. Polyethylene codend with two selective windows, made of double twine, 4.0 mm in diameter.

The basic selectivity parameters of this codend were as follows: L_{50} - 33.3 cm, L_{25} -28.2 cm, L_{75} - 38.5 cm, selection range, 10.3 cm. Values of all selective parameters of this codend are much better than in the case of the codend with mesh size 120 mm. For this polyethylene codend a selection factor of 3.11 was obtained. Also, factors of selective quality are relatively low - 58.1% and 49.7% for cods of lengths 35 cm and 38 cm, respectively.

The selectivity characteristics of this codend reveal that it does not comply with selectivity requirements at the appropriate level.

3. Polyethylene codend with two windows entirely made of single twisted twine, 3.5-mm diameter.

The following selective parameters were obtained for this codend: L_{50} -36.4 cm, L_{25} - 32.8 cm, L_{75} - 39.0 cm and a selective range of 6.2 cm. Due to application of thinner single twine in netting material, selectivity of this construction improved significantly. L_{50} exceeded cod protective length by 4.0% and the selective range decreased, which confirmed the improvement of selective codend properties. The selective factor was 3.45. However, the factor of selective quality (W) of this construction is quite good - 84.8% and 80% for cod 35 cm and 38 cm, respectively. Analysis of all selective parameters shows that this construction is superior to the two other types of constructions.

Selection curves are presented in Figure 2.

Analyses of the three constructions described above reveal that not only mesh-size play an important role in codend selectivity, but also codend construction. Introduction in the codend of selective windows with smaller meshes (even by 10%) than in the standard codend results in selectivity on a similar level for both cases. Construction of codend using thinner twine, preserving their durability and rigidity, improves the selectivity of the codend. Therefore, it is clear that the choice of proper netting material is an important issue.

The described above comparison of the three codend constructions reveals that in terms of cod protection single twine polyethylene codends with two selective windows are the most suitable.

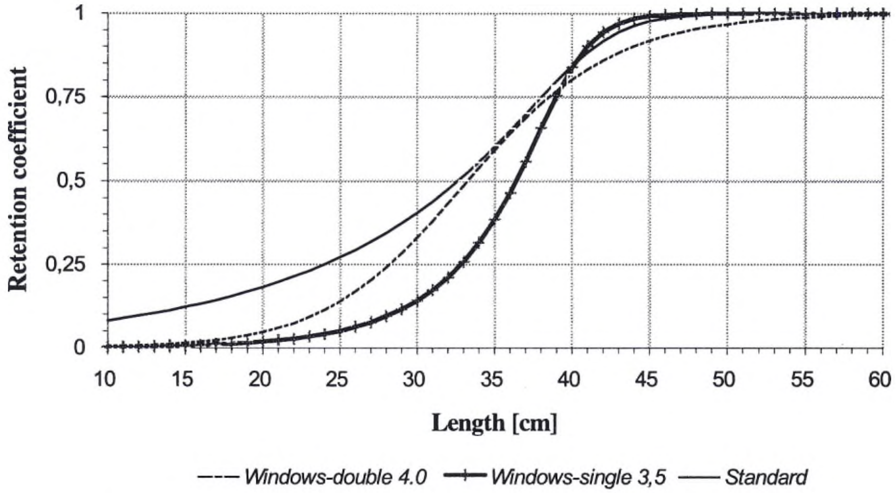

Figure 2. *Selection curves for the tested codends.*

Conclusions

The analyses of selective properties of polyethylene codends yield two very important conclusions:

1. Codends with selective windows have better selective properties than codends without such windows. Such findings are true, even when a codend with mesh opening of 105 mm is compared to a standard codend with mesh opening of 120 mm. This construction should be recommended for use in Polish fisheries.

2. Diameter of twine used and types of netting [multi or monofilament] significantly influence its selective properties.

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The Sex Ratio of Baltic Cod in Studies on Selectivity

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Abstract

The depletion of Baltic cod stocks in the late eighties resulted in attempts to introduce new protection measures and to improve already existing. One of them, selectivity of fishing gears, was investigated in Poland in 1996 and in 1997. Experiments with three different codend constructions were conducted on R. V. Baltica in ICES Subdivision 26. The sex ratio and length composition of both sexes of cod were determined during a pilot study. The results of these investigations revealed that the differences in codend constructions, even though quite considerable, did not influence the sex ratios of caught cods.

***Key Words**: Baltic cod, sex ratio, codend, cover, selective windows*

Introduction

For many years Baltic cod have played an important role in Polish fisheries. Due to decrease of cod catches, various actions have been initiated, on an international scale, in order to protect the commercial stocks. One such activity was an attempt to increase the selectivity of cod fishing gears. Since 1 June 1995, cod trawl codends in Polish fisheries should be made of netting with mesh size not smaller than 120 mm or with mesh size 105 mm but with two selective windows. Due to these changes the Sea Fisheries Institute conducted many investigations on various constructions of codends, looking for the best solution that would allow undersized fish to escape the codend.

This paper present the preliminary results obtained, which describe cod sex ratios of cod in the codend compared to the escapees in the codend cover.

Materials and methods

In the investigations, the following codend constructions were used:

1. polyamide codend with Swedish exit windows, made of twisted twine, 3.5 mm diameter and mesh size 105 mm, window of 6x85 meshes made of especially reinforced material, twisted twine 5 mm diameter and 105 mm mesh size. The construction of this codend is presented in Figure 1 a.
2. codend with two standard, Polish selective windows, sewn together, i.e. 16x59 meshes, mounted in the upper part of the codend, which is made of polyamide netting material, twisted twine, 3.5 mm diameter and mesh size 105 mm. The selective windows were made of twisted twine, 4.2-mm diameter, with mesh size 105 mm. The construction of this codend is presented in Figure 1b.
3. polyamide codend without selective windows, made of netting material, twisted twine; 3.5-mm diameter and mesh size 120 mm. This codend varied from the others, because its meshes were turned 90°.

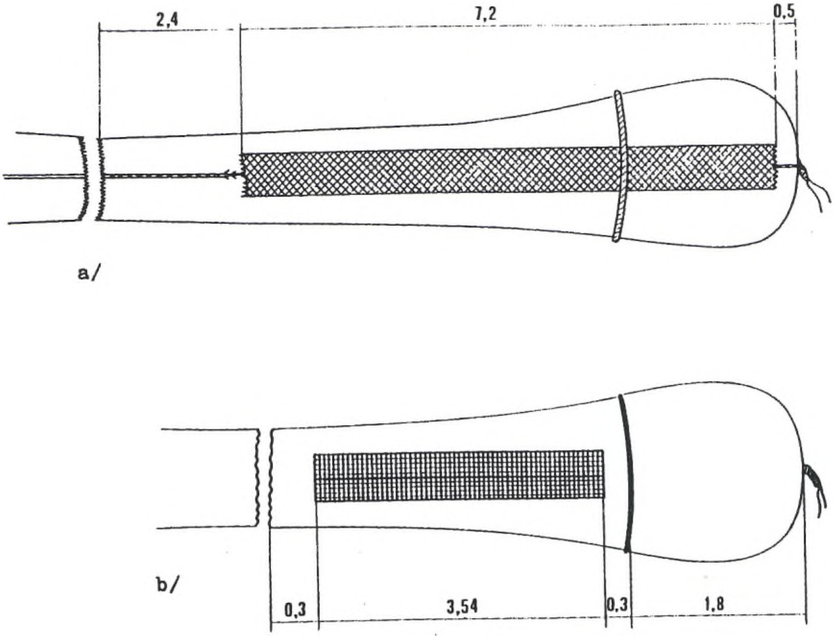


Figure 1. Diagram of codends with selective windows of square meshes: a: Swedish codend (side view), b: codend with two Polish windows mounted together in the upper part of the codend (view from top).

In addition, for determining the length composition of caught cods, polyamide standard codend, with small sized insert, made of twisted twine, 3-mm diameter and mesh size 50 mm was used. The insert was made of polyamide netting material, dtex 9406 with mesh size 10 mm.

In case of codends 1-3, an external cover was added. This cover was equipped with two hoops, 2.2-m diameter and made of polyamide netting material dtex 940/9 with mesh size 12 mm.

The investigations were carried out from RV Baltica in September 1996 and in March and September 1997 in Polish Baltic fishing grounds in ICES Subdivision 26. Cods were measured in order to determine the selectivity i.e. dividing cods into those in the codend and those that had reached the cover. The percentages of cod females and males in codends and covers were calculated. The sex of cods was determined based on at least 250 individuals investigated in each codend. Also, the sexual maturity of the cods was determined.

Results and discussion

In order to get a picture of the cod population that was fished upon during the investigations of selectivity carried out in September 1996, the length composition of males and females respectively are presented in Figure 2. This graph has been created using data originated from catches carried out with a bottom trawl with a codend with small sized meshes. It reveals that cods from two length intervals, 30-36 cm and 42-51 cm dominated the catches. Up to the length of 29 cm numbers of males and females were comparable, while in classes from 30-52 cm males dominated. However, females dominated among the biggest individuals. In general, in catches with this codend cod males constituted 60% and females 40% of the population, which is in accordance with catches with other types of codends (Blady *et al.* 1995).

Similar length composition of cod was obtained from several hauls carried out with codend with selective windows in their upper ends (codend type 2). Also the sex ratios of the catches of these two types of codends, were very similar

Males dominated also in catches in trials carried out in September 1996, with codends with meshes turned 90° (codend type 3), in the length range up to 50 cm, with dominating classes 40-50 cm. In large length classes, i.e. the oldest cod, females dominated, however.

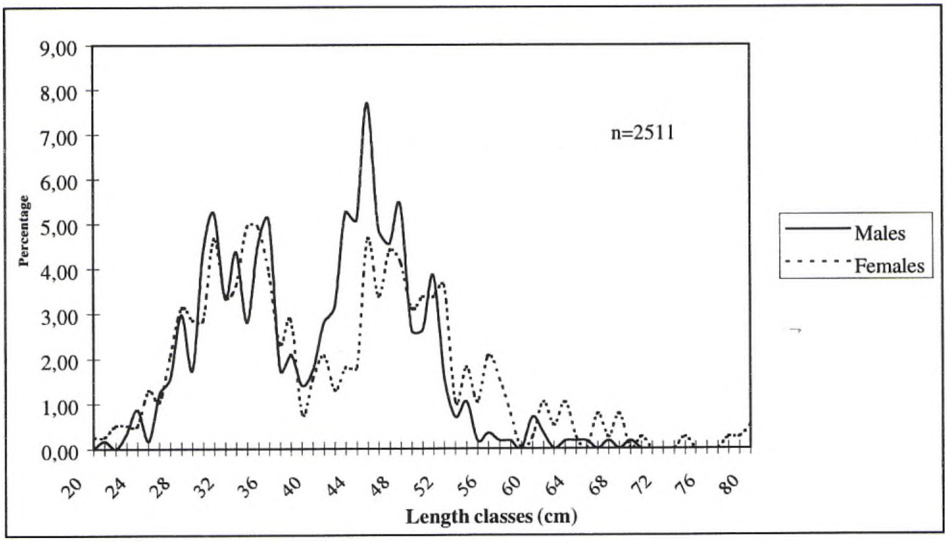
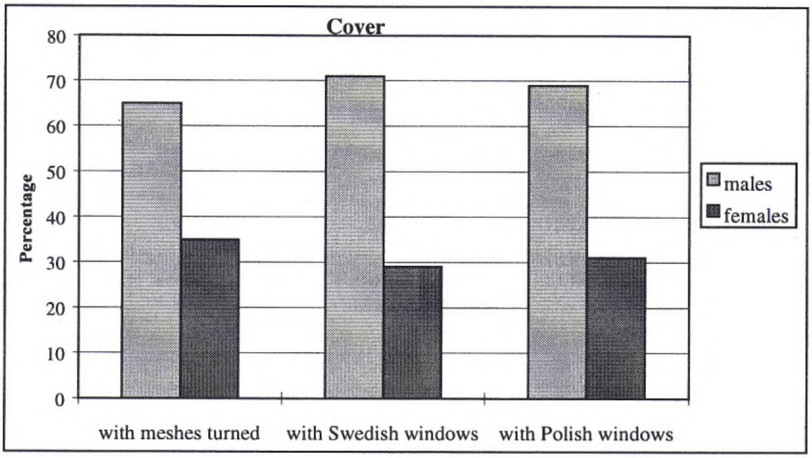


Figure 2. Percentage length distribution of Baltic cod males and females, fished in September 1996 using bottom trawl WD-20/25 with small sized insert

Total results of sex ratios of cod in codends and in covers of three analyzed types of codends are presented in Table 1 and shown in Figure 3. In every case, females were at least twice as abundant as males in the codends. In the codend with Swedish exit windows there were 67% females, in the codend with two Polish windows sewn together and mounted in the upper part, there were 71% females, and in the codend with meshes turned, 72% females. The obtained results confirmed Polish and international literatures that males predominate in the youngest groups (2-4 years), but in the older groups (above 5 years) females were predominant and for cod older than 8 years females made up nearly 100% of the population (Kosior 1994, Tomkiewicz *et al.* 1997, Zukowski 1957).

***Table 1.** Percentage contribution of males and females in the cover and codend.*

Codend type	% of sex			
	in cover		in codend	
	males	females	males	females
With Swedish type windows	71	29	33	67
With two Polish windows sewn together in the upper part of the codend	69	31	29	71
With meshes turned 90°	65	35	28	72



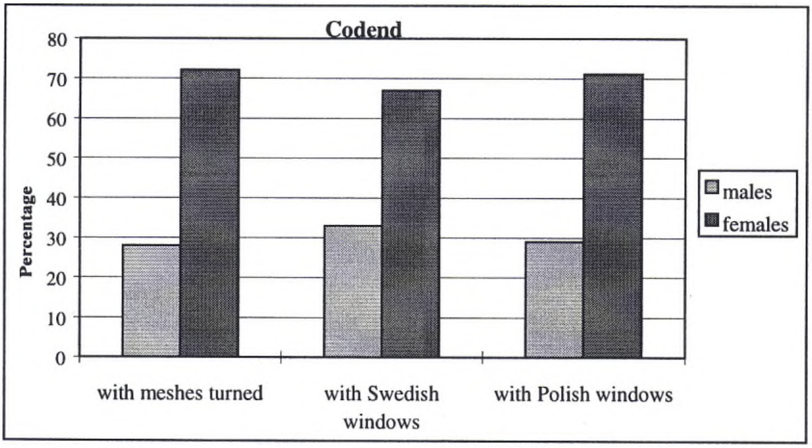


***Figure 3.** Percentage contributions of cod males and females in cover and three various types of codends in years 1996-1997.*

In the cover the situation was opposite, there were 71, 69 and 65% males, respectively. It is clear that during the time of the investigations in the Wladyslawowo fishing grounds, in catches from depths of 60-80 m, with a small predominance of males in the cod population, the number of male escapees from codend was significantly higher in comparison to females (about twice as high). The maximum lengths of females in the covers of the codends were 43 cm, 44 cm and 53 cm for type 1, type 2 and type 3 codends, respectively. In turn, the maximum lengths of males found in codend covers were in every case greater than females and amounted to 47 cm, 49 cm and 58 cm respectively.

The majority of cod males caught during the investigations in September 1996 were in phase II and VII of gonad development, while the majority of females were in phase II and VIII. Therefore among the males escaped from the codend, specimens from various phases of development occurred in the cover, with a predominance of specimens in phase II and VII. Among females from the cover, specimens in phase II and I phase of gonad development clearly dominated.

Based on these preliminary results of the investigations, it may be stated that, even though quite considerable, the difference in codend constructions did not influence the sex ratios of caught cods.

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New Ways for an Improvement of the Selectivity of Trawl Codends in the Baltic Cod Fishery

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Abstract

Two trawl types of innovative design constructed with the aim to release at least 50 % of the caught cod of 38 cm length, as demanded by the new fishery rules of the IBSFC, as tested on German research cruises with the FRC „Solea“ in 1998. One of the trawls was derived from the Swedish Multipanel codend design as described by Suuronen *et al.* (1996) whereas the other one was built from material turned around 90 degrees as described from Polish trials by Moderhak (1997). The first one was tested on three cruises in April, June and September 1998 whereas the second one was tested with one mesh-size in April 1998 and with two mesh-sizes in September 1998.

Both trawl types proved scarcely reduced selectivity compared with a 120 mm standard legal codend even when their mesh openings were considerably diminished. With regard to the selectivity factor the Multipanel codend demonstrated a significantly improved selectivity whereas the apparent achievements of both codends with turned meshes were masked by the strong between haul variance. Seasonal variation could not be used as explanation for this phenomenon. In contrast to observations with other gadoids cod showed hardly any effect of seasonal variation.

Key words*: codends, trawl selectivity, Swedish multipanel, turned meshes, cod*

Introduction

Since years the situation of the stock of cod in the Central Baltic is considered as being critical (Tschernij *et al.* 1996). The decision of the International Baltic Sea Fishery Commission (IBSFC) issued already in 1993, to raise the minimum codend mesh opening from 105 to 120 mm has not been able to improve this situation. This is demonstrated by a backward trend in the catches of cod from the Baltic by German fishermen as illustrated by Figure1. In 1998 in total 10985 t of cod were landed. The quota received for this year amounting to 16846 t could only be used at a rate of 65 %.

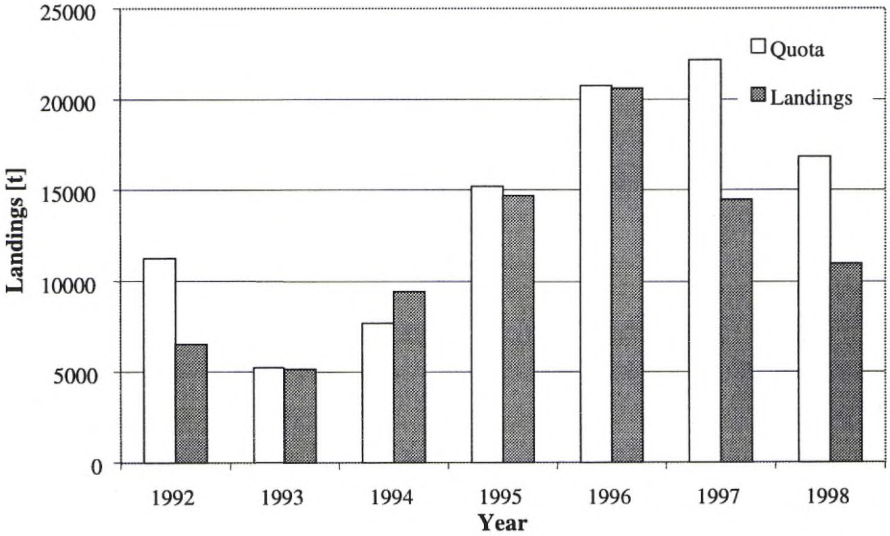


Figure 1. *Quotas and actual catches of cod of German fishermen in the Baltic in the period from1992 to 1998.*

In account of protests of the commercial fishery in 1993 also alternative and cheaper codend constructions were allowed. All these modified codends have to prove that they are efficient in releasing cod of 38 cm at a rate of at least 50 percent before being accepted.

Two new codend constructions with so-called escape windows, one of Swedish (Larsson 1994) and the other of Danish design (Lowry *et al.* 1995), however, were declared immediately as being in accordance with the fishery rules of the IBSFC without having to prove this in a scientifically sound manner.

When a group of experts of the International Council for the Exploration of the Sea in 1995/1996 examined this new construction it was shown that at least with the Danish type of codend the requested selectivity for cod could not be reached. With the Swedish codend the requested properties could be proven (Anon 1996). However, Swedish investigations indicated that the selective properties of these alternative codends deteriorated after short time of operation by washing out of the special impregnation of the exit windows (Tschernij *et al.* 1996).

With conventional diamond meshes, in addition, numerous methods to manipulate the actual codend mesh opening became common knowledge in the meantime (Stewart & Galbraith 1989). As examples for the widespread use of such means should be mentioned here the increase of the codend circumference or of the codend netting yarn or special strengthening bags particularly designed to impede the full opening of the codend meshes.

Further, in an EU-project a seasonally conditioned changed selectivity of codends could be proven for the haddock of the North Sea (Özbilgin 1998). Since cod is also a gadoid and temperature was demonstrated as a main effective factor. As first suggestion it can also be assumed that Baltic cod would react likewise. If verified, it would make any previous findings on cod selectivity by a given mesh size doubtful.

Recently, at this state of the art, the European Union has decided to finance a bigger research project (BACOMA = Baltic Cod Management) which shall clarify the following points:

1. Investigation of factors affecting the variability of trawl codend selectivity in the Baltic cod fishery. It is intended to investigate the effectiveness of different codend modifications and of the mode of operation with cod trawls.

2. Investigations of different codend types with regard to their effect on the survival of escaped fishes.

3. Development of a numerical model able to describe the biological and socio-economical effects of an improvement of the selectivity of Baltic cod trawls.

Directly participating at this ambitious project are researchers from Denmark, Sweden and Finland. Germany contributes to the project by a nationally implemented additional research program, which is co-ordinated with the current EU-program.

General aim of the effort of the researchers from all countries bordering the Baltic is to find until the year 2000 a scientifically sound and generally accepted solution for an optimum technical mean for the protection of young cod.

Material and Methods

Few remarks in an earlier publication (Tschernij *et al.* 1996) as well as a recent work (Moderhak 1997) indicated particularly prospective codend constructions with good selective properties. They were tested in spring, summer and autumn 1998 in the Western and Central Baltic during three cruises with the FRV „Solea“. All selectivity trials were carried out with the „Kabeljauhopser“, a bottom trawl with 528 meshes circumference at the forward edge of the belly.

64 hauls were carried out with the codends mentioned on the cruises in April, June and September. Due to low catches of cod the average towing duration was 2 to 3 hours. There was no danger of masking the codend meshes with the catches obtained below 1 t per haul.

Fishing grounds used lay predominantly in the Arkona bight West of Bornholm. Towing speed, opening height and spread were continuously recorded.

All cod caught in main codend and cover were measured and weighed. Other by-catch was sorted by species and recorded by weight only. 74823 cod with a weight of 24.572 t were measured in total.

The cover used (Fig. 2, I) was fixed at the end of the tunnel and spread by a ring made from PVC plastic pipe with a diameter of 2.6m. Floats at the upper panel of the cover created a further empty space above the upper panel of the codend so that fishes can escape there unimpeded through the codend meshes.

Covers with 40 and 60 mm mesh opening which had an aft part of meshes of 80 mm mesh opening were used to catch the escaped fishes. This uncommonly big mesh opening in the end of the cover had become necessary to bypass problems with the high by-catch of herring which otherwise would have created sorting problems with the catch.

A conventional diamond mesh codend made from 4 mm PE single yarn and a mesh opening of 117 mm served as reference. This mesh size refers to measurements being made with an ICES mesh gauge. Careful experiments carried out in Scotland have shown that such values have to be corrected by ca 1.03 to obtain what would have been measured with the official legal measuring instrument wedge gauge (Ferro & Xu 1996). Hence the codend used could be assessed to correspond to legal requirements.

Two new codend constructions offered good prospects for a better and sharper selection.

The first codend was completely made of the same diamond meshes as the reference and differed in so far as the netting was turned clockwise 90 degrees. If diamond meshes are stressed in different direction to the main running direction of the netting yarn they will show a different shape (Fig. 2, II). Case (*b*) shows the effect if the netting is turned 90 degrees. The stiffer the netting yarn is the more open the mesh will be. At equal mesh opening and netting material an improved selectivity should be expected.

In recent Polish experiments (Moderhak 1997) this type of codend has exhibited better selectivity indices and increased properties to better protect undersized fish. Two different mesh openings of 103 and 113 mm were tested in the experiments reported here.

The second codend was a so-called Multipanel codend. A similar design was first tested in Swedish/Finnish experiments in the early 90's (Suuronen *et al.* 1996) and demonstrated some favourable properties but, nevertheless, had proved inadequate to release cod of 38 cm at the required rate due to the fact that its mesh size was only 95 mm. As in the Swedish tests the codend examined in trials reported here was made completely from knot-less netting of PE with 6-mm yarn diameter (Fig. 2, III).

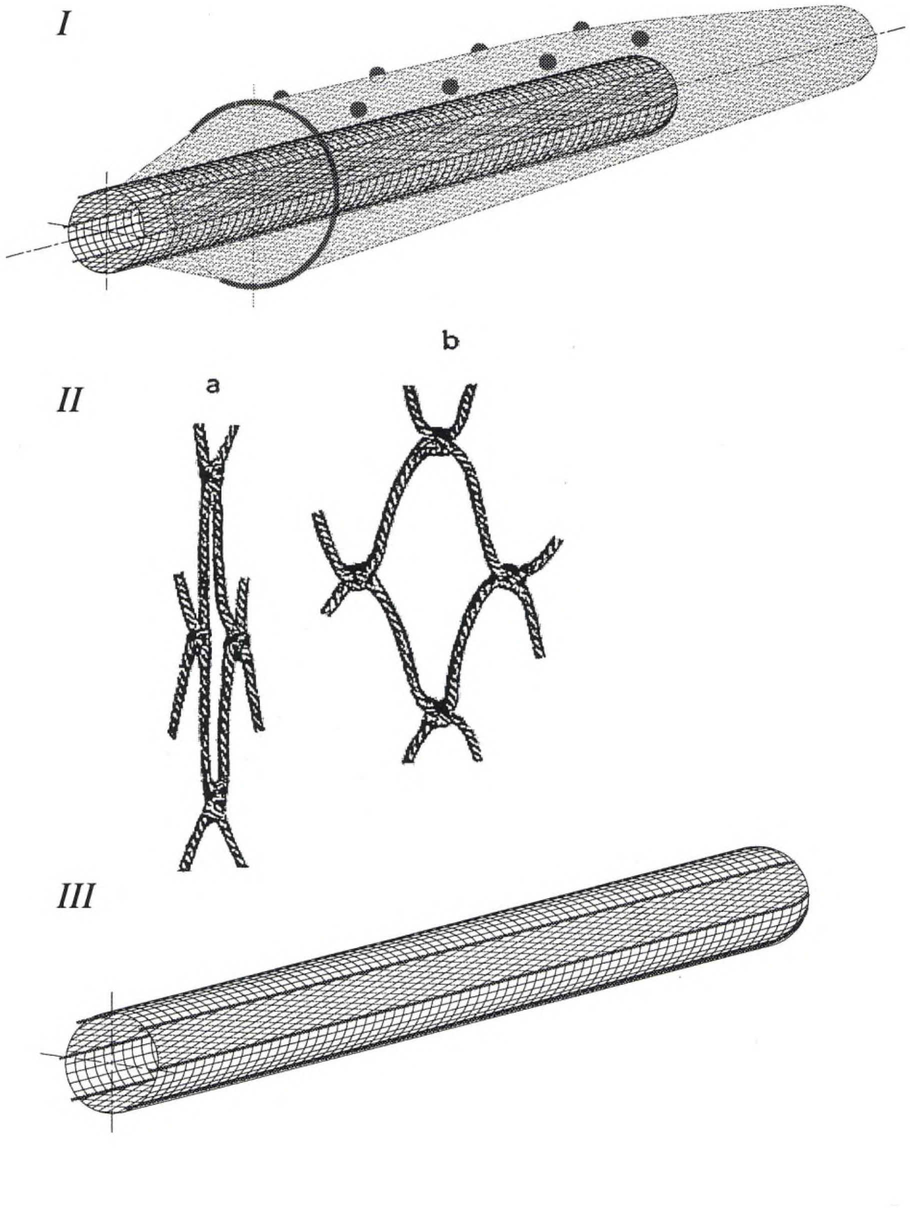


Figure 2. *I. Schematic drawing of the cover type used*
II. Shape of a knotted mesh torn in different direction:
a) in N-direction, b) in T-direction (after Moderhak 1997)
III. Sketch of the appearance of a multipanel codend in operation

This codend consists of 6 panels of which 3 are of diamond and three of square meshes. They had a mesh opening of 105 mm. The combination of diamond and square meshes results in a more flexible codend in comparison to a codend totally made from square meshes without ignoring the already demonstrated advantage of an improved selectivity.

Previous own underwater observations of a pure square mesh codend have revealed that fishes increasingly demonstrate panic reactions at the transition of the tapered fore net to the square mesh codend. Underwater observations during the experiments with the MPC revealed that the transition between tapered sections and the extension is now much more smooth and even.

So far, an unsolved question in square mesh netting in general is the mode of production. Knotted diamond mesh netting turned by 45 degrees from its normal orientation takes the shape of square mesh netting but holds this shape only for a limited time. The meshes are only stressed on two of their four bars and may degenerate by shifting of the knots in a rather short time.

Hence in these trials knot-less braided netting (trade name „Ultracross") was used which allows for no mesh deterioration due to its different main running direction of the netting yarn.

This material, however, can only be purchased with difficulties on the European market.

For the calculation of the selection parameters the logistic curve (Pope *et al.* 1975) is commonly used to describe the distribution of retention rates in codend selection experiments.

$$y = \frac{1}{1+e^{(a+b\cdot x)}} \qquad \textbf{(1)}$$

y = retention rate
x = fish length
a,b = parameters of the curve

$L(50) = \frac{a}{b}$
L(50) is the retention length of 50 %

The calculation of the resulting symmetric sigmoid curve from several hauls with similar configuration was performed with the help of a computer program according to the Variation Component Analysis as described by Fryer (1991).

Fish reactions as well as codend shapes were recorded with a manoeuvrable underwater video camera.

Results

The length distribution of cod population is given in Figure 3. The two-peak distribution of the cod lengths as detected in spring has only one peak in September because of the natural growth of the cod population. In account of the selectivity of the cover the length classes of cod below 25 cm are underrepresented. The length classes of cod essential for the investigation of selectivity, however, lie well above 25 cm. The calculated L_{50} lie at the descending slope of the main frequency peak of the cod length distribution.

It was already mentioned that on all trips, only small to medium sized catches of cod could be achieved.

Figure 4 shows the resulting selectivity curves of all codend types investigated. It has to be stated that, in spite of considerably smaller mesh openings compared to the reference, all codend types tested fulfil the condition of the escape of more than 50 % of the cod at 38-cm length.

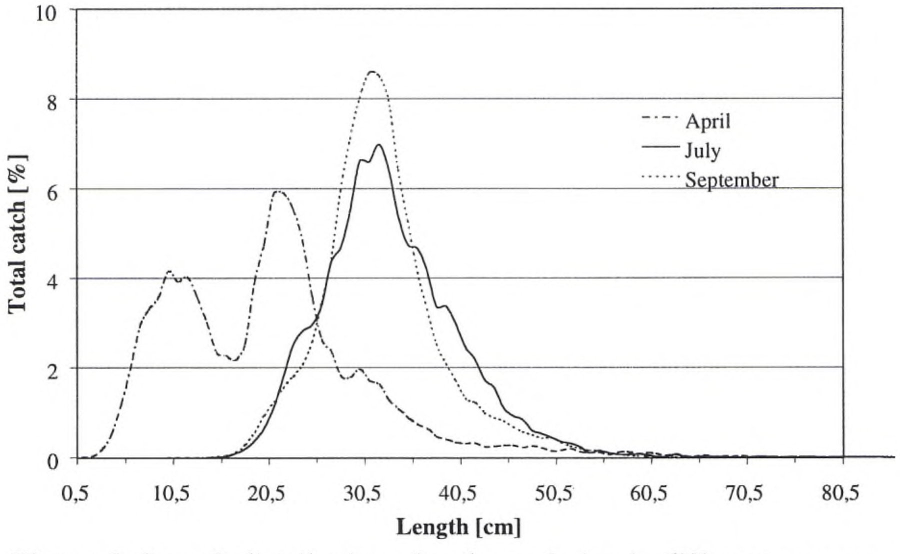


Figure 3. *Length distribution of cod population in different seasons*

The reference codend made of diamond meshes and a mesh opening of 117 mm also showed this condition on both cruises in April and September which is in clear contradiction to the findings of the mentioned ICES group of experts. Even with the smaller type of the codend with the meshes turned 90 degrees this condition could be met exactly.

By grouping the selectivity curves according to codend types differences can be demonstrated in the results of the tests made at different times of the year (Fig. 5). Seasonal effects have a distinct influence on the selective effect of the different codend types. The reference trawl showed the same effect over the year. Smaller sizes of cod were caught at a higher rate in spring because of being more abundant then.

For the codend with the meshes turned 90 degrees the escape rates deviate to smaller sizes from April to September. A similar trend was confirmed for the Multipanel codend with the observed effect being even bigger.

Table I contains the essential parameters of the resulting selectivity curves. These are:

- the fish length, L_{50}, where 50 % of the caught fishes are able to escape from the net.

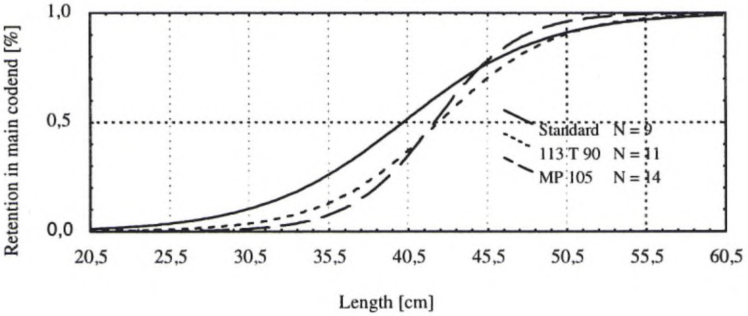
- the selection range SR, the length range between 25 and 75 % escape. It serves as a measure for the slope of the selection curve and hence the sharpness of the selection.

- the selection factor SF, calculated as the relation of L_{50} to the mean mesh opening of the codend in question. It serves as a criterion of goodness of the selectivity in comparisons of different codend types.

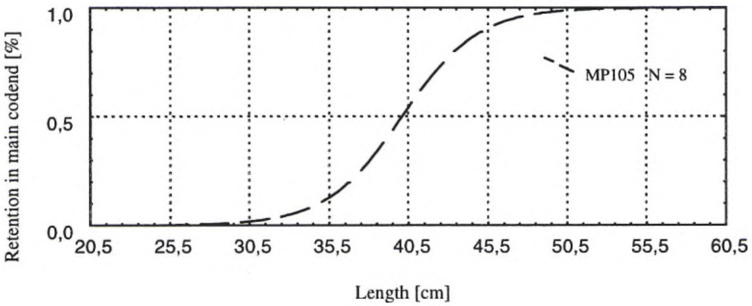
The L(50) exceeds for all codend types and for all seasons the 38-cm condition. In the comparison of the new codend types against the reference the selectivity range decreases meaning that the selection takes places in a essentially smaller length range and, thus, leads to fewer undersized fish in the catch.

Cod selection

Resulting selectivity curves for cod in April



Resulting selectivity curves for cod in July



Resulting selectivity curves for cod in September

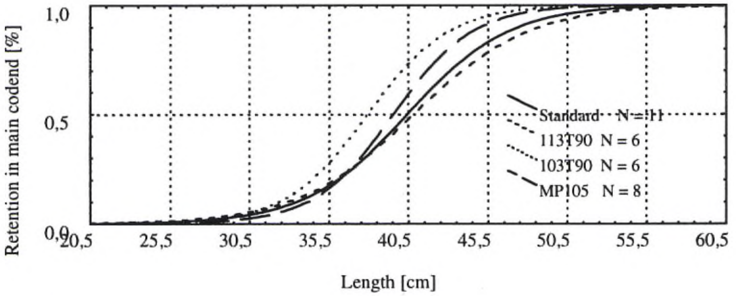
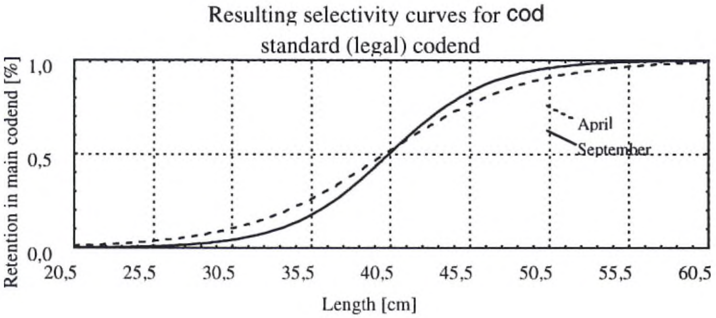
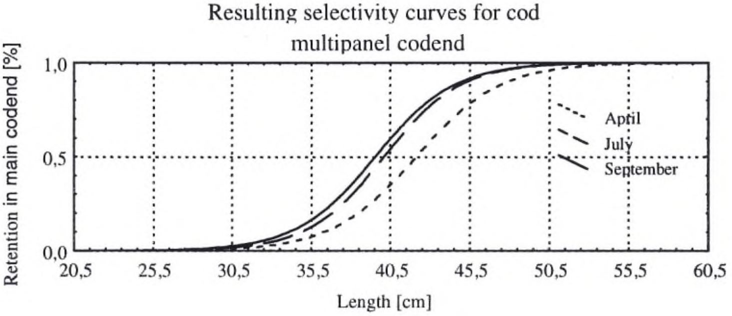


Figure 4. *Resulting selectivity curves of all codend types investigated in three different cruises*

Seasonal effects


Resulting selectivity curves for cod
standard (legal) codend


Resulting selectivity curves for cod
multipanel codend

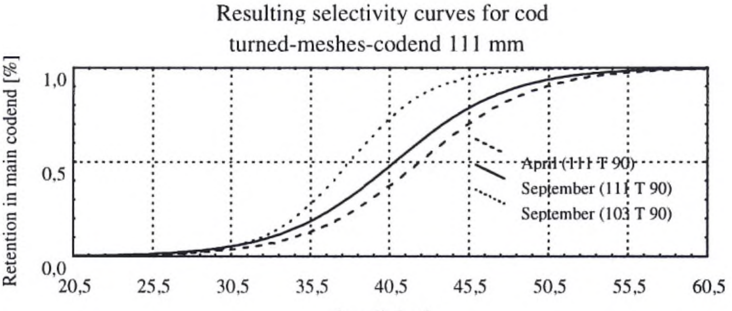

Resulting selectivity curves for cod
turned-meshes-codend 111 mm

Figure 5. *Seasonal effects on the selectivity of three different codend types*

***Table 1.** Resulting numerical selectivity parameters of the three codend types investigated*

	L50	SR	SF
April 1998			
117 mm standard	40.2	9.8	3.43
113 mm T90	42.4	8.0	3.75
MP 105 mm	42.1	5.8	4.01
July 1998			
105 mm MP	40.1	5.2	3.82
September 1998			
117 mm Standard	40.4	7.0	3.45
113 mm T90	40.8	8.0	3.61
103 mm T90	38.0	5.6	3.67
105 mm MP	39.5	5.4	3.77

During all cruises the Multipanel codend attained the highest selection factor. If regarded under the aspect of the selective effect this codend lies ahead. It is closely followed by the type of codend with meshes turned 90 degrees with the smaller mesh opening, than by the one with the bigger meshes and the reference codend carries the closing red light. A statistical test (F-test) on the significance between the selection factor for each codend and haul shows that it exists with a probability of 95 % between standard codend and Multipanel codend for the September cruise and at the 90 % level for all tests carried out over the year. The attempt to prove significant differences between standard codend and codends with turned meshes, however, failed.

Discussion

From results of this study it was obvious, that with the use of a Multipanel codend type with a mesh opening of approximately 100 mm, the minimum landing size can be attained with optimum selectivity and lowest percentage of discard. Problems, however, have to be anticipated with regard to the acceptance by the commercial fishery. They will certainly oppose to such relatively complex construction. As an alternative it may be sufficient to provide conventional codends with three of such square mesh windows. Problems with repairs are than confined to the windows which may be changed in whole.

The used Ultra Cross net material is not available on the European market and very expensive, but with increasing demand availability and costs of the knot-less material are thought to improve.

The codend with the meshes turned 90 degrees has to be considered as an alternative with still existing advantages compared to the reference codend. There are, however, technological questions to be solved in further tests. Thus it has to be investigated by longer operation on commercial fishery ships with their bigger catches if this will lead on the long run to deformation of meshes and subsequent fitting towards the properties of a normal codend.

As demonstrated by underwater observations loose meshes and wrinkles could be detected at the joining of the codend to the extension. During the trials they were joined in a 1:1 relation. It remains open whether this or stiffness of the netting material has an influence on the selective efficiency in this codend type. Polish trials demonstrated even more positive results as those presented here. Their codends however, were made from less stiff PA netting and attached to the extension in a two to one relation.

It is hard to understand what may have caused the seasonal variation being just contrasting to what has been found with haddock in the North Sea. A few records of the temperatures close to the bottom taken during the experiments, however, show few seasonal changes in the Baltic. This is completely different from the environmental conditions observed in the mentioned haddock trials in the North Sea. Obviously there was no physiological reason for the Baltic cod to react more vigorously in summer than in spring.

Though the existing results are conclusive, selectivity curves derived from catches with several tons of cod are lacking. As is general knowledge large catches lead to an important negative influence in selectivity in schooling pelagic fish. Thus, it might be assumed that such results from a research ship are not adequate to commercial fishing. However, recent research results from an EU-project on round fishes (VARSEL) show against expectation a steadily improving selectivity with increasing catches. Thus, the results presented here give a rather conservative assessment of the selective effects of certain codend mesh openings or codend types and, hence, taken as a basis for legal definitions of the codend mesh size would take into consideration the now much stressed precautionary approach.

This research will be continued in the coming year with the main objective to attain an optimum protection of the young cod. As it seems there are good prospects to present to the IBSFC an acceptable and scientifically sound solution until the end of the BACOMA project.

Acknowledgements

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Size and Species Selectivity Studies of Hauling and Fixed Gears in Estonia in 1970-1990s: Implementation on Survey Results

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Abstract

Methods and results of the studies of size and species selectivity of pelagic trawl in herring and sprat fishery, bottom trawls in flounder fishery and traps in coastal fishery are described. The appropriateness of the results and effect of methods used are discussed. Possibilities and efficiency of implementation of the results in fisheries regulation are analysed in the light of the principles of sustainable fisheries and on a socio-economical background.

As a main result of studies of selectivity of pelagic trawls in herring and sprat fishery, the low efficiency of mesh size as a regulatory tool is highlighted. In further investigations a focus on the temporal-spatial aspects as on fleet selectivity of trawl fishing and on the optimisation of the balance between herring trawl and poundnet fisheries is recommended. Due to the high number of species fished, the implementation of combined measures including closed areas and seasons, restriction of specific gears and permitted range of mesh sizes in each particular type of gear allowed to use are pinpointed as probably the most effective regulatory tools of the size and species selectivity in coastal fishery.

Key Words: *pelagic trawl, bottom trawl, trap, selectivity, regulation, efficiency.*

Introduction/Historical background

The fishing intensity of Baltic herring (*Clupea harengus*) and sprat (*Sprattus sprattus*) increased dramatically in the former USSR in the beginning of the 1950s, particularly after the introduction of pelagic trawls. Also, in many areas the artisan fishery intensified considerable. As a result, the catches of herring and several freshwater species began to decrease in the 1960s. The urgent need for implementation of regulatory measures, both biological and technical, became evident.

On these grounds, the minimum landing sizes for herring, sprat, cod (*Gaduas morhua*), flounder (*Platichtys flesus*) and for some others' species were introduced, the fishing effort in some fisheries was restricted, closed areas and seasons were established. Furthermore, catch constraints were implemented step by step for almost all main fish stocks in the 1970s (Ojaveer and Järvik, 1996).

Simultaneously, the investigations of gear selectivity were commenced in Estonia in the 1970s with the aim to estimate appropriate minimum mesh size in codends of pelagic trawls for herring and sprat fishery in the Gulf of Finland. Later, studies of selectivity of flounder bottom trawl and that of traps in coastal fishery in Estonian waters were started as well. Additionally, the possibilities of separate fishing of herring and sprat in the fishery of mixed shoals, the meshing of fish in pelagic trawl codend and the size and species selectivity of fishing process (depending on type of vessel and gear), were also examined.

Almost all results of those investigations were introduced into fisheries, obviously with different success. The socio-economical effects of regulation of gear and fishing selectivity were also highlighted. (Järvik, 1974; Järvik, 1981; Shevtsov, 1988; Järvik, 1989; Järvik and Raid, 1991, Järvik and Suuronen, 1990; Suuronen *et al.*, 1991; Raid, 1996).

In this paper the main attention is taken to assess the possibilities and efficiency of using the results of selectivity investigations mentioned above in fishery regulation.

Material and methods

Pelagic trawls

In the beginning of the 1970s, studies on selectivity in pelagic pair trawls with diamond meshed codends were carried out in the Gulf of Finland using medium-size (L= 27.3 m, 150 HP or L= 21m, 150HP) side-trawlers fishing with regular commercial trawls with 400 mm meshes in wings and first section of trawl body. Experiments with between nine and twelve 60 minute hauls per mesh sizes (whole mesh length A) of 20, 24, 28 and 32 mm were performed using the small meshed cover-bag method (Treschev 1974). The circumference of the cover bag was 1.5 times greater than the one of the codends. The trawling speed was approximately 3 knots. Total catches per haul varied from some hundred kilos to some tons. The number of fish measured from, both codend and cover-bag, were in average 300-350, but not less then 250 per haul.

In the late 1970s, the medium-size side-trawlers were equipped with more powerful engines (225 or 300 HP) and the new Baltica-type stern-trawlers (L=26.5 m, 300 HP) became in use in the pelagic fleet. Furthermore, the upgraded trawls with ropes in the wings and in the first section of the body were implemented in both medium-size and small vessel fisheries. As a result, the mean trawling speed of medium-size trawlers increased from 2.8-3.3 knots in the beginning of 1970s to 3.2-4.0 knots. A new minimum landing size l (body length) of 11.0 mm for herring in the Gulf of Finland was enforced in 1981. A new series of selectivity investigations of herring trawls in the Gulf of Finland were carried out in 1981-1984 to estimate the effect of the regulatory measures mentioned above. The method used was the same as during the first series, except the trawling speed that was increased to an average of 3.6 knots. The diamond meshes of 28 and 36 mm and square mesh of 28 mm in codend were tested.

Meshing (fish engaging in meshes), an additional factor, effecting on selectivity of herring and sprat in diamond mesh codends, was studied in the Gulf of Finland in 1981 and in 1986 in relation to the type of vessel and season (Järvik and Raid, 1991).

Bottom trawls

The codend selectivity of bottom trawls codends with diamond meshes of 80 and 90 mm for flounder was studied in the Gulf of Finland in the mid-1970s, using small trawlers (L=16 m, 150HP) and a commercial 27.8 m bottom trawl. The same method as described above for pelagic trawls was used, except that the small mesh bag covered only the upper part of the tail of the codend. The trawling speed was 2-2.6 knots.

Traps

The dependence of mesh size in leader-net on the size and species selectivity of traps in perch (*Perca fluviatilis*) and pike-perch (*Stizostedion lucioperca*) fishery was studied in Pärnu bay (North-eastern part of the Gulf of Riga) in May-June 1979. Two traps with mesh size of 40-48 mm (regular commercial) and of 80 mm (experimental) in the leader-net were set to fish at the same fishing ground and exploited by the same order. All caught specimens of perch and pike-perch were measured and weighted. By-catches of other species (vimba-bream (*Vimba vimba*), roach (*Rutilus rutilus*), etc.) were also counted from both traps.

The efficiency of using the large mesh (80 mm) in the traps' leader-net was also studied in 1979-1981 in the Moonsund Archipelago area by the same comparative fishing method.

Results and discussion

Pelagic trawls

The fitted experimental selection curves of pelagic trawl codends for the first period of selectivity investigations in the beginning of 1970s, are presented in Figure 1 for herring and for sprat in Figure 3, whilst Figure 2 shows the fitted selection curves for herring from the experiments in the 1980s. It can be concluded for both herring and sprat that the 50% or more of undersized fish (l_{min} = 10 cm for herring and l_{min} = 8 cm for sprat) escaped from codends with all mesh sizes studied.

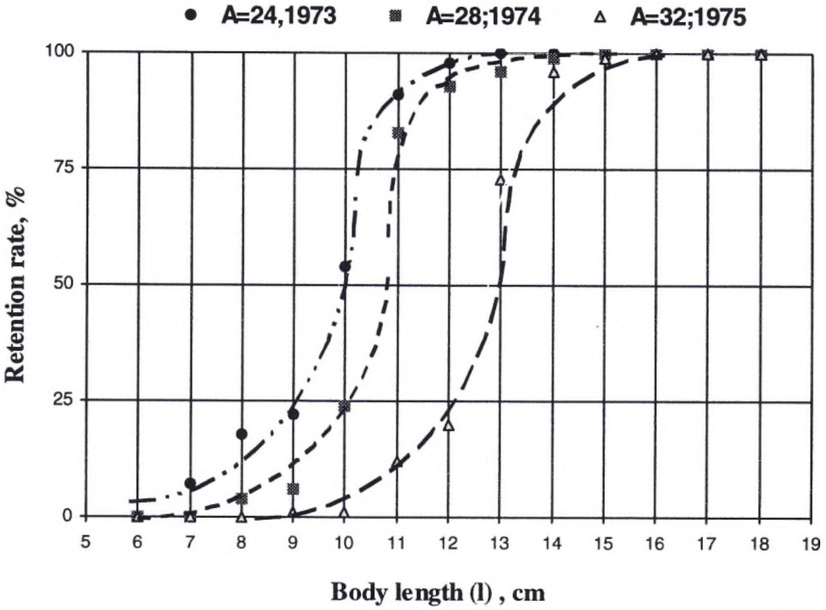

Figure 1. *Fitted selection curves for herring (Clupea harengus) in pelagic trawls in three investigations performed in the early 1970s, using diamond meshes of three different sizes (24, 28 and 32 mm)*

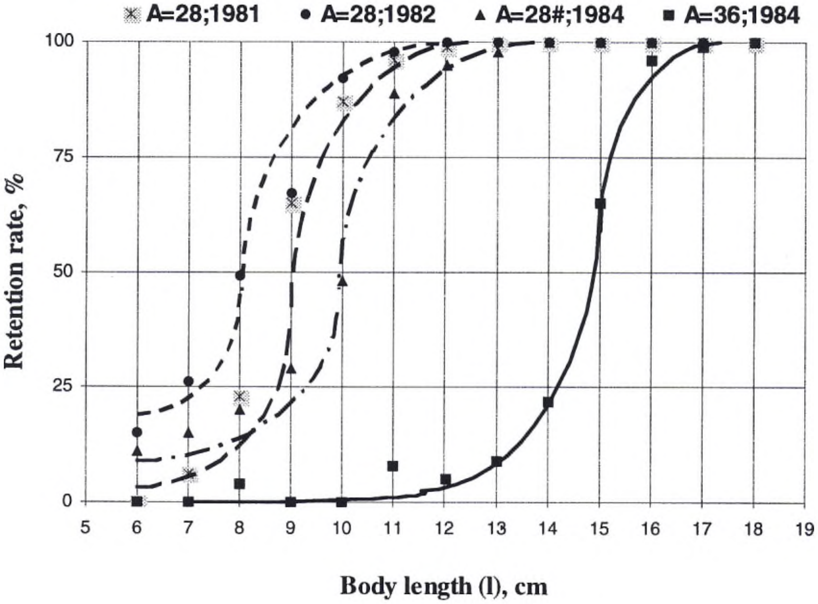

Figure 2. *Fitted selection curves for herring (Clupea harengus) in pelagic trawls in four investigations performed in the early 1980s, using diamond meshes with two different sizes (28 and 36 mm) and 28 mm square mesh (A=28#).*

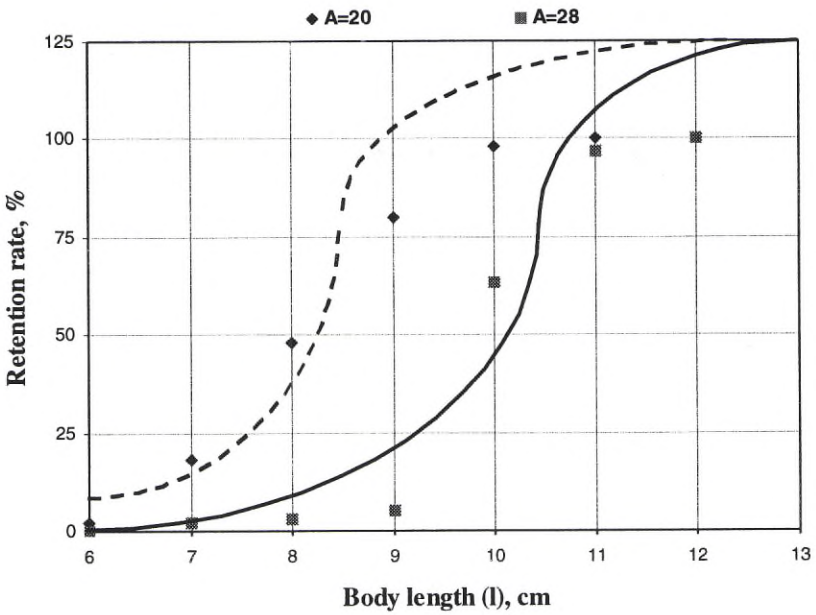

Figure 3. *Fitted selection curves for sprat (<u>Sprattus sprattus</u>) for pelagic trawls in the experiments performed in the early 1970s with two different mesh sizes (A=20 and A=28)*

When assessing the results of the selectivity experiments mentioned above, one should keep in mind that pelagic trawls in the Gulf of Finland fish mostly mixed aggregations of herring and sprat. In codends with a mesh size of 28 mm, the amount of sprat (sometimes also young herring) in meshing was estimated at a substantially high level and the use of 32 mm codends resulted in more than 50% of full sized herring and almost all sprat escaping. It was concluded that in the Gulf of Finland mesh sizes in pelagic trawl codends of 24 mm, used predominantly for herring, and 20 mm, used predominantly for sprat fishing, could be recommended as minimum allowable. These conclusions were based on the facts that during the experimental trawling, the use of those meshes resulted in less than the allowed 15 % by-catch of undersized fish (l < 10 cm for herring and l < 8 cm for sprat, respectively), the meshing of fish in codends was not large and escaping of full sized specimens was low.

These recommended minimum mesh sizes were implemented in 1976 (Anon., 1976). However in practice the efficiency of that regulatory measure was not high. Since the common hauling duration in herring and sprat fishery was about 4 - 6 hours, the catches per haul were generally much higher than during our experiments. In the commercial medium-size fleet using codends with meshes of 24 mm, the meshing of sprat and young herring, especially during the wintertime, was quite high. Both mentioned factors generated additional negative effects on selectivity. From time to time, the by-catch of undersized fish of one or both species become very high, resulting in limited or total temporal ban for pelagic trawl fishery in the Gulf.

As was expected, the selectivity of pelagic trawl codends during the second series of experiments in the beginning of the1980s was lower than in the first series. (Figures 1 and 2). Even when using square meshes, the mesh size of 28 mm was not enough to satisfy the 15 % by-catch limit of undersized (l < 11 cm) herring. In the codend with diamond mesh of 36 mm, the by-catch of undersized herring was close to zero, but also about 80 % of herring length (l) over 11 cm escaped, to say nothing about the sprat escapement. Though the experiments with 32 mm diamond meshes in the codend were not provided in this case, according to the results of previous experiments it was predicted, that using 32-mm mesh in pelagic trawl codends is not the best solution for the Gulf of Finland. Furthermore, the doubts in efficiency of pelagic trawl codend selectivity regulation by mesh size only became increasingly evident.

Results of previous investigations, performed by Efanov (1981) in the Gulf of Riga, on survival rate of the Baltic herring after escapement through the codend, only supported this opinion. The mortality rate of 0- and 1-group herring was estimated to be up to 20-30% or more, even despite of very low catches during the experiments.

The studies on meshing showed that the highest meshing of herring and, especially, sprat was found in spring for medium-size fleet using the 28-mm mesh codends. Meshing of sprat was high also in the 24-mm codends. (Figures 4 and 5).

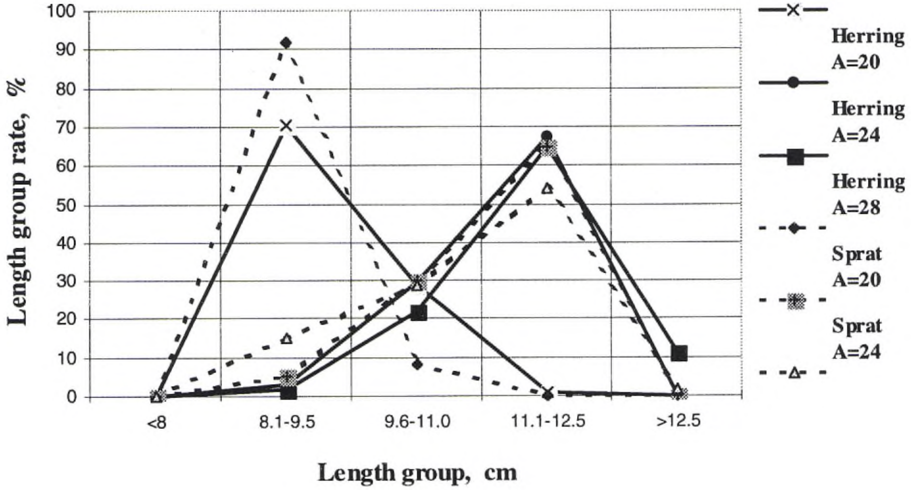

Figure 4. Length (l) distribution of herring and sprat meshed in codends of pelagic trawls with different mesh sizes in experiments performed in autumn 1981.

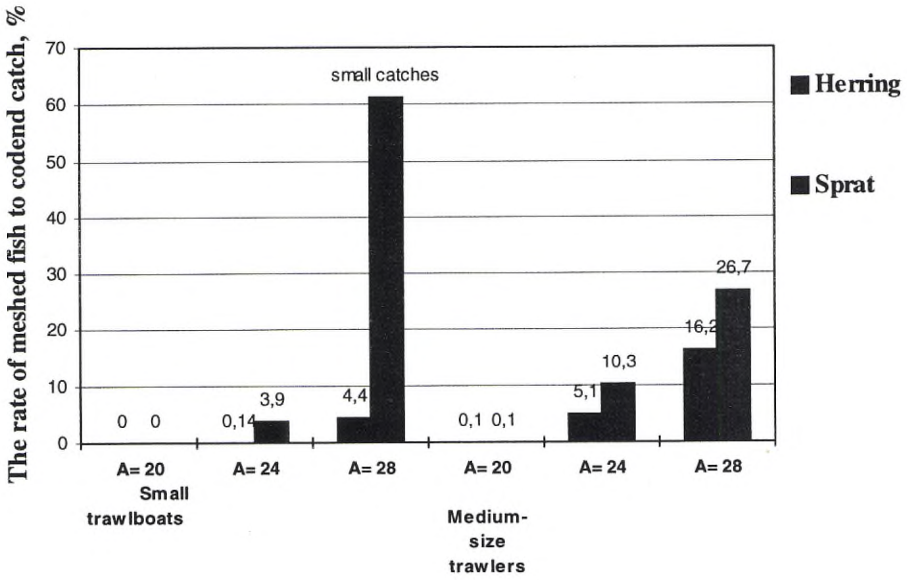

Figure 5. Rate of meshing of herring and sprat in pelagic trawl codends with different mesh sizes using dfferent types of vessel in autumn 1981.

The minimum mesh size of 20 mm was recommended for introduction in pelagic trawl fishery of herring and sprat in the Gulf of Finland in 1987.

It should be added that in 1989, the selectivity for herring of pelagic pair trawls with diamond mesh codends was also studied during an Estonian-Finnish joint project in the Gulf of Finland in Estonian waters on board medium-size stern trawlers (L=26.5 m, 300 HP) using both small mesh cover bag and twin codend methods (Järvik and Suuronen, 1990). The experiments with a hexagonal mesh codend were continued in 1990 in Finnish waters (Suuronen *et al.*, 1991). An important goal of those investigations was also to estimate the possibilities of using gears with higher selectivity to improve the marketing quality of herring for human consumption without onboard sorting. However, there were no adequate recommendations done because of the high uncertainties of the results (Suuronen *et al.*, 1991). Further investigations conducted in Finland in 1991-1994 included estimation of survival of herring escapees and the effect of using different sorting grids in the codend. An underwater towing vehicle was used to observe the fish behaviour and the process of escaping. It was concluded that concerning the Baltic herring fishery, the benefits gained by using the traditional codend mesh size regulation alone to protect the resources, may turn out substantially smaller than expected (Suuronen, 1995).

Bottom trawls

The fitted experimental selection curves for flounder are presented in the Figure 6. As a result of those investigations, the minimum mesh size of 90 mm in bottom trawl codends was implemented in the Gulf of Finland. No problems with by-catch of undersized (L < 18 cm) flounder in that fishery were observed after the implementation.

According to the decision of International Baltic Sea Fisheries Commission (IBSFC) from June 1995, the minimum mesh size of 110 mm in bottom trawls and Danish seine codend fishing for flounder, was implemented also in the Gulf of Finland south of 59° 30' (Anon. 1994). Since, however, high escapement of sized (L > 18 cm) flounder was observed, this measure seems to be inappropriate, especially for the period of low abundance of cod in the Gulf of Finland.

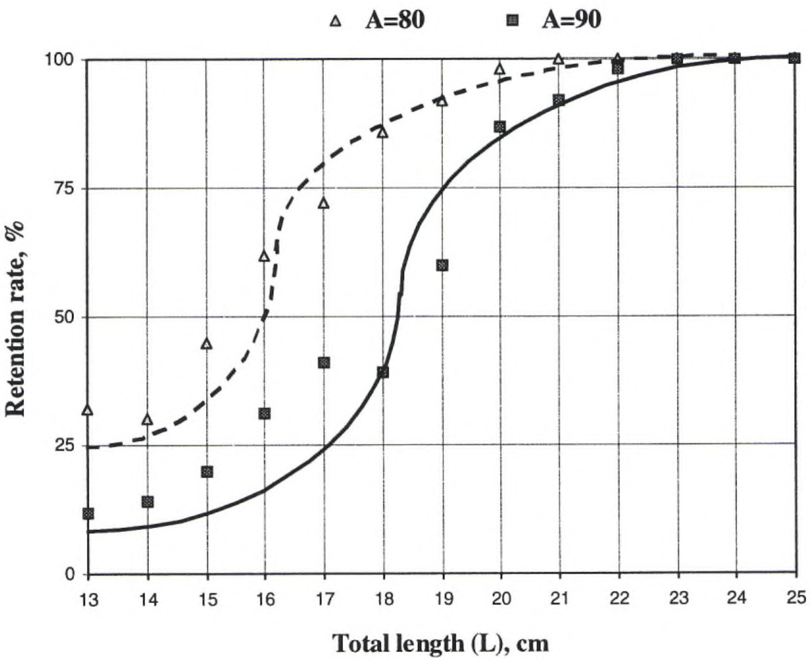

***Figure 6.** Fitted selection curves for flounder (<u>Platichthys flesus</u>) for bottom trawls' codends with mesh sizes A=80 and A=90 mm in Gulf of Finland in the mid-1970s.*

<u>Traps</u>

As can be concluded from Figures 7 and 8, the by-catch of undersized pike-perch (l < 38 cm) as well as small perch (no size limit was established) was lower in the experimental trap. However, an increase of mesh size in leader-net to 80 mm as minimum mesh size and a 30% decrease of fishing effort (number of gears) for traps with opening of more than 3 m were recommended and implemented in the early 1980s. For traps with openings under 3 m, the increase of mesh size in leader-net was inapplicable because it resulted in a drop of vimba bream and roach catches, which usually are of great importance in catches of those gears. Additionally, a total ban for trap fishery of at least 10 days in Pärnu Bay during the spawning period of pike-perch was recommended. Due to very high economical impact on the local fishermen of the latter measure, it was implemented only in 1997.

No recommendations were made for the Moonsund Archipelago area though, due to highly controversial results. The increase of mesh size in the leader-net to 80 mm ensured close to zero by-catches of immature perch but had no notable effect on by-catches of undersized ide (*Leuciscus idus*) and vimba bream. Additionally, the catches of roach and silver bream (*Blicca bjoerkna*) decreased substantially.

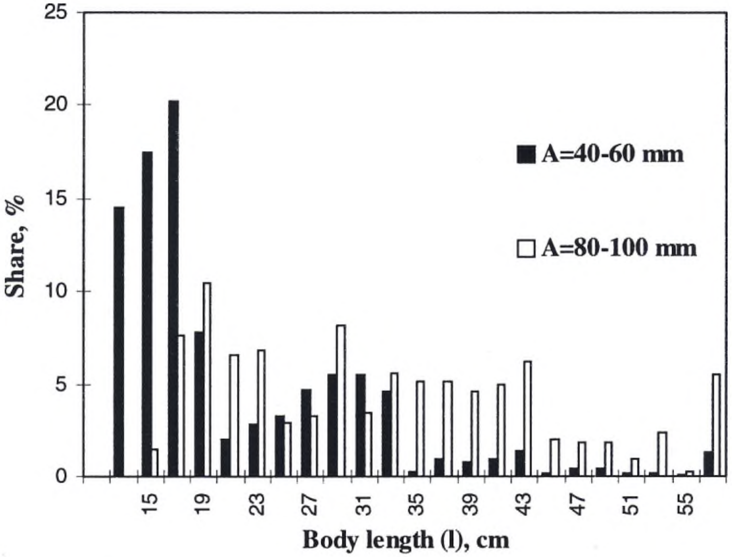

Figure 7. *Length distribution of pike-perch (Stizostedion lucioperca) in trap catches with two different leader-net mesh sizes in Pärnu Bay in 1983.*

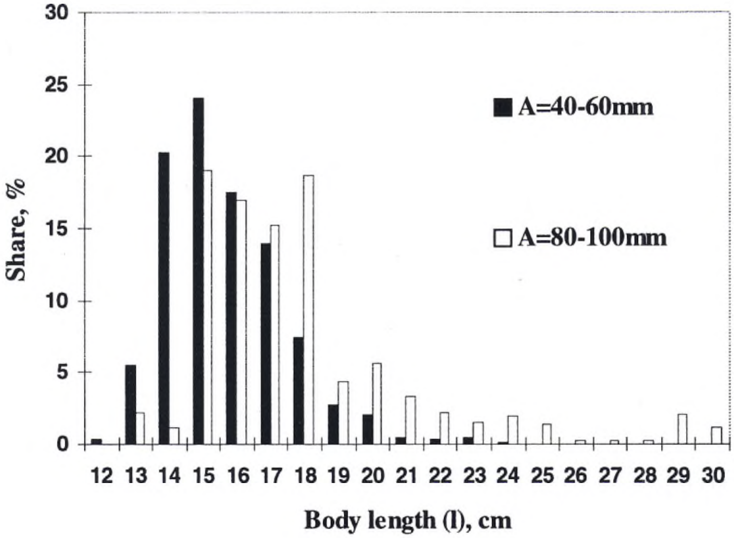

Figure 8. *Length distribution of perch (Perca fluviatilis) in trap catches with two different leader-net mesh sizes in Pärnu Bay in 1983.*

Fishing methods and fleet selectivity

Traditionally, 70-80 % of the total annual Estonian herring landings are taken by pelagic trawls in open sea (deeper than 20 m) and the rest by pound nets (large uncovered traps) in the coastal zone. The trawl fishery is not limited seasonally and the pound net fishery takes place during spawning time in April-July only.

For estimation of the actual share of both trawl and pound net fishery in total fishing mortality of herring, the spatial variability of age-length-weight structure of herring catches was studied in the 1990s (Figure 9). From a study performed in the Gulf of Finland (ICES' rectangles 47H7, 48H7 and 48H6) in April-June 1986, we have the length structure of herring in catches from small trawlers (90 HP) using bottom trawls, medium-size trawlers (150 HP) using pelagic trawls as well pound nets (Figure 10).

The age composition of pound net herring catches can be characterised by the substantially higher share of older age groups and almost zero by-catch of immature fish, whilst trawl fishery remarkably exploited also immature part of the stock (ages 1 and 2) (Parmanne *et al.*, 1997). Catch in numbers per 1000 t of herring landings in pound net fishery is considerable smaller than in trawl fishery (Figure 9). Therefore, shifting the balance between trawl and pound net fishery towards the latter seems to benefit the herring stocks by decreasing the fishing mortality in both immature and mature fractions. The Figure 11 shows how the calculated catch levels of herring in numbers per 1000 t of catch in the second quarter are depending on the share of pound net catches in different areas investigated. It was concluded, that the intensity of trawl fishery should not be increased in the Gulf of Riga or Gulf of Finland and in case of increasing the catch quotas of herring for those areas, the increase should be recommended in pound net fishery only. Still, due to the seasonal character of pound net fishery and to the fact that it is directed to the harvest of spawning shoals, the increase of the share of pound net fishery must be carefully assessed to prevent the decrease of reproduction capacity of the herring stocks fished. Above all, market conditions should be taken into account, as should the socio-economical effects.

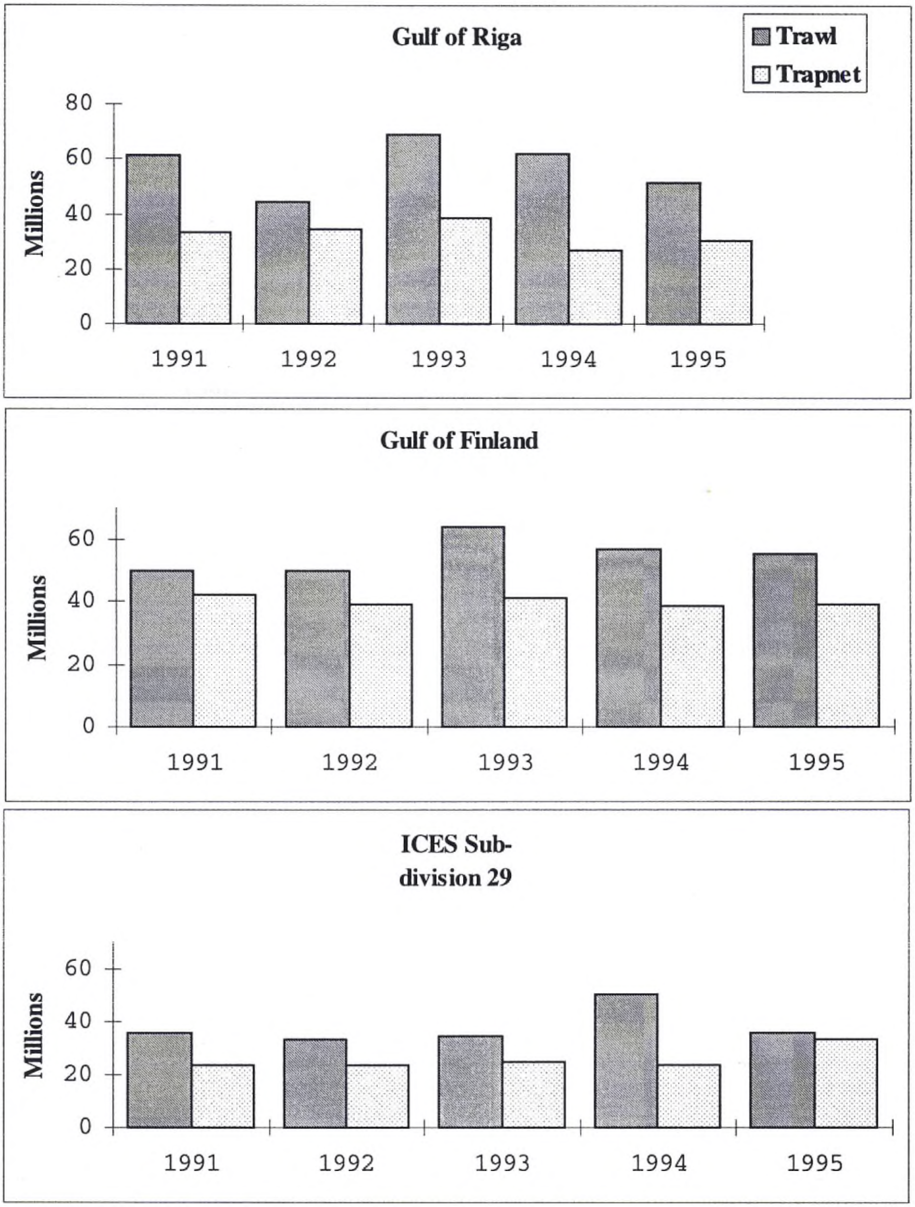

Figure 9. *Catches of herring (Clupea harengus) in numbers per 1000 t of total catches in the second quarters of 1991-1995 in three areas of investigations.*

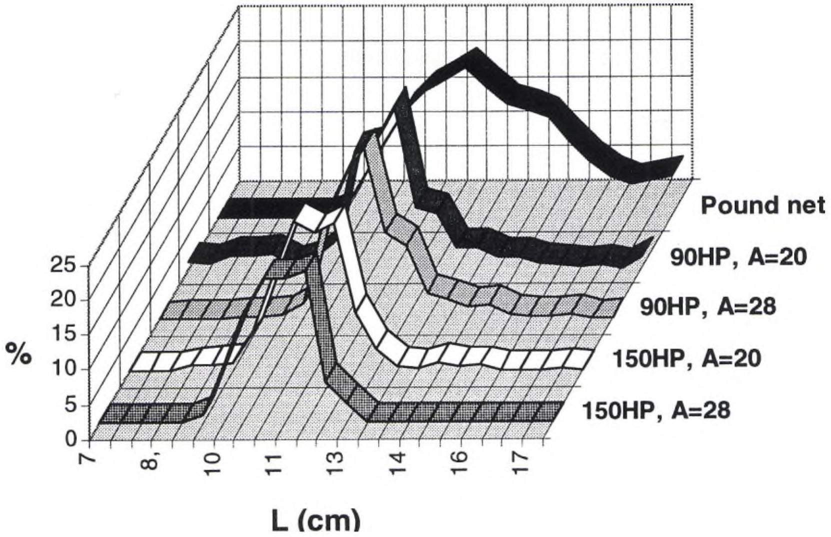

Figure 10. *Length distribution of herring catches in pelagic (150 HP) and bottom trawls (90 HP) with different mesh sizesand pound nets in the Gulf of Finland in the spring of 1986.*

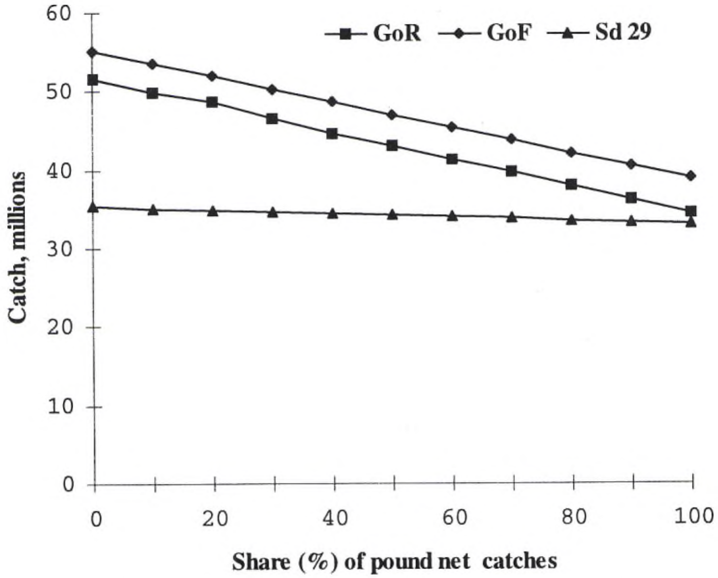

Figure 11. *Calculated catches of herring (Clupea harengus) in numbers per 1000 t of total catches based on share of pound net catches in the second quarter (GoR- Gulf of Riga, GoF- Gulf of Finland, Sd 29- ICES Sub-division 29.)*

Conclusions

The above-presented results of fishing selectivity studies in Estonian waters indicate the versatility of factors effecting efficiency of any regulatory measure in improving size and species selectivity. The effects of mesh size regulation in Baltic herring and sprat pelagic trawl fishery in the 1970s and 1980s have been uncertain. It may be concluded, that for sustainable management of Baltic herring, an optimisation of the ratio between trawl and pound net fishery is needed. However, simultaneously changes in numbers of fishermen employed in both trawl and pound net fishery and their incomes should be the subject of special socio-economical studies.

The selectivity investigations, for the time being mainly focused on the estimation of the most appropriate mesh sizes of gears, should in the future be more incorporated in the studies of the influence of the type of vessel and fishing process used. The necessity of taking into account the seasonal, geographical and socio-economical aspects should be highlighted. Survival of escapees and discarding of meshed fish, as additional factors in regulation of selectivity, should be assessed, also in fixed gear fishery.

Acknowledgements

Many colleagues from Estonia and abroad have been involved in these investigations. The authors would especially like to thank the crewmembers of the commercial fishery vessels that participated in the experiments. The contributions of Dr. S. Shevtsov, Dr. P. Suuronen and Dr. R. Parmanne have been extremely important in realisation of field experiments as well as in interpretation of the results.

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Size Selectivity and Relative Fishing Power of Baltic Cod Gill nets

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Abstract

Sea trials were carried out on commercial vessels measuring the size selectivity and fishing power of Baltic cod gill nets in Autumn 1997 and Spring 1998 in Denmark and Sweden. Nominal mesh sizes of 70-130mm were used. In Denmark a comparison was made of standard nets hung at 50% hanging ratio with nets of the same specification but made of thicker twine. In Sweden a comparison was made of similar standard nets with nets of 40% hanging ratio. For most sets the nets were hauled approximately 24 hours after setting.

Condition factors of the cod were found to be very similar for the four trials as were girth to length ratios. Method of capture was recorded for sub-samples of the cod caught. Most cod (60-90%) were gilled. A smaller proportion (10-21%) were enmeshed between the maxillaries and the start of the gill covers. A few cod were entangled by their teeth or otherwise entangled without being enmeshed.

A model of the size selectivity of the gill nets was formulated and fitted to the catch data by set. This was based on a bi-normal selectivity curve with the two normal distributions describing cod that were gilled and those caught by other methods (principally enmeshed behind the maxillae). Analyses were carried out to determine if gear design or trials period had a significant effect upon the selectivity curve parameters when random between set variability was taken into account.

It was found that twine thickness, hanging ratio and trials period had relatively little effect upon the shape of the selectivity curve. Retention was highest when the cod length was approximately 4.4 times the mesh size. Twine thickness had a substantial effect upon the fishing power of the nets. It was found that gill nets of the legal minimum mesh size of 105mm for Baltic cod have much superior size selection characteristics to diamond mesh trawl codends of the legal minimum mesh size 120mm.

Key words: *Baltic cod (Gadus morhua), gill nets, selectivity, fishing power.*

1. Introduction

1.1 Background

Baltic cod is a stock which is of considerable commercial importance but has been considered to be both overexploited and subject to an unsatisfactory exploitation pattern with high catches of juveniles. There have in recent years been temporary closures of the fishery, severe quota rationing and an increase in the minimum mesh size for towed gears from 105mm to 120mm in standard codends. In recent years the importance of Baltic cod gill net catches has increased. Over 40% of the Danish and Swedish Baltic cod catch weights are taken in gill nets. Minimum mesh size for cod gill nets in the Baltic has been maintained at 105mm but the minimum mesh size for targeting cod with gill nets in other European waters is now 120mm. There may be a future wish to review the present gill net regulations for fishing Baltic cod.

Such a review should be based on knowledge of the selectivity of the gillnets used commercially. Several experiments have been conducted comparing catches of Baltic cod in different gill net mesh sizes, (e.g. Zaucha et al. 1995; Mohr 1983; Lowry et al. 1994), but no selectivity curves have been obtained. In most cases the number of mesh sizes used was too limited and the different mesh sizes were not fished at the same time on the same grounds within the same group of nets.

This paper presents the main results of experiments carried out by the Danish Institute of Fisheries Technology (DIFTA), the Institute for Marine Research, Sweden (IMR) and ConStat, Denmark in the study "Size selectivity and relative fishing power of Baltic Cod gill nets". The study was undertaken in the period January 1997 – April 1999 with the financial assistance of the European Commission. There were two specific objectives for this study;

· to measure the effect of gill net design parameters upon the size selectivity and relative fishing power of Baltic cod gill nets.

· to produce a statistical model describing these changes in selectivity which can be used in simulations of possible fisheries management scenarios.

Sea trials with experimental gill nets were carried out on commercial fishing vessels by DIFTA in Denmark and by IMR's Baltic Fisheries Research Station, Karlskrona in Sweden. The resultant data were analysed by ConStat. Additional gill net selectivity raw data were provided by the Institut für Fischereitechnik, Hamburg, Germany (BFAFI-IF). These were collected in a parallel study also receiving the financial assistance of the European Commission entitled "Selectivity and efficiency of gill nets on cod in the Baltic", (Mentjes 1998).

1.2 Terms and definitions

1.2.1 Enmeshing, entangling, mesh penetration ratio and girth to mesh periphery ratio

A fish that has penetrated a mesh in a gill net and become caught with a mesh stretched tightly round its body behind some projection, e.g. gill covers, will be said to be **enmeshed**. Fish that have been enmeshed normally then turn around and swim back through the netting becoming enmeshed two or more times (Mentjes 1998). A fish which has not penetrated a mesh but has been otherwise caught by netting catching on projections e.g. teeth or a fin and then the fish wrapping itself up in netting or being contained in a slack pocket of netting, will be said to be **entangled**.

Cod have previously been observed to normally be either enmeshed behind the gills or behind the maxillae (jawbones), (Hovgård 1996; Anon 1997). The girths of cod at these two positions of enmeshing have been measured and the **girth to mesh periphery ratio (GPR)** calculated where the mesh periphery is twice the inside mesh size. If a fish has been enmeshed then a single clear mark can sometimes be left on the fish body showing exactly where the first mesh penetrated has held the fish fast. The ratio between the circumference of this mark and the mesh periphery has been called the **mesh penetration ratio (MPR)**.

1.2.2 Monofilament, multimono and multifilament twines

These are the 3 different types of nylon twine construction commonly used in gill nets.

- A monofilament twine consists of one solid nylon thread. It is relatively stiff and transparent.
- A multimono twine consists of a limited number (typically 3 to 12) of monofilament threads over 0.1mm diameter which are loosely twisted

round each other, but not usually round their own axis. The resultant twine is less stiff than a monofilament twine of the same overall thickness. The twines used in these sea trials are designated 1.5*4 and 1.5*6, a Japanese numbering system indicating that there were 4 and 6 threads respectively of number 1.5 monofilament thread which is in fact approximately 0.2mm in diameter.

- A multifilament twine is composed of two or more twisted strands each of which is composed of numerous small filaments normally of under 0.05mm diameter twisted together. The twine is non-transparent.

1.2.3 Mesh size

The **inside mesh size** or mesh opening (as measured by fishery inspection officers) is the measurement of mesh size that has been used throughout this report for calculations. Mesh sizes are always measured and quoted in mm but converted to cm for calculations of fish length (measured in cm) to mesh size ratio (this ratio is known as the transformed length). In general manufacturers supplying sheet netting used for gill nets quote the **full stretched mesh size** (centre of knot to centre of knot) instead as this is the measure used to set up net making machines. The manufacturers quoted mesh size is always referred to in this report as the **nominal mesh size.** It should be noted that gill net fishermen and netting manufacturers in many countries including Denmark and Sweden use the bar length or half full stretched mesh size instead.

In these experiments gill net mesh sizes have been measured ashore prior to and some time after the sea trials and therefore in the dry state. Tests made with the materials used in these experiments showed that mesh sizes increased by 2.7% on soaking. Ideally for legal purposes mesh sizes should therefore be measured in the wet state. The dry mesh size has, however, been used in all calculations in this report unless otherwise stated.

1.2.4 A fleet of nets

Gillnets are not used individually, several nets are joined together to form what is termed a **fleet** of nets. Usually when fishing for demersal species the ends of the fleet are connected by short ropes to anchors which in turn are connected by long ropes to surface buoys. Two or more fleets can be joined together and set in the same location on good ground in which case there will often be no intermediate anchors or buoys between the fleets.

1.2.5 A set

A set (or soak) is the term used for a unit operation of the complete gillnet fishing gear in use i.e. setting all the fleets of nets on the sea bed, allowing them to soak for several hours then retrieving them and removing the fish caught.

1.2.6 Absolute selectivity, relative selectivity and contact selectivity of gill nets

In its most general definition the size selectivity of a gill net encompasses all those processes that cause the probability of capture of a fish to vary with its size.

The size selectivity of gillnets can either be measured "directly" where the population has a known size-frequency distribution or "indirectly" where catches are compared between series of nets made to a standard design but in different mesh sizes, (Hamley 1975; Millar and Fryer 1999).

The direct method gives an **absolute** measure of selectivity but requires capture of previously tagged fish or use of a non-selective gear. Its use is in fact normally only feasible in lakes.

The indirect method of measuring selectivity is used in this study. It only gives a **relative** measure of selectivity. Gillnets have the particular property that each net j has for a given species a particular fish length l_0 at which retention probability is highest. This optimal length class is referred to as the **modal length** and the selection $r_j(l)$ of other length classes are measured relative to the selectivity for this modal length.

$r_j(l)$ is in fact most correctly referred to as the contact-selectivity for net j or relative retention rate of fish length l in net j as it is measured relative to the numbers of fish of each length class contacting the net as opposed to those in the population or those that are available to the gear but may avoid it, (Millar and Fryer 1999). $r_j(l_0)$ is for convenience set to 1.0. It should not be assumed that all fish of this modal length contacting the net are retained. This is most certainly not the case. For example, nets made in thin twine catch far more fish of all sizes, including those of modal length, than similar nets made in thicker twine, (Hamley 1975).

1.2.7 Relative fishing intensity and effort

The relative fishing intensity for fish of length l in net j is the probability $p_j(l)$ that a fish of length l contacts net j given that it contacts the combined fleet of nets, (Millar and Fryer 1999). In gill net selectivity studies the assumption is made that this is independent of fish length and is therefore a function of the net only p_j and is simply proportional to the effort for net j.

For gill nets the effort e_j for net j can be expressed by

$$e_j = g_j * t_j$$

where g_j is its length (on the floatline) and t_j is the soak time. When using gill nets in tidal conditions it is said by fishermen that fish are mainly caught when the tide changes (and the nets have maximum height). The best measure of soak time in these circumstances might therefore be the number of periods of slack water as opposed to the number of hours submersed. Fortunately these gill net selectivity experiments have been arranged such that each fleet of nets contains one net of each net type and mesh size tested so the sum of the soak times is the same for each net category and it does not matter what the effective soak times for the different fleets are.

So here

$$p_j \propto g_j$$

1.2.8 Relative fishing power of a gill net and efficiency of its netting

In this study the catching performance of different designs of gillnet are investigated. Two different designs can have both different size selectivity and different fishing power i.e. ability to retain fish at the optimal modal length. If the modal length class for net j is considered then an optimal mesh size can be found in some "standard" design of nets where catches of this length class again reach a maximum. The **relative fishing power** f_j of net j to the standard nets is the ratio of the expected catch numbers of this length class in net j to the expected catch numbers in the optimal mesh size for the standard nets (providing that the soak times are the same for each net).

It is then convenient to define the **relative efficiency** q_j of the netting materials in net ***j*** as being the relative fishing power if it had the same length as the standard nets so:

$$f_j \propto g_j * q_j$$

1.2.9 Baranov's principle of geometrical similarity and transformed lengths

This is the axiom on which most studies of gill net selectivity have been based. Baranov (1948) stated "since all meshes are geometrically similar and all fish of the same species (within a reasonable size range) are geometrically similar, the selectivity curves for different mesh sizes must be similar (for gill nets of the same design)". So effectively selection of 40cm cod in 100mm mesh size nets is said to be the same as for 52cm cod in 130mm mesh size nets of the same design. Selectivity curves for nets of different mesh sizes should, therefore, all collapse onto the same common curve if selection is plotted against **transformed length** = fish length/mesh size.

Functional forms for the selectivity curve based on this principle have often been found to give good fits to gill net selectivity catch data but this has been found not to be the case for some species e.g. Gummy Shark (Kirkwood and Walker 1986).

2. Materials and methods

2.1 Gear surveys

Gear surveys were made in Denmark and Sweden. The aims were to determine which gill net design parameters varied most between fishermen targeting Baltic cod and which of them were likely to have a significant effect upon selectivity or fishing power.

The Danish survey was restricted to fishermen from the island of Bornholm where the main part of the Danish Baltic cod gill net fleet is based. Contact was made with the local Fishermen's Association and net makers who recommended eight fishing skippers for interview. This group was said to give a cross-section of the island's different fleet sectors (by home port and vessel size). Information was collected by phone using a standard questionnaire on vessel dimensions, total length of nets used per set and the detailed specification of the individual nets' sheet netting, floatation and weighting. The data were entered into spreadsheets and the mean value and variation of key parameters assessed.

A more statistical approach was taken to selecting Swedish fishing vessel skippers for interview. A list of active gill net vessels landing in Swedish Baltic harbours was drawn up and vessels selected at random for study. A total of 46 skippers were interviewed by telephone using the same questionnaires as those used in Denmark.

2.2 Experimental design

The results of the two national gear surveys were collated. The two gill net design parameters (in addition to mesh size) that varied most between fishermen and were reputed to have a significant effect upon selectivity or fishing power, (Hamley 1975), were twine thickness and floatline hanging ratio.

Sea trials obtaining measurements of selectivity were to be made in Denmark and Sweden in the autumn and in the spring. It was hoped that the condition of the cod would differ at these two times of the year.

In order to determine the number and range of mesh sizes required, simulations were carried out using a Baltic cod population length frequency distribution obtained by the IMR research vessel Argos during a trawl survey and the selectivity curves reported in Anon 1997 for North Sea cod. It was found that 6 nominal mesh sizes from 70mm to 130mm, ideally increasing in geometric progression, should be sufficient. The specified nominal mesh sizes were therefore 70,79, 90, 101, 115 and 130mm.

The Danish tests were to compare two twines of different thickness giving 12 different experimental nets. Fleets could then be a typical commercial length of 12 nets - one net of each category arranged in random order.

The Swedish tests were to examine the effect of different hanging ratios on the floatline: 40%, 45%, 50% and 55%. It would be impossible at sea to conduct a full matrix experiment of 4 different hanging ratios and 6 different mesh sizes. It was decided for the first trials to have the 4 different hanging ratios in the smallest and largest mesh sizes only with the 4 intermediate mesh sizes having the standard hanging ratio of 50%. This also gave 12 different experimental nets.

It was found in the first trials that the catches in the Swedish 130mm nominal mesh size nets were very low. There was therefore insufficient contrast in the data to determine the effect of the different hanging ratios. The experimental design for the second trials was therefore changed and a simple comparison made of 40% and 50% hanging ratios in all 6 mesh sizes.

2.3 Experimental nets

A net manufacturer was found in Finland who was prepared to make sheet netting to order in different mesh sizes. The standard nets were made in 1.5*4 twine and in the Danish experiments the effect of using thicker 1.5*6 twine evaluated. Twine colour was orange.

The nets were all made to the same finished length of 65m on the floatline. The full stretched depth of the netting was 3.66m. The nets were constructed in accordance with the trials vessel skipper's normal commercial practice. There were two main differences between the Danish and the Swedish nets. The Danish nets had the leadlines made 14% longer than the floatline whereas the leadlines were only made 6.5% longer in the Swedish nets. The floatation on the Danish nets was in the form of plastic floats giving a buoyancy of 24g/m whereas the Swedish nets were fitted with a line with floats woven in giving a higher buoyancy of 33g/m. Each different net category (mesh size and twine thickness or hanging ratio combination) was colour coded to simplify identification on hauling and recording of catches.

Inside mesh sizes were measured by inserting a steel ruler and using light hand force to stretch the mesh. It was found that mesh sizes were not sensitive to increases in the tension used to stretch the mesh provided the tension was kept low. An increase in tension from 200g to 1kg only gave an increase in mesh size of 0.6% for 1.5*4 twine and 0.3% for the 1.5*6 twine. Mesh sizes were measured in the dry state before the first sea trials and at the end of the second trials. It was found that repeated soaking for periods of at least 12 hours increased mesh sizes by approximately 2.7%. The variability in the mesh size for a given net was extremely low. The difference in mean mesh size between nets of the same specification was extremely low for the Danish nets but up to 5mm for some of the Swedish nets.

Thickness of the twines used was measured optically by DIFTA by the light extinction method, (Ferro 1989). 10 measurements were taken for each twine sample, each at a position midway along a bar. 10 samples were taken for each twine. New 1.5*4 sheet netting was produced for the second Swedish trials period for the nominal 79mm, 90mm, 101mm and 115mm nets hung at 40% required after the change in experimental design. This was found to have a significantly different thickness compared to the original 1.5*4 twine. The measured twine thicknesses were:

1.5*4 twine	First production	0.26mm	(standard deviation 0.023)
1.5*4 twine	Second production	0.31mm	(standard deviation 0.016)
1.5*6 twine		0.36mm	(standard deviation 0.015)

The individual twine filaments were approximately 0.17mm in diameter for the first production of 1.5*4 twine, 0.20mm for the second production of 1.5*4 twine and 0.19mm for the 1.5*6.

The length of the floatline and leadline of each net were measured at the end of the trials in the dry state using a 20kg hanging weight to tension the line. Differences between nets were relatively small with the measured lengths varying by up to 2m. Mean floatline length of the Danish nets was 68.1m whereas the original specified length was 65m. This is equivalent to the hanging ratio increasing from 50% to 52%. Comparison with measurements taken before the trials revealed that this seemed to be partly due to the 20kg weight giving the line more tension than that applied when the netting was mounted to the line (using a sewing machine) and partly due to the lines stretching with use at sea. The mean length of the Swedish floatlines was 65.1m, very close to that specified.

The Danish leadlines had a mean length of 75.5m as opposed to the 74.1m specified. The leadlines were originally specified to be 14% longer than the floatlines but after use this had reduced to approximately 11%. The mean length of the Swedish leadlines was 67.6m which was significantly shorter than the specified 69.2m. The leadlines were therefore only 2.5% longer than the floatlines after use as opposed to the 6.5% originally specified.

2.4 Danish Trials Period 1

The 10.4m vessel R220 Britta was selected for the Danish trials. The first trials were carried out in the period 7-21 September 1997 using the harbour of Nexo, Bornholm, as a base. Only 5 of the 6 available net fleets were used because of bad weather giving a total net length of 3.9km. The vessel went out to haul, clean and reset the nets each morning, giving soak times of approximately 23 hours. 14 valid sets were completed.

The following measurements were made:

- length of all fish caught by net category (twine and mesh size)
- numbers of incidental by-catches of mammals and birds by net category
- ungutted weight of individuals for a sub-sample of the cod (in g)
- maxillary, gill and maximum soft body girths for a sub sample of the cod (in mm using a 1.7mm diameter polyethylene twine and 300g tension)
- method of capture (enmeshed behind the gills, enmeshed behind the maxillaries, entangled by the teeth or otherwise entangled) for a sub-sample of the cod.

Lengths were measured to the cm below except for the sub-samples where weight and girth were measured. Lengths were measured in mm for these fish. 0.5cm was added to the length of those fish measured to the cm below in all calculations.

The catches in a given net type and mesh size were pooled over all fleets used to the give the catch taken in a set by that net type and mesh size.

2.5 Swedish Trials Period 1

The 11.6m vessel SG 34 Najaden was selected for the Swedish trials. The first trials were carried out in the Sound of Hanoe in the period 12 September to 16 October 1997. The trials had to be stopped and restarted several times because of bad weather. All 7 available net fleets were used most days giving a total net length of 5.5km. 17 valid sets were completed. On one occasion the nets had to be left to soak for 3 days before hauling because of bad weather. Mean soak time was 21 hours for the other sets. The rigging of the fleets of nets was different to the Danish trials in that no anchors were used at the ends of the fleets. This rather unusual technique (from an international point of view) is in fact commonly used in Sweden.

The same measurements were made as in the Danish trials. In addition measurements were also obtained of the circumference of the main mark left by a mesh on the cod body for a sub-sample of those caught. These marks could be readily identified for cod that had been enmeshed behind the gills but not for cod enmeshed between the maxillae and the gills as these cod tended to have several different marks on them.

2.6 Danish trials period 2

The second trials were carried out in the period 14-28 April 1998. The same grounds were used. Weather was good throughout the trials. All 6 of the available fleets were used giving a total net length of 4.9km. 14 valid sets with soak times of just under 24 hours were completed.

Measurements made were the same as for the first trials except that weight, girths and method of capture were recorded for all cod caught on two of the sets.

2.7 Swedish trials period 2

The fishing took place between 18 April and 13 May 1998 again using the maximum available total net length of 5.5km. Fishing was concentrated in a much smaller area closer to the coastline than during the first sea trials. The weather was relatively calm and stable. 15 valid sets were obtained. Soak time was 20-25 hours for most sets but extended to 45-50 hours (as used by most commercial vessels at that time) for 3 sets.

Measurements taken were the same as for the first Swedish trials except that girths and method of capture were measured together for the same sub-sample of the cod.

2.8 Cod weight - length relationships

It is traditionally assumed that

$$\text{Weight} / \text{g} = \boldsymbol{k} * (\text{length} / \text{cm})^{\mathbf{b}}$$

where ***k*** is a constant and the power **b** is close to 3.0. Linear regressions were therefore made of log(weight) against log(length) such that **b** is given by the slope and ***k*** estimated by back transformation of the intercept. This relationship was then used to estimate catch weights by mesh size.

The above relationship is not very suitable for making comparisons between trials periods as ***k*** and **b** are strongly correlated so estimates of ***k*** and **b** tend to vary by quite large amounts between trials. Instead many authors set **b** to 3.0 and make a regression of weight against length cubed with ***k*** then being referred to as the condition factor. This procedure was also used and the condition factor estimate compared with that for other trials.

2.9 Cod girth - length relationships

Linear regressions were made of the girth measurements against length. Girth to length ratios were estimated even if the intercepts in the linear regressions were significant as these are more useful in interpreting modes of selectivity curves and making comparisons between trials periods.

2.10 Method of capture data

The data were condensed by converting fish lengths to transformed lengths by dividing by mesh size. This assumed that Baranov's principle of geometric similarity applied. The proportions of cod caught by the different methods of capture were calculated for chosen transformed length intervals and net category (twine thickness and hanging ratio).

Mesh penetration ratio was calculated for those cod in the Swedish trials with clear net marks left behind the gills.

MPR = mark circumference in mm/ mesh periphery in mm
where the mesh periphery is two times the inside mesh size.

Girth to mesh periphery ratios were calculated for the second Danish and Swedish trials data when girths and method of capture had been recorded for the same fish. For cod that had been enmeshed behind the gills or behind the maxillae

GPR = gill or maxillary girth in mm/ mesh periphery in mm

Linear regressions were then made of MPR and GPR against cod length to investigate if there was any evidence of large fish enmeshed in large mesh sizes stretching the meshes more than small fish enmeshed in small mesh sizes.

2.11 German sea trials

Three 10 days trials were carried out on board a commercial vessel in February 1997, November 1997 and February 1998. The nominal mesh sizes and corresponding twines tested were 100mm 1.5*3, 110mm 1.5*3, 120mm 1.5*4, 140mm 1.5*3 and 160mm 1.5*6. The nets were made in Bornholm, Denmark and were 500 meshes long, 20.5 meshes high, hung at 50% on floatline and had the leadline 15% longer than the floatline. Two fleets of 15 nets were used, each made up of 3 nets in one mesh size then three nets in the next mesh size etc.

2.12 Indirect analyses fitting selectivity curves by gear and trip

Several different functional forms for the selectivity curve were fitted to the catch data using the theory and procedures given in Holst et al. (1999). A bi-normal form previously used for estimating gill net selectivity for other demersal roundfish species, e.g. Greenland cod (Hovgård 1997), was found to give the most satisfactory fits.

The selectivity curves had 5 parameters and the following form:-

$$r_j(l) \propto \varphi(l, m_j, \alpha_1, \beta_1) + \omega * \varphi(l, m_j, \alpha_2, \beta_2)$$

where $$\varphi(l, m, \alpha, \beta) = \exp(-½*((l-\alpha * m)/(\beta * m))^2)$$

The j signify 2 normal distributions with modal values a_1 and a_2 and spreads b_1 and b_2 in principle describing the relative probabilities of cod being gilled and enmeshed behind their maxillae respectively. The parameter w was the efficiency of maxillary enmeshing relative to gilling. The relative selectivity was scaled such that maximum value was 1.0. These curves had the feature that they could be bimodal and that relative selectivity approaches zero for very small and very large fish (as one would expect). Entangling of cod by their teeth or by their fins were not specifically included so only two of the four possible catch processes identified were specifically described. The resultant selectivity curves were consistent with Baranov's principle of geometric similarity.

Estimates of the selectivity parameters and their variances were obtained for each set where the selectivity curve gave a satisfactory fit to the catch data. These were then combined to give parameter estimates for a gear and trials period using the same basic techniques described by Fryer (1991) for combining hauls when estimating codend selectivity. The between-set variation was modelled by assuming that the selectivity varied randomly between sets about a mean selectivity curve according to a multivariate normal distribution, see Holst et al. (1999). These techniques allowed realistic estimates to be made of the variances in the parameter estimates. It was then possible to examine if any of the parameters appeared to differ significantly between gears or trials periods. An estimate of the size distribution of the population contacting the nets was simultaneously obtained for each trials period and gear.

2.13 Direct analyses determining the effect of gear parameters

The analyses in the previous section were termed indirect because no use had been made of the fact that some gears were tested simultaneously and therefore subject to the same fish population. Direct analyses were then made where the fish population contacting unit length of the nets was constrained to be the same for the two different gear types tested within the same fleets. Fixed and random effects models of the type also described in Fryer (1991) were used. The controlled changes in the gear design were incorporated by allowing the mean selectivity curve to change with the gear design by giving offsets to those parameters where the indirect analysis indicated that there was a likely significant difference between gears. Random between-set variation was again modelled and taken into account, see Holst et al. (1999). The relative efficiency $\boldsymbol{q}$ of the non-standard nets (thicker 1.5*6 twine or 40% hanging ratio) was simultaneously estimated as was the length distribution of the population contacting the nets.

2.14 Fitting of an overall model of gill net selectivity

A final indirect analysis was made where a general random and fixed effects model of the gear selectivity was fitted simultaneously to the catches for all trials periods and gears. Trials period was treated as a random effect. The model had gear effect offsets to those selectivity curve parameters where the direct analyses had shown there was a significant effect for the non-standard gear in one or both trials periods, see Holst et al. 1999.

3. Results

3.1 Gear survey Denmark

The gear survey revealed that Danish Baltic Sea gill net vessels are typically small, under 15 GRT, have 1 or 2 crew members and operate a day fishery for cod where the nets are cleaned and reset every 24 hours. Approximately 5 km of nets are used per crew member. Only traditional single sheet gill nets are used mainly in multimono twine. Height varies between 2.7 and 4.6m. Mesh sizes range from 105mm to 200mm with 130mm most popular in 1997. Each net is 1000 meshes long. Twine thickness is generally increased with mesh size but the most popular mesh size is used in 3 different twine thicknesses 1.5*4, 1.5*5 and 1.5*6. Netting is available in a variety of different colours. This was said by the fishermen to have little if any effect upon performance. Floatlines are always hung at a hanging ratio of 0.5 (whereas Danish North Sea fishermen usually hang their cod nets at 0.38). Leadlines are made 10-16% longer. Floatlines now mainly have plastic floats attached (60-100g buoyancy each) but some smaller vessels still use floatlines with polystyrene floats woven in. Floatation varies between 18 and 43g/m. Leadline weighting is either 70 or 110g/m.

3.2 Gear survey Sweden

The gear survey revealed that Swedish Baltic Sea gill net vessels are also typically small, 73% being under 10 GRT. A vessel sets between 2 and 12 km of nets (average 5.8 km) increasing with vessel size. The netting materials and mesh sizes used are the same as in Denmark. Most fishermen use 3.7m high nets but heights up to 6m can be used. Each net is usually 2000 meshes long. Twine thickness is generally increased with mesh size, 1.5*4 is used by most fishermen using the most popular mesh size 120mm. There is considerable variation in the hanging of the nets. Floatlines are hung at hanging ratios of 0.38 to 0.52 (mean 0.45). Leadlines are made 1-13% longer (mean hanging ratio 0.47). Most fishermen use floatlines with the floats (traditionally polystyrene but now increasingly plastic) woven in. Floatation varies between 12 and 43g/m. Leadline weighting is usually 70 g/m.

3.3 Danish and Swedish sea trials

3.3.1 Total numbers of cod caught

Table 1. *The total numbers of cod caught by trials period, net type and mesh size.*

Trials	Twine	Hanging Ratio	70 mm	79 mm	90 mm	101 mm	115 mm	130 mm	Total
DK 1	1.5*4	50%	604	572	564	364	370	217	2691
DK1	1.5*6	50%	256	424	415	282	200	188	1765
SW1	1.5*4	55%	324					81	405
SW 1	1.5*4	50%	343	581	691	648	271	89	2623
SW1	1.5*4	45%	403					77	480
SW1	1.5*4	40%	459					80	539
DK2	1.5*4	50%	241	311	312	301	172	97	1434
DK2	1.5*6	50%	148	200	184	144	138	55	869
SW2	1.5*4	50%	1052	572	304	253	194	131	2506
SW2	1.5*4	40%	1227	387	261	215	177	160	2427

Total catch numbers in the second Danish trials were rather low, approximately half those of the first trials despite using one more fleet of nets, see table 1. The nets in thicker 1.5*6 twine tested in the Danish trials caught only approximately two-thirds the number in the standard nets. In the first Swedish trials catch numbers in the largest (nominal 130mm) mesh size were very low making it impossible to determine the effect of hanging ratio satisfactorily as this was only varied in the smallest and largest mesh sizes. It appeared that catch numbers increased with decreasing hanging ratio for the 70mm nets. The total catch numbers were very similar for the 40% and

50% hung nets in the second Swedish trials. It was noticeable, however, that the catch numbers in the nominal 70mm and 130mm nets hung at 40% were higher than those in the nets hung at 50% whereas in the intermediate mesh sizes the catches in the nets hung at 40% were lower. New netting had to be made for these intermediate mesh size nets hung at 40% so there is a suggestion that the relative fishing power of the new nets could have been lower than that of the original nets. Approximately half the total catch numbers in the second Swedish trials were in the smallest mesh size.

3.3.2 Cod length distributions

The length distributions of the total catches of cod in the standard nets were very different in the four trials periods. In the first trials periods the Danish catches peaked at 32cm length (1996 year-class) and then decreased steadily with length to a length of 55cm whereas the Swedish catches peaked sharply at 45cm (1995 year-class). There were more cod below 40cm and above 50cm in the Danish catches. In the second trials the Danish catches were primarily a mixture of 1995 and 1996 year-class fish in the interval 30-45cm whereas the Swedish catches were completely dominated by 1996 year-class individuals of 28-33cm. There were very few cod below 25cm or above 60 cm caught in any of the trials. There were clear differences in the age composition of the cod in the Bornholm and SW Sweden coastal areas.

Examination of the cod length distributions in the different mesh sizes showed clearly that the gill nets were highly size selective. The distributions were all unimodal except for the nominal 70mm nets in the first Swedish trials where they were bimodal. Peak length increased from approximately 30cm at nominal 70mm mesh size to over 50cm at nominal 130mm mesh size.

Table 2. *Mean cod lengths in cm for each net type and mesh size.*

Trials	Twine	Hanging Ratio	70 mm	79 mm	90 mm	101 mm	115 mm	130 mm
DK 1	1.5*4	50%	33.0	36.3	40.2	44.3	48.4	52.3
DK1	1.5*6	50%	31.8	35.5	39.3	43.9	50.7	53.5
SW1	1.5*4	55%	35.6					51.9
SW 1	1.5*4	50%	35.7	37.4	40.8	43.5	46.6	50.0
SW1	1.5*4	45%	36.1					52.0
SW1	1.5*4	40%	36.5					51.3
DK2	1.5*4	50%	32.9	35.4	40.3	43.8	48.7	53.1
DK2	1.5*6	50%	33.0	35.3	39.3	43.1	49.3	55.0
SW2	1.5*4	50%	31.2	34.9	40.9	44.0	47.2	50.9
SW2	1.5*4	40%	31.7	35.4	40.7	43.7	49.2	53.8

It can be seen in table 2 that the mean lengths of the cod caught in a given mesh size vary very little between gears or trials periods except possibly in the case of the smallest (nominal 70mm) mesh size.

3.3.3 By-catches

By-catch numbers were very low in all trials consisting mainly of flounder in the largest mesh sizes and some herring in the first Danish trials. Incidental by-catches of birds were two goldeneye, one guillemot and one cormorant. No sea mammals were caught.

3.3.4 Cod weight - length relationships

The first trials in both countries were carried out in September and October 1997 when cod were well fed and in post-spawning condition with gonad development at a minimum. The second trials were carried out in April and May 1998 when the cod were in fact found to be in a very similar condition. Very few individuals contained roe.

The weight - length relationships for ungutted cod in the four trials were rather different:

Denmark trials 1	$weight / g = 0.0164*(length / cm)^{2.863}$
Sweden trials 1	$weight / g = 0.0265*(length / cm)^{2.757}$
Denmark trials 2	$weight / g = 0.00779*(length / cm)^{3.061}$
Sweden trials 2	$weight / g = 0.00668*(length / cm)^{3.098}$

It should be noted in these formulae that length is exact and not rounded to the cm below.

Linear regressions assuming weight was proportional to length cubed gave the following estimates for the condition factor:

Denmark trials 1	0.00972 se 0.00008
Sweden trials 1	0.01009 se 0.00009
Denmark trials 2	0.00975 se 0.00007
Sweden trials 2	0.00978 se 0.00006

The cod appear to have been in slightly better condition or with sexual gonads slightly better developed in the first Swedish trials.

3.3.5 Cod catch rates

Mean catch rate of cod in numbers per net per set with the standard nets was 6.4 in the first Danish trials, 3.9 in the first Swedish trials, 2.8 in the second Danish trials and 4.1 in the second Swedish trials. Catch weights of cod above the 35cm minimum landing size were always highest in a mesh size above 100mm, table 3.

Table 3. *The catch weight of cod above the 35cm minimum landing size in kg per net per set.*

Trials	Twine	Hanging Ratio	70 mm	79 mm	90 mm	101 mm	115 mm	130 mm
DK 1	1.5*4	50%	1.2	2.8	5.3	4.6	6.1	4.6
DK1	1.5*6	50%	0.3	1.6	3.4	3.5	3.7	4.2
SW1	1.5*4	55%	1.0					1.1
SW 1	1.5*4	50%	1.2	2.7	4.7	5.2	2.6	1.1
SW1	1.5*4	45%	1.4					1.1
SW1	1.5*4	40%	1.8					1.1
DK2	1.5*4	50%	0.4	0.9	2.5	3.1	2.4	1.8
DK2	1.5*6	50%	0.2	0.5	1.3	1.4	2.0	1.1
SW2	1.5*4	50%	0.4	1.2	2.0	2.0	2.0	1.7
SW2	1.5*4	40%	0.7	0.9	1.6	1.6	2.1	2.5

3.3.6 Girth - length relationships

The linear regressions of cod girths against length gave intercepts that were small but significant, positive for the maxillary and negative for the gill and maximum soft body measurements.

Table 4. *Estimated girth to length ratios and standard errors for the four trials periods.*

Trials	Maxillary girth/length		Gill girth/length		Maximum girth/length	
	Ratio	St. error	Ratio	St. error	Ratio	St. error
DK 1	0.298	0.0019	0.479	0.0024	0.504	0.0030
SW 1	0.312	0.0012	0.476	0.0022	0.488	0.0024
DK 2	0.303	0.0019	0.484	0.0019	0.509	0.0028
SW 2	0.321	0.0019	0.481	0.0020	0.494	0.0041

As the condition factor was high in the first Swedish trials one would have expected that the maximum girth to length ratios would also be high but this was not the case, see table 4. The Swedish maxillary girth to length estimates were higher than the Danish ones. There did not appear to be any significant differences in girth to length ratios between the first and second trials periods.

One would expect that enmeshing directly behind the gills would occur when the mesh circumference approximately equals the gill girth. So for probability of gilling to be optimal:-

gill girth = meshsize*2.0
or gill girth to length ratio * length = mesh size*2.0
or transformed length = 2.0 / gill girth to length ratio.

From the above gill girth to length ratios this should occur at transformed lengths of about 4.2. Similarly enmeshing directly behind the maxillae should peak at transformed lengths somewhere in the range 6.2 to 6.7. Most cod under transformed length 4.0 should be small enough to squeeze through a mesh.

3.3.7 Method of capture

Classification into the different methods of capture was relatively easy despite the fact that the cod normally had penetrated the netting several times and were well and truly entangled in the netting. Gilled cod were characterised by having a series of meshes caught behind one or both sides of the gill covers, behind the ventral fins or behind the pectoral fins. Maxillary caught cod tended to have a large ball of netting behind the maxillae and the main part of the body was only loosely entangled in the netting.

The majority of the cod were in fact found to be gilled, 60-90% depending on trials period, see table 5. The measurements of the marks left by meshes on or behind the gills were on average approximately 6% larger than the mesh periphery. This was presumably due to a combination of the wet mesh size being 2.7% larger than the dry mesh size and the fish stretching the mesh or the mesh compressing the fish body. The girth to mesh periphery ratios showed that measurements of gill girths similarly underestimated the size of fish gilled by about 6%. Optimal transformed length for gilling can therefore be predicted to be approximately 4.2 + 6% i.e. 4.4 which corresponds well to mean transformed length of the gilled fish. Cod as small as 2.8 transformed length and as large as 6.6 were found to be gilled. There was little evidence of large fish gilled in large mesh sizes stretching the meshes more than smaller fish gilled in smaller mesh sizes (MPR and GPR were not strongly correlated to cod length).

A much smaller proportion of the total sample were caught by the maxillae, 10-26%, see table 6. The mean transformed lengths of the maxillary caught cod were much lower than the expected optimal value suggested by girth measurements taken directly behind the maxillae. For most trials periods and gears they were only about 10-20% higher than those of the gilled cod. Many of the maxillary caught cod were in fact small enough to have been gilled. In the first Swedish trials the mean transformed length of the maxillary caught cod was actually found to be less than that of the gilled cod. Mean GPR was only approximately 0.8 so in most cases either the cod must have been enmeshed at a position well behind the maxillae or the meshes holding the cod twisted up at the ends. In the Danish trials photographs were taken of some cod showing obvious mesh marks between the maxillae and gills. These were located well behind the maxillae, in fact a short distance behind the eyes where the gill covers met the underside of the cod. It appears that a wide size range of cod can be caught in this way from 2.4 to 7.7 on the transformed length scale.

Some cod were entangled by their teeth without being enmeshed, up to 15% of the total number caught, table 7. None were caught this way on the days the Danish method of capture measurements were taken but some small cod were observed caught in this way on other days during the first Danish trials. It appears that both large and small cod can be caught in this way.

Few cod were otherwise entangled, up to 5% of the total caught, table 8. Most of these were relatively large fish.

Table 5. *Data for cod that were found to be gilled.*

Gilled cod	DK1 1.5*4 50%HR	DK1 1.5*6 50%HR	SW1 1.5*4 50%HR	DK2 1.5*4 50%HR	DK2 1.5*6 50%HR	SW2 1.5*4 50%HR	SW2 1.5*4 40%HR
Number	127	101	61	129	64	55	77
Proportion total %	84	89	61	88	86	68	75
Mean transf. length	4.43	4.34	4.63	4.41	4.32	4.54	4.52
Range	2.9-5.6	3.6-5.8	3.9-6.3	3.6-5.6	3.7-4.9	2.8-6.6	3.8-6.0
Mean MPR			1.07			1.05	
Range			0.9-1.6				
Mean GPR				1.05	1.04	1.08	1.07
Range				0.83-1.4	0.84-1.2	0.6-1.6	0.9-1.4

Table 6. *Data for cod that were enmeshed behind the maxillaries.*

Maxillary enmeshed cod	DK1 1.5*4 50%HR	DK1 1.5*6 50%HR	SW1 1.5*4 50%HR	DK2 1.5*4 50%HR	DK2 1.5*6 50%HR	SW2 1.5*4 50%HR	SW2 1.5*4 40%HR
Number	18	11	21	17	10	21	13
Proportion total %	12	10	21	12	14	26	13
Mean transf. length	5.77	5.19	4.57	5.02	4.90	5.14	5.04
Range	4.5-7.4	3.8-6.5	2.4-7.7	4.2-7.1	4.3-6.3	3.5-6.9	3.9-6.2
Mean GPR				0.77	0.75	0.82	0.81
Range				0.60-1.2	0.64-1.0	0.6-1.1	0.6-1.0

Table 7. *Data for cod that were entangled by their teeth only.*

Teeth caught cod	DK1 1.5*4 50%HR	DK1 1.5*6 50%HR	SW1 1.5*4 50%HR	DK2 1.5*4 50%HR	DK2 1.5*6 50%HR	SW2 1.5*4 50%HR	SW2 1.5*4 40%HR
Number	0	0	15	0	0	4	12
Proportion total %	0	0	15	0	0	5	12
Mean transf. length			3.35			3.58	4.41
Range			2.0-6.3			2.3-4.2	3.1-6.8

***Table 8.** Data for the cod that were otherwise entangled.*

Entangled cod	DK1 1.5*4 50%HR	DK1 1.5*6 50%HR	SW1 1.5*4 50%HR	DK2 1.5*4 50%HR	DK2 1.5*6 50%HR	SW2 1.5*4 50%HR	SW2 1.5*4 40%HR
Number	7	1	3	1	0	1	1
Proportion total %	5	1	3	1	0	1	1
Mean transf. length	5.44	4.60	5.37	6.4		7.2	7.5
Range	4.1-10.2		4.4-6.8				

The dependence of method of capture upon cod length is shown in table 9. Most cod caught which had a transformed length between 3.5 and 5.0 were gilled. The proportion of cod caught by the maxillae was high for transformed lengths above 5. The results for the standard nets summed over all 4 trials periods are given in figure 1. There appeared to be little effect of twine thickness or hanging ratio upon method of capture.

***Table 9.** Proportion of a length class caught by the different methods of capture.*

Transf. length band	Method of capture	DK1 1.5*4 50%HR	DK1 1.5*6 50%HR	SW1 1.5*4 50%HR	DK2 1.5*4 50%HR	DK2 1.5*6 50%HR	SW2 1.5*4 50%HR	SW2 1.5*4 40%HR
3.5-4.0	Gilled	100%	95%	60%	100%	100%	0%	75%
	Maxillae	0%	5%	20%	0%	0%	75%	25%
	Teeth	0%	0%	20%	0%	0%	25%	0%
	Entangled	0%	0%	0%	0%	0%	0%	0%
4.0-4.5	Gilled	96%	96%	81%	94%	92%	90%	84%
	Maxillae	1%	4%	6%	6%	8%	3%	7%
	Teeth	0%	0%	11%	0%	0%	7%	9%
	Entangled	3%	0%	3%	0%	0%	0%	0%
4.5-5.0	Gilled	88%	91%	65%	89%	77%	77%	87%
	Maxillae	6%	6%	31%	11%	23%	23%	5%
	Teeth	0%	0%	0%	0%	0%	0%	8%
	Entangled	6%	3%	4%	0%	0%	0%	0%
>5.0	Gilled	18%	45%	60%	38%	0%	31%	33%
	Maxillae	76%	55%	30%	54%	100%	62%	47%
	Teeth	0%	0%	5%	0%	0%	0%	13%
	Entangled	6%	0%	5%	8%	0%	6%	7%

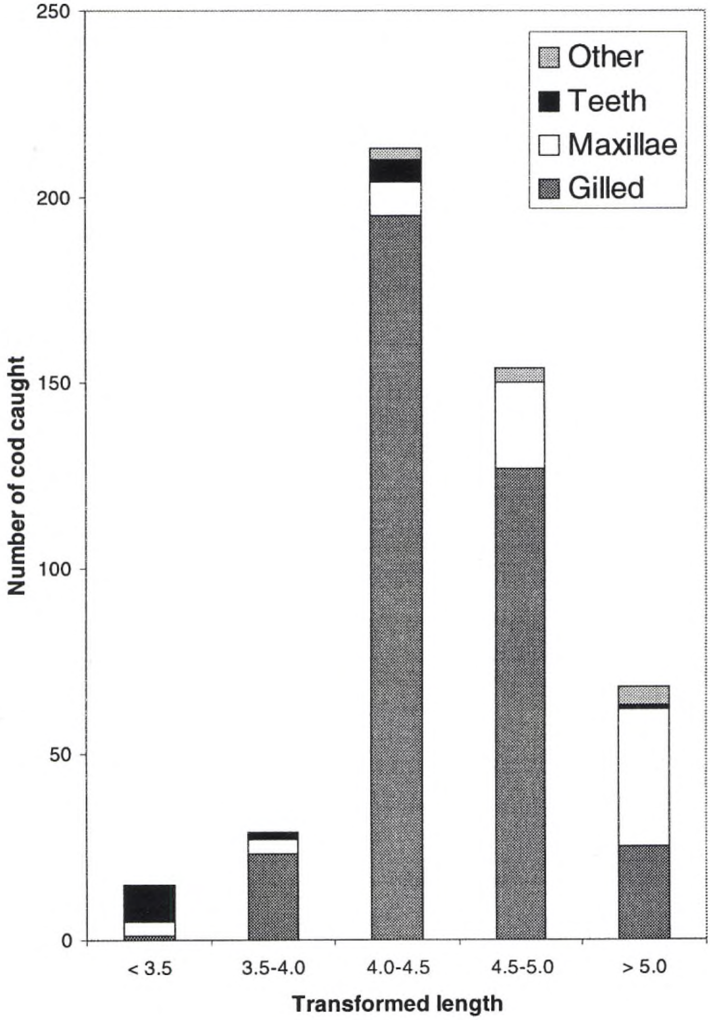

Figure 1. *Numbers of Baltic cod caught by the 4 different methods of capture: gilled, enmeshed between the maxillae and start of the gill covers, entangled with netting caught in the teeth or otherwise entangled. Data are for subsamples of the cod caught in the standard gill nets hung by 50% on the floatline in 1.5*4 twine. Transformed length is cod length cm / mesh size cm.*

3.4 Fitting of selectivity curves by gear and trip

Table 10 gives the estimated parameter mean values when analysing the different net designs and trials periods individually and when taking between set variability into account.

Table 10. *Estimated mean values of the selectivity curve parameters for each gear and trip.*

Trials	DK1	DK1	SW1	DK2	DK2	SW2	SW2
Twine	1.5*4	1.5*6	1.5*4	1.5*4	1.5*6	1.5*4	1.5*4
Hanging	50%	50%	50%	50%	50%	50%	40%
Sets included	11	13	14	14	13	12	12
Sets rejected	3	1	3	0	1	3	3
α_1	4.46	4.36	4.48	4.35	4.34	4.47	4.52
β_1	0.272	0.290	0.263	0.262	0.263	0.250	0.281
α_2	5.67	5.47	6.04	5.51	6.06	5.84	5.83
β_2	1.41	1.03	1.23	0.80	0.345	1.26	0.95
ω	0.131	0.093	0.163	0.087	0.120	0.125	0.100
Scaling factor	0.917	0.950	0.932	0.971	1.000	0.935	0.963
tl_{100}	4.46	4.36	4.48	4.36	4.34	4.47	4.53

tl_{100} is the transformed length at which retention rate is a maximum and differs little from the a**1** estimate. The scaling factor makes the relative retention rate 1.0 at this transformed length.

The primary modal length to mesh size ratios (a**1**) were in the range 4.34 to 4.52, in good agreement with the girth measurements and Swedish mesh mark (mesh penetration ratio) measurements. The a**1** estimates appear to fall into 2 groups, those around 4.35 and those around 4.5. The spread of the distribution associated with gilling b**1** was very narrow and that associated with maxillae enmeshing b**2** very wide in all but one case. This indicated that the first distribution described those cod that were perfectly gilled in the classical manner and the second all cod that were caught in any other way. The estimated efficiency of the second mode of capture compared to gilling, w, was very low in all cases and in the range 8.7 –13.1%.

There is no obvious dependence of the selectivity parameters upon gear design or season. The low a**1** estimate for the second Danish trials period with the 1.5*4 twine does not fit in with the observation that might otherwise be made of a**1** being about 4.5 for the 1.5*4 twine and 4.35 for the 1.5*6 twine.

The mean selectivity curves for each gear and trials period are shown in figure 2. It can be seen that they were in fact unimodal in most cases despite the use of two normal distributions in the functional form of the selectivity curves. Relative selectivity decreased rapidly towards zero as transformed length decreased from the modal value. Relative selectivity also decreased rapidly as transformed length increased beyond the modal value but towards a value of 0.1 from which it then decreased slowly as transformed length increased further.

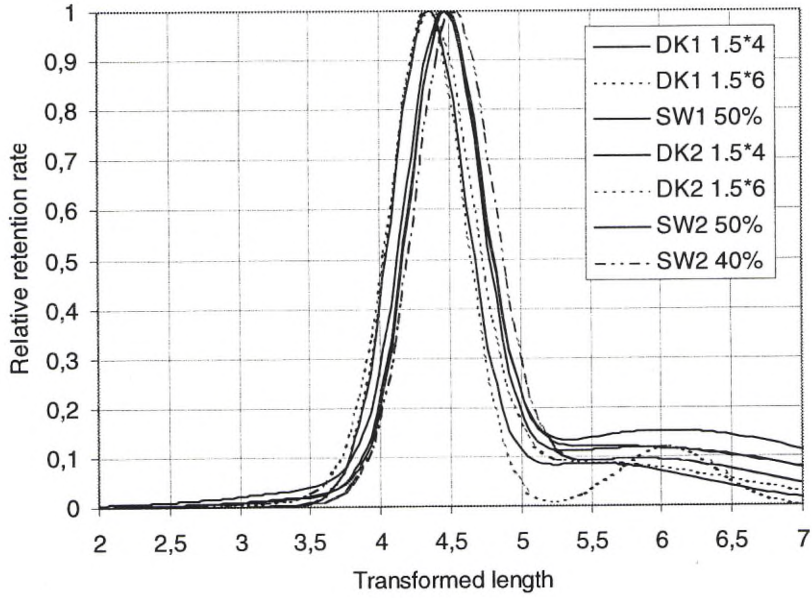

Figure 2. *Baltic cod size selection curves for each gill net design and trials period. The standard nets were hung by 50% and of 1.5*4 twine. DK1, DK2, SW1 and SW2 = Danish and Swedish trials periods 1 and 2, respectively. 1.5*6 signifies nets hung by 50% but in thicker 1.5*6 twine. 40% signifies nets in 1.5*4 twine hung more slackly at 40% on the floatline. Retention rates are given relative to that of modal length cod for each net design and trials period. Transformed length is cod length cm/mesh size cm.*

3.5 Differences in selectivity between the Danish and Swedish trials

In order to test if differences between selectivity parameters estimates for the standard nets in the Danish and Swedish trials were significant, selectivity models were fitted to the Danish and Swedish catch data simultaneously. It was found that for the first (autumn) trials there was a significant difference (at a 5% level of significance) between the estimates of a**2** only. For the second (spring) trials period the only significant difference was instead in the location of the primary mode a**1**.

3.6 Effect of twine thickness

The parameter estimates given by the direct analysis of the effect of twine thickness are given in table 11 (after deletion of insignificant terms). Fewer sets of data have to be rejected compared to the indirect analyses.

Table 11. *Effect of twine thickness on the selectivity and efficiency parameter estimates.*

Twine	1.5*4	1.5*6	1.5*4	1.5*6
Trials	DK1		DK2	
Sets included	13		13	
Sets rejected	1		1	
α_1	4.46	4.37	4.35	
β_1	0.283		0.266	
α_2	5.52		6.05	
β_2	1.27		1.14	0.67
ω	0.127	0.084	0.092	
Scaling factor	0.918	0.947	0.971	0.996
tl_{100}	4.46	4.37	4.36	
Twine relative efficiency *q*	1.000	0.705	1.000	0.641

The relative efficiency of the thicker 1.5*6 twine was estimated to be 70% of that of the 1.5*4 twine in the first trials period and 64% in the second trials. These figures are slightly higher than those given by simple comparisons of the total catch numbers with the two twines. Twine thickness appeared to have significant effects on different selectivity parameters for the two sets of trials so the difference in selectivity due to twine thickness was not consistent between the two trials periods.

3.7 Effect of hanging ratio

The direct analysis of the effect of hanging ratio in the second Swedish trials revealed that the only significant effect upon the size selectivity parameters was upon the spread of the secondary mode, table 12. The resultant change to the selectivity curve is minimal. There was no significant difference in efficiency for the nets hung by 50% and those hung by 40%.

Table 12. *Effect of hanging ratio on the selectivity and efficiency parameter estimates.*

Hanging Ratio	50%	40%
Trials	SW2	
Sets included	15	
Sets rejected	0	
α_1	4.50	
β_1	0.259	
α_2	5.90	
β_2	1.35	1.20
ω	0.098	
Scaling factor	0.946	0.953
tl_{100}	4.50	
Twine relative efficiency q	1.000	

3.8 Overall model of gill net selectivity

The indirect analysis where an overall model of selectivity was fitted simultaneously to all 7 data sets generated the parameter estimates given in table 13.

***Table 13.** Selectivity curve parameter estimates given by the overall model.*

Twine	1.5*4	1.5*4	1.5*6
Hanging ratio	50%	40%	50%
Sets included	51	12	26
Sets rejected	9	3	2
α_1	4.45	4.51	4.35
β_1	0.265		
α_2	5.92		
β_2	1.23		0.72
ω	0.137		
Scaling factor	0.937	0.934	0.987
tl_{100}	4.46	4.52	4.35

Both twine thickness and hanging ratio had significant effects upon the location of the primary mode. The resultant selectivity curves for the 3 gears are shown in figure 3. It should be noted that the relatively small changes in the a**1** estimates can give quite large changes in relative retention rate for a given length of cod because the selectivity curves are so steep. For example relative retention rate for a 40cm cod in a 100mm mesh size is predicted to be 25% with 1.5*4 twine but 42% with 1.5*6 twine. It has to be remembered that these two retention rates are measured relative to two very different things – the retention of modal length cod (44.6cm) in 1.5*4 twine and the retention of modal length cod (43.5cm) in 1.5*6 twine.

Combining the effects of efficiency and relative size selectivity is shown in figure 4. If retention rates are instead all measured relative to that of the modal length cod in the standard nets, then retention rates were rather similar for cod well below modal length. The relative retention rate for 40cm cod in 100mm mesh size and 1.5*6 twine then becomes 28%.

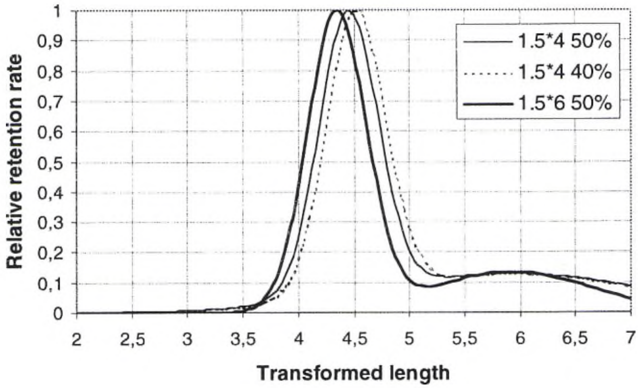

Figure 3. *Baltic cod size selection curves for three different gill net designs (different combinations of twine thickness and hanging ratios of floatlines) derived from the overall model of selectivity obtained by fitting to the catch data for all four sea trials simultaneously. Retention rates are given relative to that of modal length cod in each net design. Transformed length is the cod length cm/mesh size cm.*

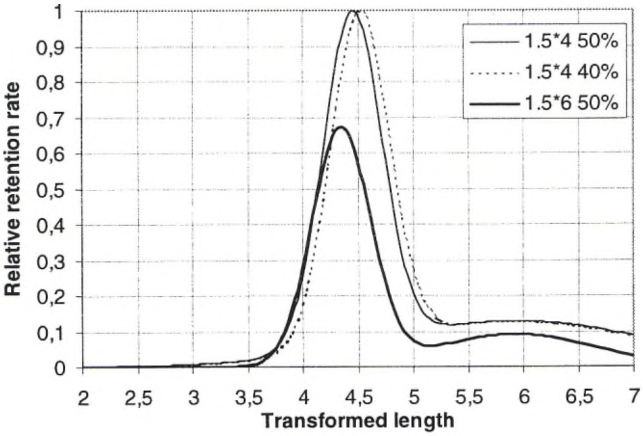

Figure 4. *Relative retention rates of Baltic cod in 3 different gill net designs with different hanging ratios or twine thickness. Retention rates are given relative to that of modal length cod in the standard nets made in 1.5*4 twine hung by 50% on the floatline. Transformed length is the cod length cm/mesh size cm.*

3.9 Selectivity in the German gill net experiments

Catch numbers in the German experiments were generally rather low and it was impossible to fit a selectivity curve for many of the sets. The catch data were therefore pooled by trials period. The resultant parameter estimates are given in table 14.

Table 14. *The selectivity parameter estimates for the German gill net experiments.*

Trials	Feb 1997	Nov 1997	Feb 1998
α_1	4.38	4.52	4.36
β_1	0.316	0.342	0.320
α_2	5.35	5.64	5.74
β_2	1.01	1.77	1.26
ω	0.372	0.231	0.324
Scaling factor	0.808	0.841	0.849
tl_{100}	4.41	4.53	4.37

The efficiency of secondary methods of capture w was higher than in the Danish and Swedish trials. The other parameter estimates were rather similar to those obtained in the Danish and Swedish trials. A possible seasonal effect was indicated with the location of the primary gilling mode a**1** being higher in November than February.

4. Discussion

4.1 Effect of twine thickness

4.1.1 Effect on efficiency and fishing power

Hamley (1975) stated in his review that "nets of thinner twine can catch many times more fish" and this is widely reported by fishermen. It was therefore anticipated that the efficiency of the 1.5*6 twine would be less than that of the 1.5*4 twine but it was somewhat surprising to find the estimated relative efficiency (or fishing power) as low as 0.64-0.70. One wonders how high the absolute selectivity of gill nets for modal length fish actually is and also whether the efficiency of all mesh sizes has in fact been the same when the same twine thickness has been used for each mesh size. The increase in twine thickness found for the second production of 1.5*4 netting must certainly have affected the catches for the intermediate mesh size nets hung at 40%. An attempt was in fact made to model the effects of both twine thickness and hanging ratio upon netting efficiency for the nets hung at 40% hanging ratio in the second Swedish trials. This was unsuccessful due to the problems of lack of contrast in the data and high between set variability in the parameter estimates.

In the modelling it was assumed that the efficiency of all mesh sizes had been the same when the same twine thickness was used for each mesh size. Baranov (1948) suggested instead that twine thickness should be made proportional to mesh size in order to have equal efficiency for the different mesh sizes. Twine thickness should be approximately proportional to the square root of the number of filaments. This suggests that if 1.5*4 is used for 100mm mesh size then 1.5*2 should be used for 70mm and 1.5*7 for 130mm. A model was used to test whether or not efficiency had increased with mesh size. It was assumed that efficiency was proportional to mesh size to the power **k**. If efficiency is unchanged when using the same twine for each mesh size (as assumed in the current analyses) then **k** should have a value close to zero. The model was fitted by set for the gears and trials periods when twine thickness was the same for all mesh sizes. It was found that the **k** estimates were equally distributed either side of zero and significantly different to zero in only five of the 88 cases. The assumption made appears to be well justified for these catch data.

4.1.2 Effect on size selectivity

Hamley (1975) suggested that "nets of thinner twine are less visible, easier to stretch, and more flexible; therefore, they should tangle more fish and catch larger fish". The overall selectivity model predicted that the modal lengths of cod in the 1.5*4 nets were in fact higher than in the 1.5*6 nets so it could be said that the thinner twine basically caught larger fish. In the first Danish trials the 1.5*4 nets only caught 27 cod under transformed length 3.0 whereas the 1.5*4 nets caught 116 giving a relative efficiency for very small cod (which were mainly entangled by their teeth) of 0.23, much less than the efficiency for modal length cod. This suggests that the thinner twine did in fact have a high efficiency of entangling cod compared to the thicker twine.

The higher w estimates obtained in the German trials could possibly be due to the fact that twine thickness was basically increased with mesh size. If one considers the size class of cod that is optimal for gilling in a given mesh size, e.g. 57cm cod in 130mm mesh, then the same size of cod should be found maxillae enmeshed in a smaller mesh size, e.g. 100mm mesh size for 57cm cod. If a thinner twine is used for the smaller mesh size, as it was in the German trials, then the number maxillae enmeshed should increase and hence the w estimate. It was first suspected that the difference found might have been a result of pooling the catch data over all sets but when the Danish and Swedish catch data were pooled there was little change to the selectivity parameter estimates.

4.2 Effect of hanging ratio

4.2.1 Effect on size selectivity

Hamley (1975) states that “loosely hung nets tangle more fish”. It could therefore be expected that size selectivity would change with hanging ratio, the spreads of the normal distributions increasing with decreasing hanging ratio. This was not found here but the results could have been affected by the problem that the twine thickness was not the same for all mesh sizes.

4.2.2 Effect on efficiency and fishing power

It is suspected that if account could have been taken of the different twine thicknesses used in the intermediate mesh size nets hung by 40%, then hanging ratio would be found to have an effect, but principally upon the efficiency of the netting materials rather than their size selectivity. Catch numbers clearly increased with decreasing hanging ratio in the 70mm nets of 4 different hanging ratios tested in the first Swedish trials. There appeared to be little difference in the length composition of the cod catches for these nets.

Commercial nets are usually made a fixed number of meshes long irrespective of mesh size. Nets hung at 40% would therefore be 20% shorter on the floatline than nets hung at 50%. Their relative efficiency would have to be 25% higher in order to have the same fishing power.

4.3 Comparison of gillnet and trawl selectivity curves

A database held at DIFTA of recent measurements of codend selectivity for Baltic cod gives a mean selection factor (= 50% retention length / mesh size) of 2.97 and a selection ratio (= (75% retention length – 25% retention length) / mesh size) of 0.73 for standard diamond mesh codends. The corresponding selectivity curve for the minimum legal codend mesh size of 120mm is shown in figure 5 in comparison with the selectivity curves for gill nets of 105mm (the current legal minimum) and 120mm wet mesh sizes, 1.5*4 twine and 50% hanging ratio (using the overall model selectivity parameters).

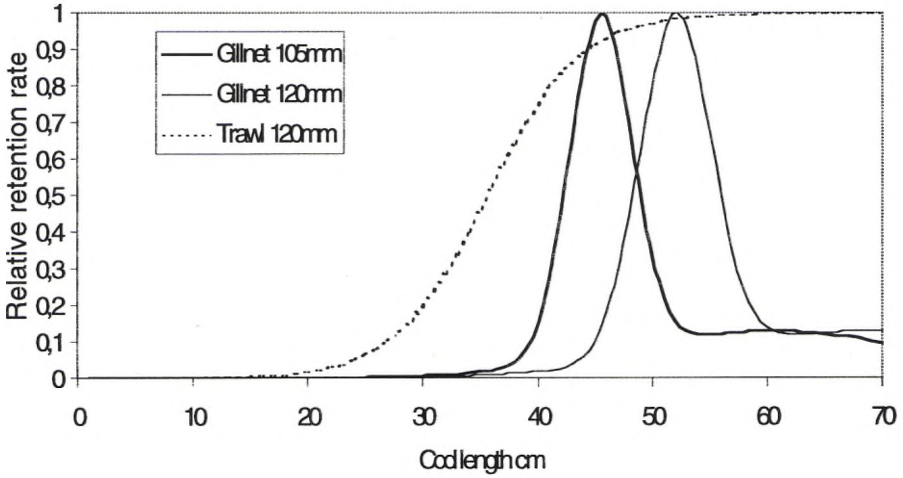

Figure 5. Comparisons of selection curves for gillnets and trawls.

Table 15. *Comparison of the relative retention lengths and retention rates for trawl codends and gillnets.*

Gear	Trawl codend	Gillnet	Gillnet
Wet mesh size mm	120mm	105mm	120mm
25% retention length cm	31.3	40.9	46.7
50% retention length cm	35.6	42.3	48.3
75% retention length cm	40.0	43.5	49.7
Rel. retention rate for 35cm cod	46.0%	1.7%	0.8%
Rel. retention rate for 38cm cod	64.4%	4.5%	1.2%

It is immediately clear that gillnets are much more size selective than trawls. The current minimum landing size is 35cm for Baltic cod. It has often been stated that this should correspond to the 25% retention length at the minimum legal mesh size. It can be seen in table 15 that the relative retention rate for 35cm cod is in fact much higher (46%) for a 120mm codend but less than 2% for a 105mm gillnet. The 25% retention length would correspond to the minimum landing size for a 90mm gillnet. The stated biological aim for the Baltic cod fisheries is for gears to have a 50% retention length of 38cm. It appears that most 120mm standard codends will not meet this requirement but a 95mm mesh size gillnet would. Gillnets of over 105mm mesh size catch 38cm cod extremely inefficiently, relative retention rates are less than 5%.

Retention lengths are estimated to be approximately 1-1.2cm less if thicker 1.5*6 twine is used in the gillnets. This will not significantly change the nature of the main observations made above.

5. Conclusions

A model of the size selectivity of Baltic cod gillnets has been obtained covering mesh sizes up to 130mm, the normal range of twine thickness used and the normal range of hanging ratios used. The assumption was made that the efficiency of catching cod of modal length was unchanged when the same twine thickness was used for each mesh size. If this is found to be false then the model will have to be revised.

Twine thickness and hanging ratio have relatively little effect upon the size selectivity of. Baltic cod gillnets. Twine thickness has a substantial effect upon their fishing power.

A gillnet of the minimum legal mesh size of 105mm has much better size selection characteristics for Baltic cod than a diamond mesh codend of the minimum legal mesh size of 120mm.

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Statistical Modelling and Analysis of Gill Net Size Selectivity Data

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Abstract

General aspects of modelling and estimating gill net size selectivity are presented. The SELECT model constitutes the basis for analysing individual sets with the gears. The model is adapted to the experimental conditions when two gears are fished on the same population and to allow for modelling different fishing powers of the two gears. It is demonstrated how the selectivity parameters are estimated and that Fryers model of between-set variance can also be used for gillnet selectivity data. These models were developed in relation to experiments with gillnet cod fishery in the Baltic Sea.

Key Words: size selectivity, gill net, SELECT model, Fryer's model, Baltic cod

Introduction

This report contains the statistical modelling and analysis of the experiments conducted within the project "Size selectivity and relative fishing power of Baltic cod gillnets". Further background on the project and the data, which are used in this manuscript, can be found in the final report of the project "Size selectivity and relative fishing power of Baltic Cod gill nets".

Materials and Methods

The SELECT model (Millar, 1992) forms the basis for the statistical analysis of the experiments conducted within this project. The method has gained general acknowledgement as the standard method for estimating selectivity parameters of all fishing gears. In its general form the SELECT model is described within the framework of generalized linear models (McCullagh and Nelder, 1989). Millar and Holst (1997) detailed the SELECT method for gillnet selectivity experiments and demonstrated how a number of uni-modal selection curves reduced the model to a log-linear case. It has, however, become evident that uni-modal selectivity curves only provide satisfactory fits in a very few cases. Hence the model has been amended with more flexible ogives.

Modelling of the catching process

Experiments with gillnets differ from those with towed gears by the lack of non-selective data. It can, therefore, be difficult to distinguish between potential candidates for the selectivity curves from empirical data. This affects the modelling and statistical analysis.

A typical set-up consists of deploying a number of different mesh sizes $m_1, m_2, \ldots, m_J.$ The fish caught are measured by length and classified into a number of length groups. These are typically chosen to be of 1-cm length intervals with half centimetre at midpoints. The *random variable* measuring the catch of length l fish in the *j'th* mesh size is denoted by $C_{l,j.}$ The corresponding *observed* catch is denoted by $c_{l,j}$. This number can be regarded as a product of the relative abundance (population) l_l of fish at length l, the probability for a fish of this length class to be retained in the *j'th* mesh size and a factor $\mathbf{f_j=e_j*q_j}$ combining the effort (e_j) and the efficiency (q_j) for this net.

The relative abundance of length l_l??fish is proportional to the (unobserved) number of length l? fish that contact the combined gear. The retention rate or selectivity for the *j'th* mesh size is denoted by $r_j(l)$ It is convenient to choose the $r_j(\cdot)$'s to be members of a common parametric family $r_j(\cdot;\theta)$ where θ denotes a vector of parameters. For the selectivity of a gillnet these are believed to have some sort of bell-shaped form, either uni-modal or multi-modal.

Standard statistical theory models count data as observations from a Poisson process. It is therefore natural to assume that the number of fish N_l that contact the gear is Poisson distributed with rate l_l. A general statistical result (Feller, 1968) then implies that

$$\textbf{(1)} \qquad C_{lj} \sim Po(\lambda_l \cdot f_j \cdot r_j(l))$$

The log-likelihood function (minus a constant) is then given by

$$\sum_{l,j} c_{lj} \cdot \log(\lambda_l \cdot f_j \cdot s_j(l;\theta)) - \lambda_l \cdot f_j \cdot r_j(l;\theta)$$

The ML estimate $\hat{\theta}$ is the value of θ which maximises the log-likelihood function. In addition to the parameters of interest, the maximisation also provides estimates of the l_l's.

Variants of this model can be used for direct modelling of the difference between two types of gear. Details are given in a section below where this approach is used for estimating the effect of the gear parameters of interest.

The Choice of Selectivity Curve

One of the most common choices for the selectivity curve has been the normal scale. The widespread use of this curve is closely related to the popularity of the Holt-method (1963). The fitting procedure in this method is directly derived from the functional form of the normal scale function. Another frequently used curve is the skew-normal, which reflects the belief that the selectivity curve is asymmetric (Regier & Robson, 1966). None of these methods are however rigorous statistical methods and provide no information about the statistical properties of the estimates.

Although little is known about the actual interaction of fish with the nets, the *principle of geometrical similarity* (Baranov, 1948) seems to have been adopted as a common basis in many estimation approaches. The principle states that the selection of a fish only depends on the ratio of the mesh perimeter to that of the fish. Fish girths are approximately proportional to their lengths. For the statistical model this can then be formulated as

$$l_{0j} = \alpha \cdot m_j \quad \textbf{and} \quad \sigma_j = \beta \cdot m_j$$

for some parameters a and b. Here l_{0j} and σ_j are the modal length and spread respectively for the selectivity curve of the *j'th* mesh size.

Kirkwood and Walker (1986) used a model similar to the one presented here, assuming the same underlying Poisson error structure. They used, however, gamma selectivity curves with fixed spreads, which do not fully observe the principle of geometrical similarity. Subsequent fitting to their data with selectivity curves observing the principle did however provide less good fits. Hence Baranov's principle of geometrical similarity (Baranov, 1948) can not be regarded as universally valid, but may depend on the species *etc*.

For the current experiments a number of selectivity curves have been assessed within the framework of the method presented above. These include different uni-modal curves and uni-modal curves declining to different constants at the ends of the two limbs. The latter was used in a former project (Anon 1997) on gillnet selectivity for North Sea cod. The mixture of two normal scales appeared, however, to provide a better overall fit to the data from the Baltic Sea.

$$\begin{aligned} r_j(l;\theta) &\propto \varphi_1(l) + \omega \cdot \varphi_2(l) \\ &= exp\left(-\frac{(l-\alpha_1 \cdot m_j)^2}{2(\beta_1 \cdot m_j)^2}\right) + \omega \cdot exp\left(-\frac{(l-\alpha_2 \cdot m_j)^2}{2(\beta_2 \cdot m_j)^2}\right) \end{aligned}$$

The use of mixtures of distributions is a common statistical technique when data are generated from different processes or composed of different populations (Hand, D. J. & B. S. Everitt, 1981). For the present use the mixture appears natural as the different components can be interpreted as separate catch processes or as a primary catch process plus a component accounting for all other catch processes. A certain interpretation cannot be imposed on the selection curves but must be derived through inspection of the data. Removing observations with a low length/mesh-size ratio had a substantial effect on the second component. This indicates that the primary mode describes the selectivity of the most predominant catch process (gilling) whereas the second mode covers all other catch processes. It could thus be argued that a proper description should involve three or more components. It appeared, however, that the data did not contain sufficient information to properly separate the different catch-processes into more than "caught-by-gilling" and "caught-otherwise".

Multiple Sets

Two aspects are of concern when several sets are made with a series of nets of different designs and used for inference on the selectivity:

1. Random effects such as the between-set variation
2. The effect of different types of gear upon the selectivity and the efficiency

It has become common practice in trawl gear selectivity studies to estimate the between-haul variation separately from the within-haul variance (the binomial error). Fryer (1991) demonstrated that neglecting the between-haul variation could lead to severe under estimation of the variance of the parameters and thus result in unrealistic narrow confidence intervals. The same argument applies to gillnet selectivity, although it has not yet, (to our knowledge), been used in this context. In addition to the extraction of the between-set variation into a separate component, the model enables testing for the effect of variables of interest. Furthermore proper estimates of the variances are necessary for assessing the power of the experiments. The benefits of this approach are at the expense of dropping sets with sparse data, i.e. those sets that do not allow for the estimation of an individual selectivity curve.

Originally the technique was described for a two parameter selectivity curve and was based on a more general method known as the Laird-Ware method (Laird, N.M. & J.H. Ware, 1982). It is, however, readily extended to arbitrary dimensions and can also be amended to include other random effects.

The model is applicable to normally distributed data under some mild assumptions. The asymptotic behaviour of the maximum likelihood estimates is well known and justifies that selectivity estimates from the individual sets can be regarded as normally distributed (Lehman, 1983) provided enough fish are observed in all length classes and all mesh sizes.

The core idea is to assume that the selectivity curves from the individual sets vary around a common mean selectivity curve, given by a parameter vector $\boldsymbol{\theta}_i = \boldsymbol{X}_i \cdot \boldsymbol{\alpha}$ according to multivariate normal distribution. Here $\boldsymbol{X}_i$ is a design matrix for the fixed effects of the *i'th set.* $\boldsymbol{X}_i$ may for instance be used to model differences between two or more types of gear.

The estimated parameter vector $\hat{\boldsymbol{\theta}}_i$ from the *i'th set* is given by

$$\hat{\boldsymbol{\theta}}_i = \underbrace{\boldsymbol{X}_i \cdot \boldsymbol{\alpha}}_{\text{Fixed Term}} + \underbrace{\boldsymbol{Z}_i \cdot \boldsymbol{b}_i}_{\text{Random Term}} + \underbrace{\boldsymbol{\varepsilon}_i}_{\text{Error}}$$

Here $\varepsilon_i \sim N_{\mathrm{n}}(0, R_i)$ Within - Set Variation

$b_i \sim N_{\mathrm{m}}(0, D)$ Between - Set Variation

$\boldsymbol{X}_i$ and $\boldsymbol{Z}_i$ are the design matrices for the fixed and random effects respectively. $\boldsymbol{X}_i$ links the parameter a for the mean curve to the parameter $\boldsymbol{\theta}_i$ of the *i'th* set. The random deviation of *i'th* set from the mean curve is given by $\boldsymbol{b}_i$. The $\boldsymbol{b}_i$'s can thus be regarded as some kind of residuals at the trip level.

The model is fitted via the E-M algorithm (Dempster *et. al., 1977).* The algorithm is very stable in finding maximum values, but can be extremely slow depending on the numbers of subjects (sets), the dimension of the problem, the ratio of within- to between set variances and their structures. This is normally not a problem for trawl data, which typically operates with only 2 parameters. For the present case, however, the parameter vectors are 5 dimensional and convergence to a tolerance level of 1E-8 required in the order of 40,000 iterations. Standard software packages (e.g. Splus) appeared to be inappropriate for this purpose and it was therefore necessary to build customised software. A typical run with this program took between 15 and 30 hours on a Pentium 150 MHz computer.

In order to identify the effect of the gear parameters on the selectivity and the efficiency of the nets, the analysis must include all data within a given set simultaneously. Each of the two gear parameters (twine size and hanging ratio) tested in the study, contain only two levels and they were tested in separate experiments. Hence the difference between the standard and the non-standard nets can be modelled as offsets to the individual parameters plus a parameter accounting for the relative efficiency. This results, however, in a very high number of parameters (5 for the standard net + 5 offsets for the non-standard net + an efficiency parameter) to be estimated for each set. Estimation in this model is likely to be unstable and may also result in different parameterisations between the sets (different significance patterns). As an intermediate step, significant parameters (including offsets and efficiency) were identified by an *indirect* approach using the Laird-Ware model. We call this approach indirect, because the differences between the standard and the non-standard nets are not part of the initial model, but only assessed by the subsequent analysis. The advantage of this approach is that significant effects are easily identified. A drawback of the indirect approach is that it fails to recognise the common population contacting the two nets, fished within the same sets. No assumptions are made on the populations contacting the two gear types. This is clearly not valid for nets that were deployed at the same time and on the same fishing grounds. It was a reasonable approach, however, for reducing the dimension of the parameter space, because a ten-parameter model would be practically impossible to estimate. Furthermore it cannot be used for estimation of the relative efficiency between the nets.

After the number of parameters had been reduced by the method described above, the parameters were estimated by a *direct* approach, in which the selectivity curves for the two gear types were estimated jointly. The key argument is that the l_l parameters in formula (1) model the same abundance of fish for both gear types, because they were deployed simultaneously and at the same locations. These parameters are not of direct interest, but are implicitly estimated. The new model was built to perform a joint estimation of the selectivity for both levels of the gear parameters. Differences were specified by offsets to the relevant parameters for the standard nets (Twine thickness 1.5*4, hanging ratio 50%).

By way of example, the indirect analysis of the Swedish 1998 trials indicated that hanging ratio only affected the spread of the secondary mode. A direct modelling of this effect in the selectivity function is thus given by

$$r_{jk}(l;\theta) \propto e^{-\frac{(l-\alpha_1 \cdot m_j)^2}{2(\beta_1 \cdot m_j)^2}} + \omega \cdot e^{-\frac{(l-\alpha_2 \cdot m_j)^2}{2((\beta_2+\delta_{\beta_2} \cdot T_k)m_j)^2}}$$

where $k=1,2$ indexes the gear type and

$$T_k = \begin{cases} \mathbf{0} \text{ for HR} = 50\% \\ \mathbf{1} \text{ for HR} = 40\% \end{cases}$$

The relative fishing efficiency was introduced by modelling the mean catch as

$$E_\theta(C_{\ell jk}) = \begin{cases} \lambda_l \cdot p_{jk} \cdot r_{jk}(l;\theta) & \textbf{for HR} = \mathbf{50\%} \\ \lambda_l \cdot p_{jk} \cdot q \cdot r_{jk}(l;\theta) & \textbf{for HR} = \mathbf{40\%} \end{cases}$$

$j=1,\ldots 6$ and $k=1,2$. Here $\boldsymbol{q}$ models the efficiency of the non-standard net relative to that of the standard net.

Finally a mean curve was estimated for each experiment, which accounted for the between-set variation, but included parameters for modelling the efficiency and the difference between the two types of nets.

The analysis for the Danish experiments with twine size were completely analogous, except that twine thickness had a different impact on the selectivity parameters. There could also be differences in the impact pattern between the two trials.

Overall Model – Including all trials

An overall model, which included data from all four trials, was built. The model aims only at modelling how various settings of the gear parameters affect the selectivity. Some of the individual analyses above did also include parameters for the relative efficiency between two levels within the same gear parameter (twine thickness or hanging ratio). This was only possible because the experiments with the two levels had been conducted simultaneously and on the same fish population. This is no longer the case for a model where data were collected in different experiments.

In addition to the gear parameters, the experimental data now also include different (two) levels of a trials period factor and two different countries. The differences in selectivity, observed between these different experimental units, are not of particular interest themselves. Although the difference in selectivity between the two trial periods can, to some extent, be given reasonable biological and environmental interpretations, it is more natural to regard the seasonal variation as a random effect. In this perspective the two trials periods are considered to be picked at random from an infinite universe of possible periods. Likewise the two countries used boats which can be considered as randomly chosen representatives from a very large population of gillnet vessels operating in this fishery.

The statistical model can therefore be described by

$$\hat{\boldsymbol{\theta}}_{thpci} = \boldsymbol{\theta} + \boldsymbol{\alpha}_{th} + \boldsymbol{\varepsilon}_{p} + \boldsymbol{\varepsilon}_{c} + \boldsymbol{\varepsilon}_{pci} + \boldsymbol{\varepsilon}_{pci}$$

where θ is the mean selectivity, α_{th} is the effect of using twine thickness *t* and hanging ratio *h*. Here ε_{p}, ε_{c} and ε_{pci} are the random effects associated with trials period p, with country c and with set *i* within period p and country c respectively. The within-set variation of the *i'th* set within period *p* and country c is given by ε_{pci}.

An advantage of this approach is that the estimated selectivity parameters along with the estimated effects of the gear parameters are based on a much larger data set. The extraction of variance components for the variation between trial periods and countries has the purpose of ensuring more realistic estimates of the variability within each experimental unit.

Furthermore it quantifies the variation between levels of these factors. As the two random factors only have two levels each, it makes little sense to make separate inference about these random effects.

The major drawback of the model is the inability to model relative efficiencies. The model also does not utilise the inherent information on the fish population related to the pair-wise deployment of both twine thicknesses and both hanging ratios within the trips.

Population index

The number of length *l* fish,?which get in contact with the combined gear, is denoted by 1_l. Although this parameter is often not of primary interest, it is part of the model and is implicitly estimated along with the selectivity parameters. This also means that each length class, containing a sufficient number of fish, costs one degree of freedom. The validity of the index and proper circumstances, under which it can be used, will not be discussed here.

The ML-estimate of the population index is given by

$$\hat{\lambda}_l = \frac{\sum_j c_{l,j}}{\sum_j f_j s_j(l,\theta)}$$

After obtaining an estimate $\hat{\theta}$ for θPopulation, catch and selectivity are highly confounded by the model and the estimates of the selectivity and the population can only be determined up to a constant. Population and selectivity for a given length class cannot be determined absolutely. In the present study the selectivity is, by specification, defined to attain a maximum height of 1.0[1] In order to reflect that the index should only be interpreted on a relative scale, it should afterwards be scaled to unit height.

At extreme length classes the total estimated selectivity can be very low. This results in unrealistic high estimates of the population index. When this coincides with low catches, the population estimates for these length classes should be ignored.

[1] Alternatively the efficiency may be assumed dependent on the mesh size, in which case the heights of the selectivity curves may vary. See Wulf (1986) for an interesting approach.

Results

Seven experiments were conducted in total, details on each experiment are given in table I.

Table I. *Details on seven conducted experiments*

Time	Country	Twine Size	Hanging Ratio	No of Sets
Sep. 1997	DK	1.5*4	50%	14
Sep. 1997	DK	1.5*6	50%	14
Sep-Oct. 1997	S	1.5*4	50%	17
April 1998	DK	1.5*4	50%	14
April 1998	DK	1.5*6	50%	14
April-May 1998	S	1.5*4	50%	15
April-May 1998	S	1.5*4	40%	15

All experiments were initially analysed separately. Catch length frequency plots by mesh size (fig. 1) for the experiments and plots for the total catch by year and experiment (fig. 2) show similar patterns between experiments within country and year, but different structures between years and between countries. The dynamics and exploitation of the stocks naturally explain the differences between the two trial periods. The difference between the Danish and Swedish catches indicates that the two countries conducted their trials on different populations of cod. All sets within each experiment were fitted individually to obtain selectivity curves by sets. Each fit was assessed by examination of the deviance statistic and the residual patterns. Sets that gave poor or meaningless fits, were not included in the subsequent analysis. Only 1-3 sets had to be rejected from each of the 7 experiments. Inspection of the catch tables for those sets that were rejected showed they had low catches and thus carried relatively little information. Table II lists the (REML-) mean primary modes on a transformed length scale and 95% confidence intervals estimated from the individual trials. This and similar information for the other parameters are depicted in figure 3 and gives a first assessment of potential significant differences in selectivity between the experimental units (countries, periods and gear parameters).

***Table II.** Primary modes and 95% confidence intervals of the seven trials.*

Experiment			Primary mode	95% Conf. Interval	
Country	Twine Size	Hanging Ratio		Lo	Hi
DK	1.5*4	50%	4.457	4.429	4.486
DK	1.5*6	50%	4.361	4.330	4.392
S	1.5*4	50%	4.475	4.448	4.503
DK	1.5*4	50%	4.351	4.311	4.391
DK	1.5*6	50%	4.337	4.299	4.376
S	1.5*4	50%	4.470	4.440	4.499
S	1.5*4	40%	4.525	4.478	4.571

Next, a preliminary assessment was made of the influence of the gear parameters on the individual selectivity parameters, by an *indirect* analysis for each experiment. The purpose of this was to reduce the dimension of the model, before data were analysed in the *direct* approach (See the "materials and methods" section above for further details)

The catch from a particular set depends partly on the net features (the selectivity and the efficiency) and partly on the availability of fish at the particular time and location of the set. Due to these confounding, inference about the relative efficiency between two gear specifications can only be drawn from sets where the nets have been fished simultaneously on the same fishing grounds. Effectively this means that we cannot compare the efficiency between the Swedish and the Danish experiments. Likewise comparison of the relative efficiency between the Danish 1997 and 1998 experiments can only be done by a direct comparison of the estimated efficiency parameters.

The results from comparisons between relevant experiments by year are listed in the following sections. In addition to modelling within each experiment a comparison is made between Swedish and Danish experiments with standard nets (50% hanging ratio and twine thickness 1.5*4) for each of the two trial periods. The "country"-effect is nested within year. This has been dealt with in an ad-hoc manner, as the theory for this is not elaborated.

Finally the results from an overall-analysis including all experiments are given in the last section. The results from this analysis should however be regarded with some caution, because not all combinations of all factors has been tested (Twine thickness 1.5*6 have only been tested in combination with HR 50%).

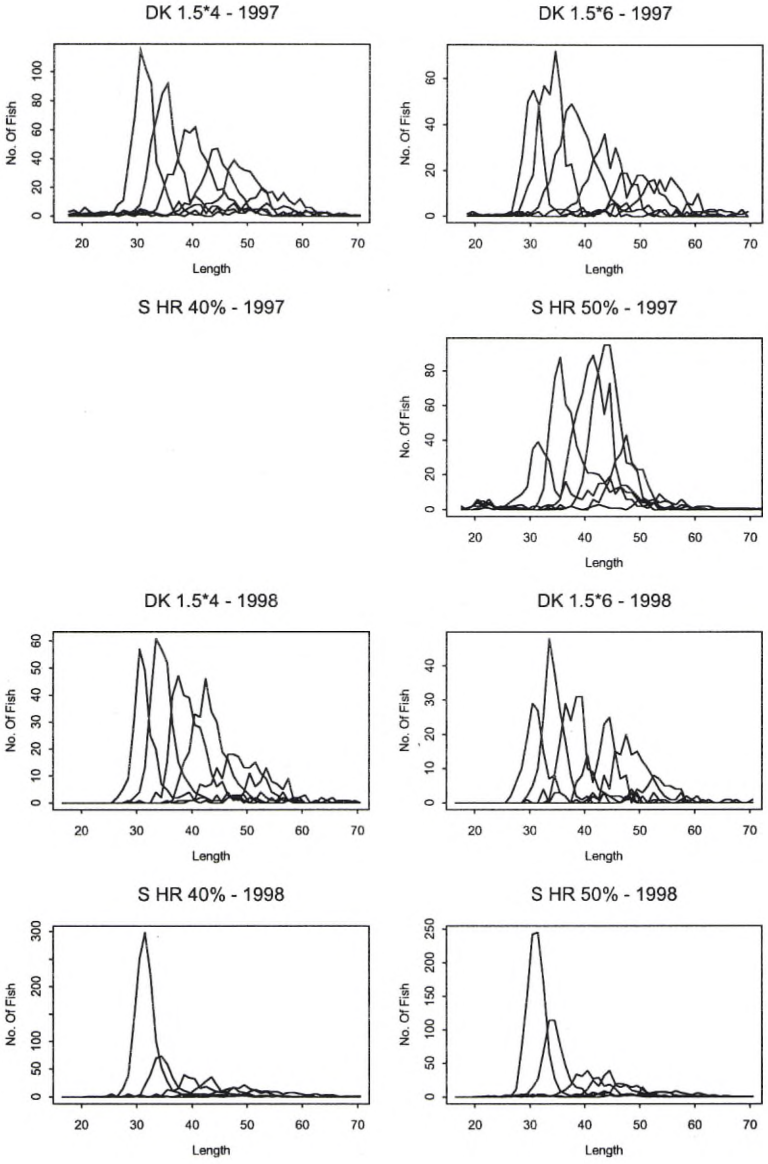


Figure 1. *Length frequencies of total catch by mesh size for each of the seven trials.*

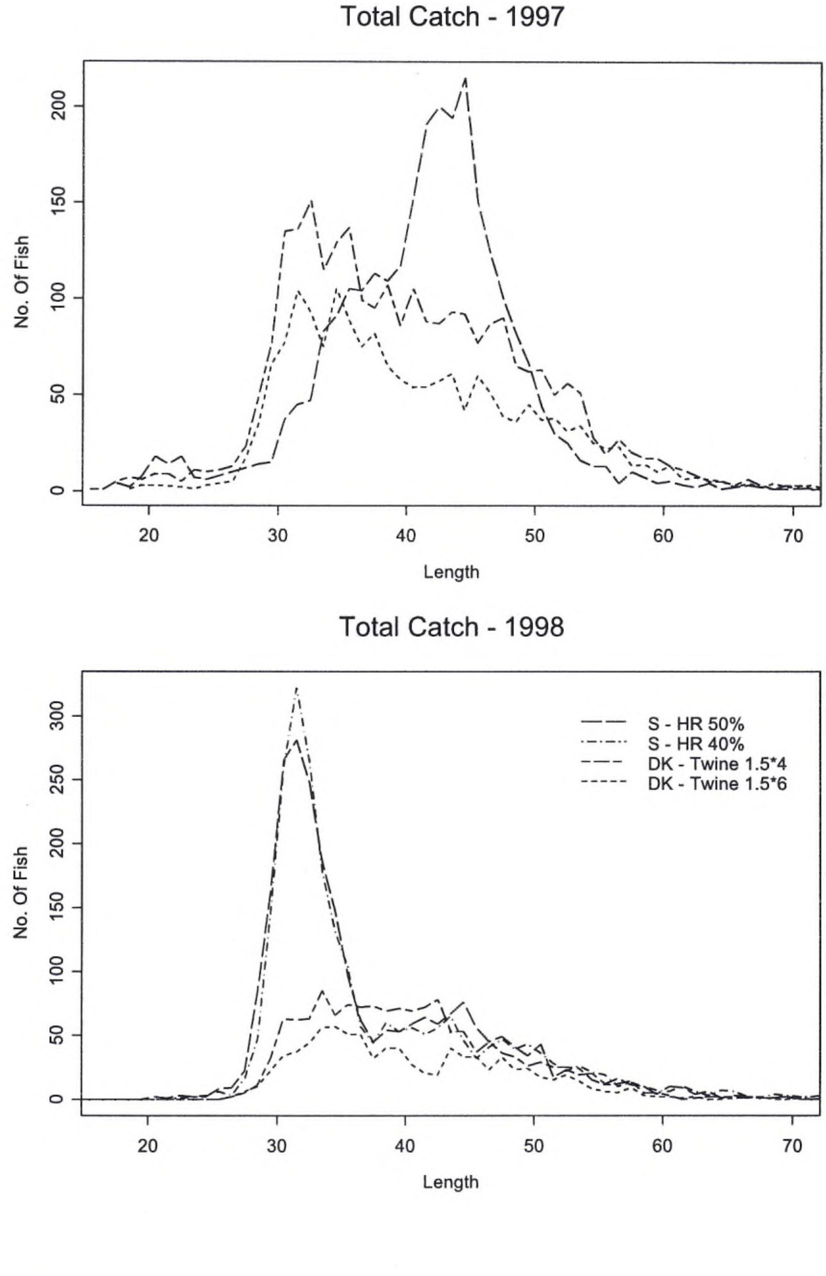


Figure 2. *Length frequencies of total catch in all nets by experiment for both trial periods.*

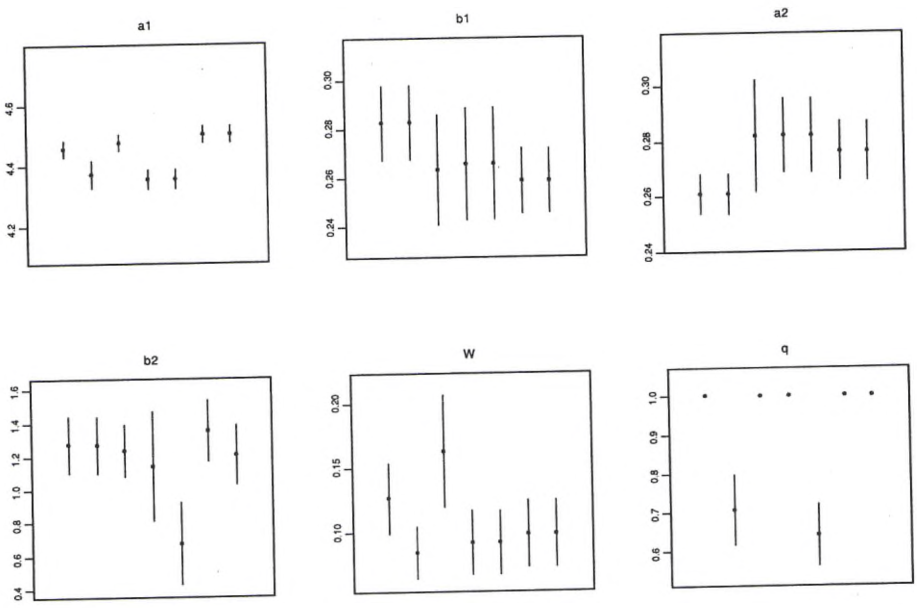


Figure 3. *Confidence intervals for all parameters and all trials. Trials listed from left to right: DK 4 97, DK 6 97, S 50 97, DK 4 98, DK 6 98, S 50 98, S 40 98.*

1997 Experiments

It is of interest to compare the Danish experiments with twine thickness 1.5*4 with the Swedish experiments with 50% hanging ratio as well as analyses for the individual experiments. The net specifications for these two experiments were virtually identical and consistent with the standard nets used in the commercial fishery in the Baltic Sea.

Results from the separate analyses of the individual experiments in the first trials period are given in tables 1-9.

*Danish experiments with twine thicknesses 1.5*4 and 1.5*6*

The data obtained from the Danish 1997 trials, where two different twine thicknesses were tested, were compared in a Laird-Ware analysis, after the initial fitting of selectivity curves by individual sets and level of twine thickness. For each of the five parameters defining the selectivity curves, the difference between the two types of gear was modelled by an offset. The model was reduced in a number of steps until all parameters (and offsets) showed significance. From the indirect analysis, only differences in the location of the primary mode and height of the secondary mode could be detected. This comprised the *indirect* analysis.

This model plus an additional efficiency parameter was next estimated in the *direct* approach. The selectivity parameters stayed almost unchanged. The efficiency of the twine 1.5*6 was estimated to be 70.5% relative to the 1.5*4 net. The location of the primary mode on a transformed length scale were estimated to be 4.46 and 4.37 for the 1.5*4 and the 1.5*6 nets respectively. Because the selectivity curve is so steep the change in retention rates for a given fish length can be very large. For fish at transformed length of 4.1 for example, the retention rate changes from 43% to 64%. There is, however, little change (only about 1 cm.) in the fish length for a given retention rate.

The results from the estimation of this model were very similar to the results from the indirect analysis. Selectivity curves from individual sets and for the mean curves are plotted in figure 4. Estimates and covariance matrices are found in tables 10-12.

Swedish experiments

The only hanging ratio that was tested in a sufficient number of mesh sizes was (the standard) 50%. The Swedish nets with hanging ratios other than 50% did not provide sufficient information for making valid inference and comparisons.

The location of the primary mode for the 50% hung net was estimated to be 4.48. Selectivity curves estimated from individual sets and the mean selectivity curve are plotted in figure 5.

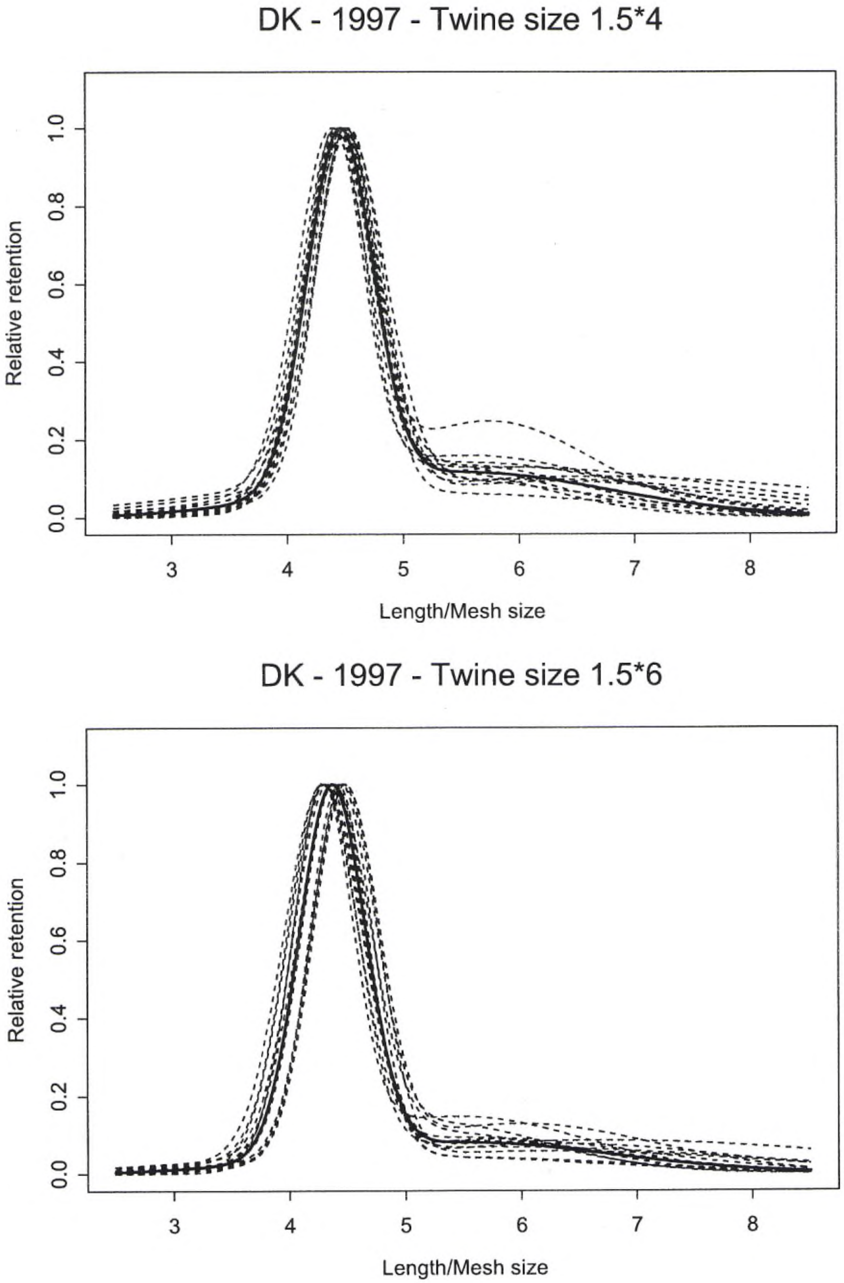


Figure 4. *Selectivity curves from the Danish 1997 experiments. Curves estimated from individual sets (dashed lines) and the mean selectivity curve (solid line).*

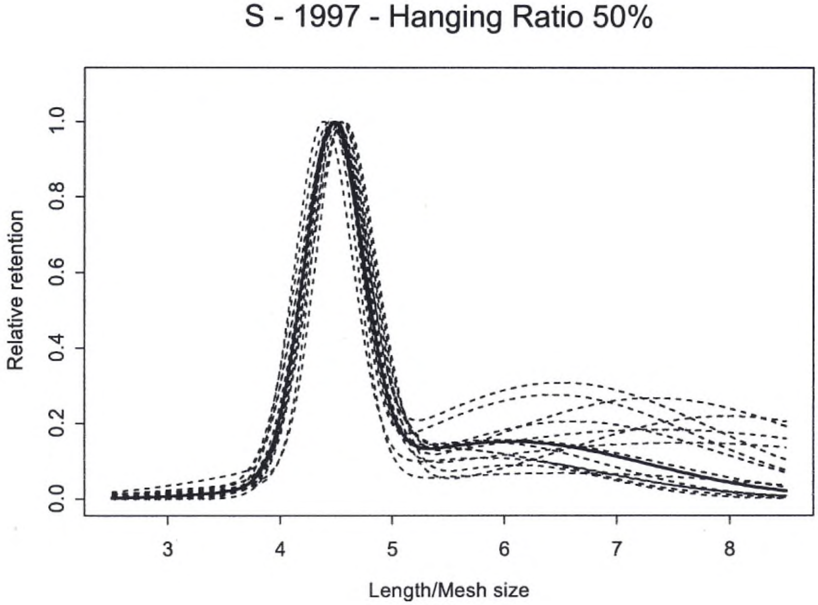


Figure 5. *Selectivity curves from the Swedish 1997 experiment. Curves estimated from individual sets (dashed lines) and the mean selectivity curve (solid line).*

1998 Experiments

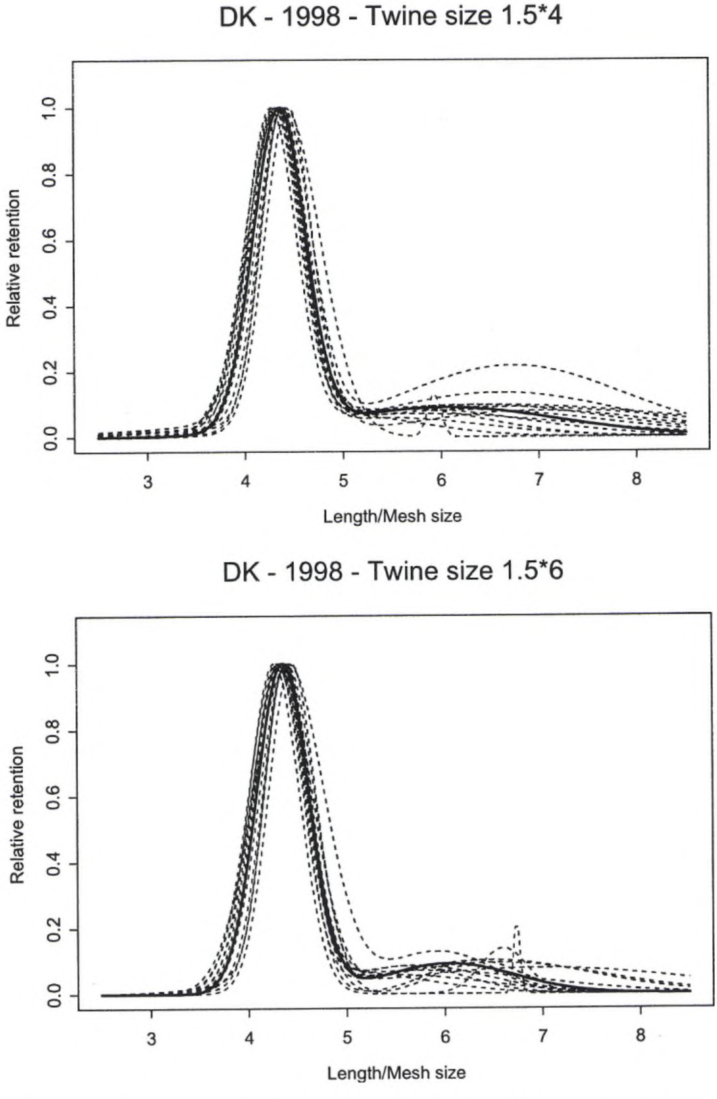
Results from the separate analyses of the individual experiments are given in tables 13-24. For the 1998 trials three comparison are of interest, namely comparisons of the Danish 1.5*4 and 1.5*6 experiments, the Swedish 40% hanging ratio and the 50% hanging ratio experiments and a comparison of the Danish and Swedish experiments with the standard nets.

*Danish experiments with twine thicknesses 1.5*4 and 1.5*6*

The indirect analysis indicated potential differences in three of the parameters: Location, spread and height of the second mode. The direct analysis revealed, however, difference in the spread of the second mode only. Again, the difference in selectivity was negligible for practical purposes.

The common primary mode for the two twine thicknesses was estimated to be 4.35. This is a little lower than that estimated from the 1997 experiments, particularly for the 1.5*4 net.

The relative efficiency between the two was also estimated to be slightly lower (q=0,6412, table 25) for the 1998 experiments compared to the 1997 experiments (q=0,7054, table 10). See figure 6 for plots of the selectivity curves. Tables 26-27 give the between-set variation and estimated covariance of the parameters estimates respectively.



DK - 1998 - Twine size 1.5*4

DK - 1998 - Twine size 1.5*6

***Figure 6.** Selectivity curves from the Danish 1998 experiment. Curves estimated from individual sets (dashed lines) and the mean selectivity curve (solid line).*

Swedish experiments with 50% and 40% hanging ratios

In the indirect analysis, the only detectable difference was in the spread of the second mode where the spread of the second mode for the 50% hung nets was about 24% wider than that of the 40% hung nets. The direct analysis reduced the difference to about 13%, but shifted the location of the second mode to the right. No difference in efficiency could be detected between the two hanging ratios. A new run with equal efficiencies estimated a common primary mode of 4.50 and the spread of the primary mode to be 0.259 (table 28). The primary mode is slightly higher than the primary mode estimated from the Danish 1998 trials, whereas the spread is a little smaller. The selectivity curves (individual and mean) are plotted in figure 7. Estimates of covariance between sets and for the parameter estimates are given in table 29 and table 30 respectively.

Mean curves for each experiment are plotted by country and trials period in figure 8. These plots compare the variation in selectivity over the gear parameters within each experimental unit given by country and trials period.

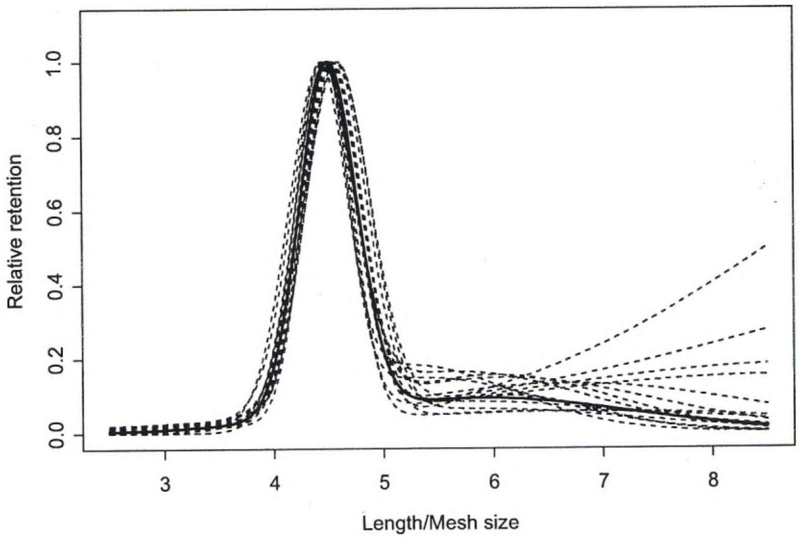
Comparison of the Danish and the Swedish experiments with standard nets

The Danish 1997 experiments with the 1.5*4 twine thickness were compared to the Swedish 1997 experiments with the 50% hanging ratio. The gears used in these experiments had virtually identical specifications and differed only by their experimental entity.

The only difference that could be detected in the Laird-Ware analysis was in the location of the second mode. In practice the difference in selectivity is negligible, as can be seen from the plots of the selectivity curves (fig. 9). This is partly due to the high value of the spread of the second mode, giving a very flat and wide second mode. The small variances of the parameters allow for the detection of very small differences. The estimates of the heights of the second mode have relatively high variances and the apparent difference between them is insignificant.

From this analysis the primary mode was estimated to be 4.47, which is consistent with the separate analyses reported above.

S - 1998 - Hanging Ratio 50%



S - 1998 - Hanging Ratio 40%

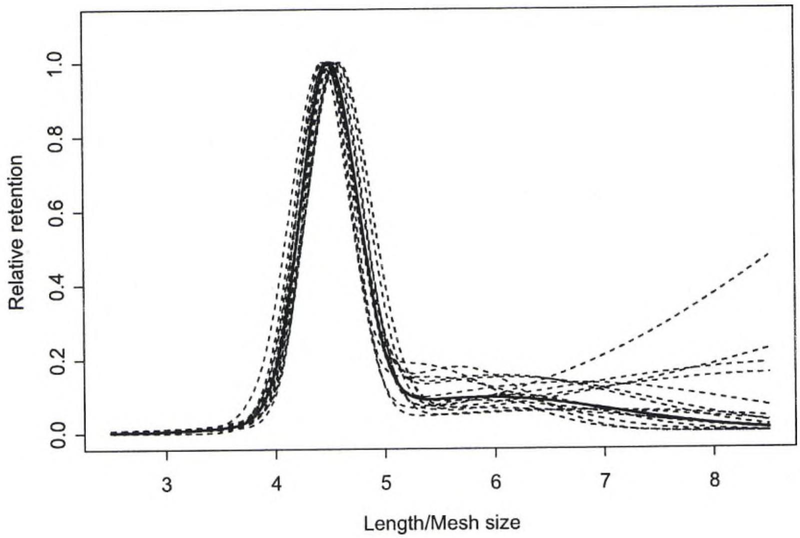
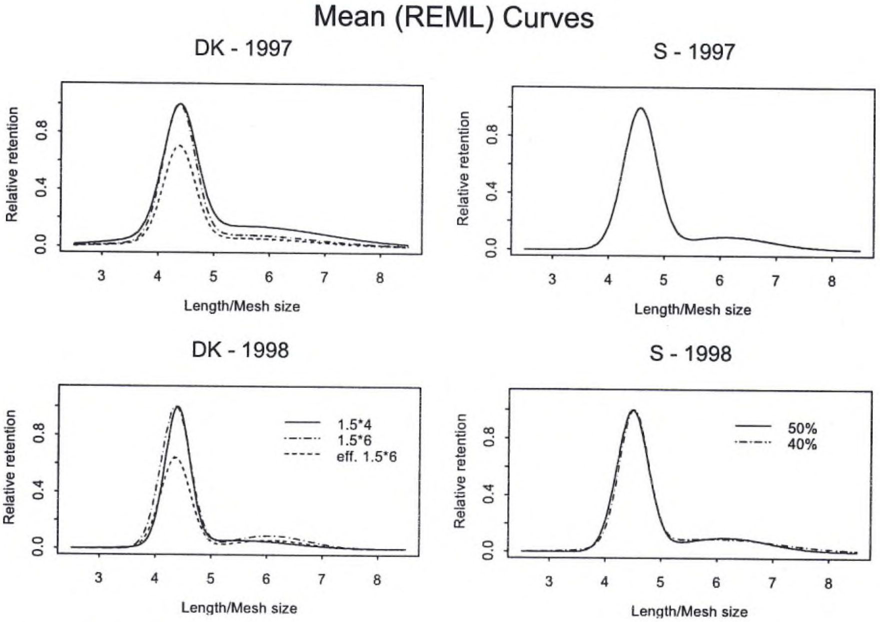


Figure 7. *Selectivity curves from the Swedish 1998 experiment. Curves estimated from individual sets (dashed lines) and the mean selectivity curve (solid line).*



Mean (REML) Curves

DK - 1997

S - 1997

DK - 1998

S - 1998

Figure 8. *Mean selectivity curves for each of the four trials.*

The difference in selectivity between the Danish and Swedish standard nets changed from 1997 to 1998. The Laird-Ware analysis estimated a difference in location of the primary mode of 0.126 between the Danish and the Swedish trials in 1998. This is in good agreement with the estimates found in the independent direct estimations above. Furthermore the analysis revealed a difference in the spread of the second mode, which also agrees with the former indirect analyses. There are no obvious reasons for the different patterns of comparison between the two trials periods and the variation between the two trials periods are properly deemed to be a random seasonal-country interaction effect. The differences are however again too small to be of any practical importance and should not be the cause of any deep concern.

Comparison of the two trials periods

In figure 10 the estimated mean selectivity curves for the standard nets for the two trials periods are compared by country. The Danish 1998 curve is shifted to the right compared to the 1997 curve, whereas the Swedish curve is unchanged. The difference in the heights of the second modes is insignificant.

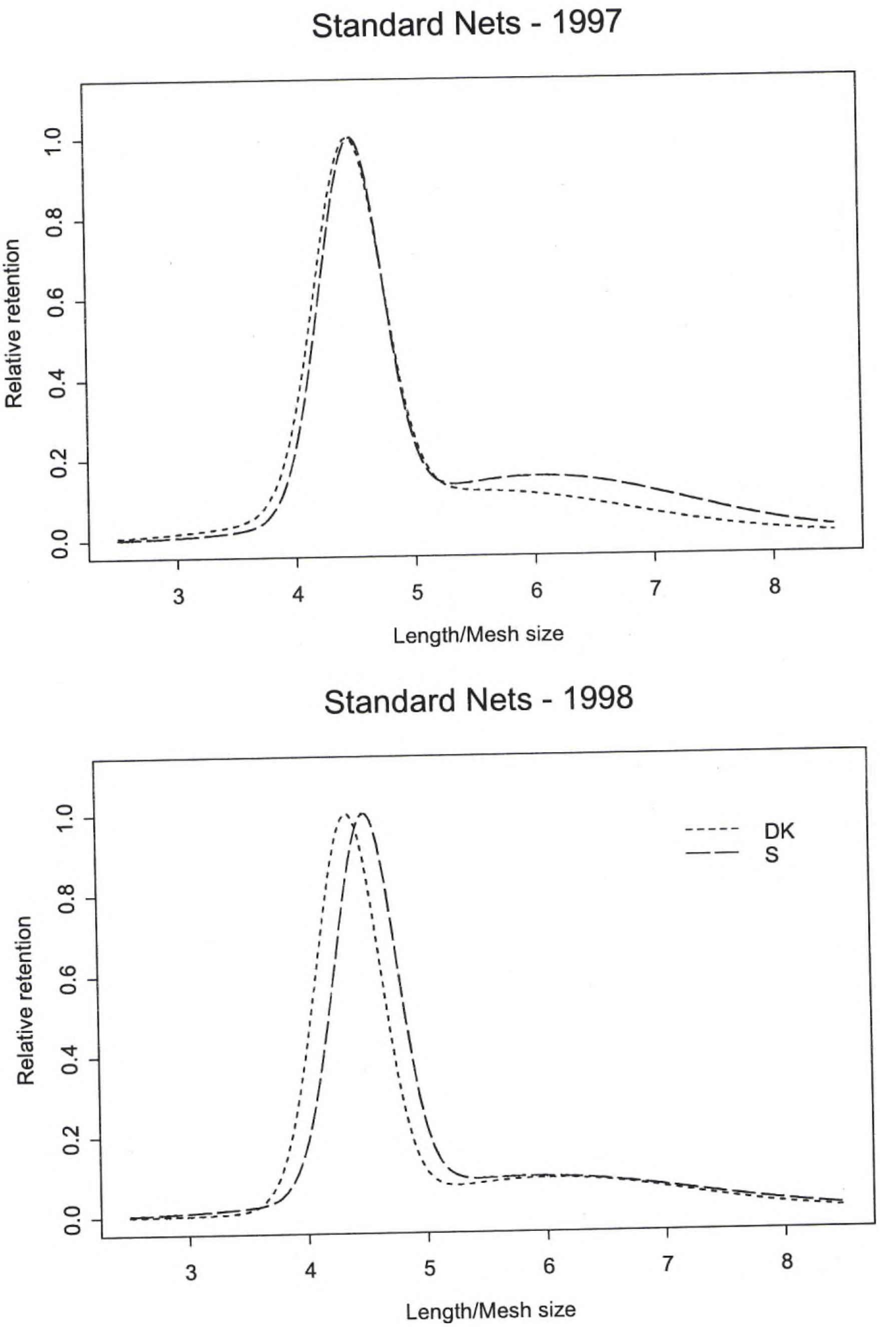


Figure 9. *Comparison of Danish and Swedish mean selectivity curves for the standard nets.*

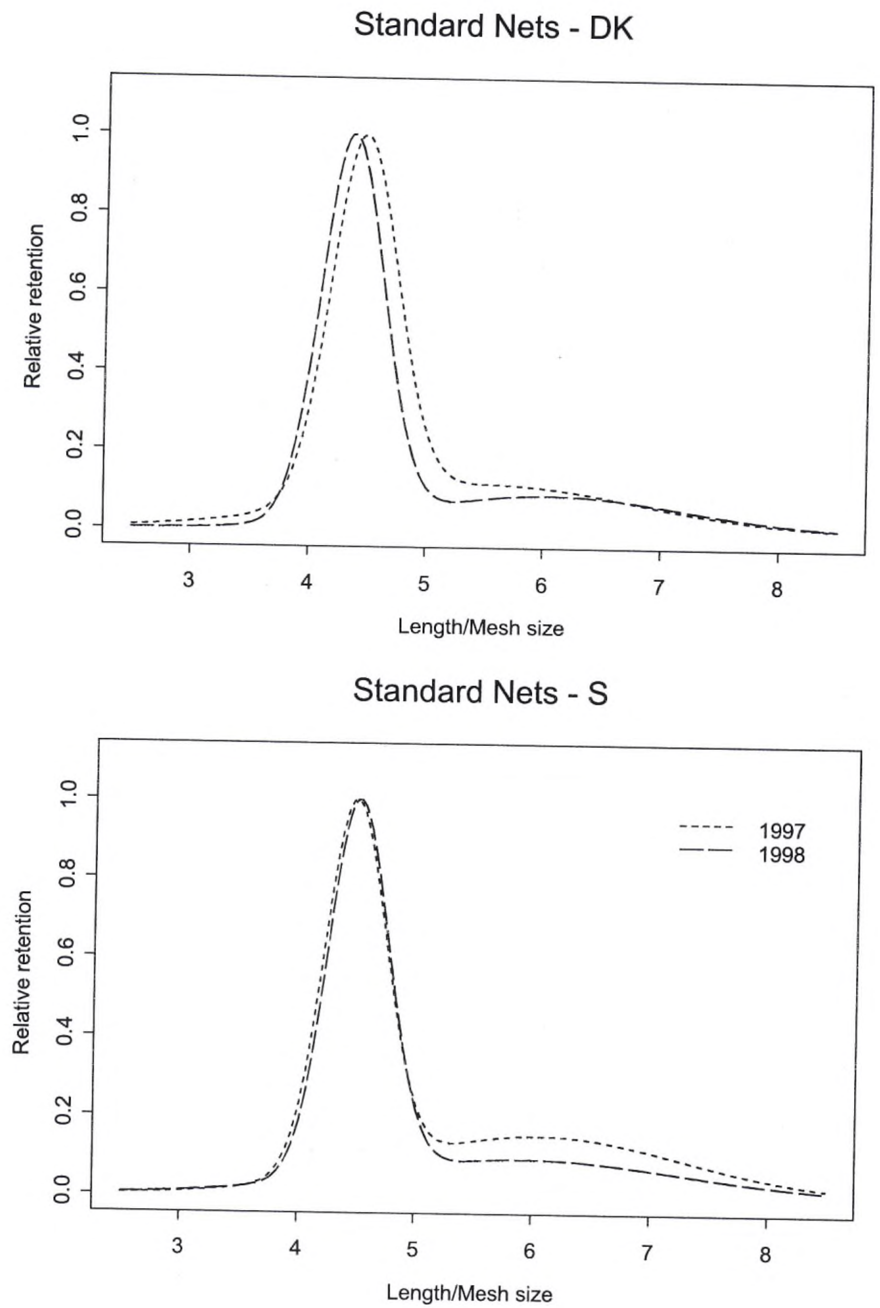


Figure 10. *Comparison of 1997 and 1998 mean selectivity curves.*

Overall Model

The result of this analysis showed revealed significant impacts of twine on the location of the primary mode and spread of the second mode and an impact of hanging ratio on the location of the primary mode. Estimates of the individual parameters and the estimated covariances of these are listed in table 31 and 32 respectively. Estimates of primary modes for the four combinations of gear parameters are presented in table III.

Table III. *Estimates of primary modes of the four combinations of gear parameters.*

Twine	*HR*	*Country*	α_1
1.5*4	50%	DK+S	4.454
1.5*4	40%	S	4.515
1.5*6	50%	DK	4.349
1.5*6	40%	---------	4.410

The bottom line is greyed out because this estimate does not correspond to an actual experiment, but is simply extrapolated from the fitted model.

The variance components for the primary mode indicate that the between-set variation was of the same magnitude as the random variation between the two trial periods, whereas the random variation between the two countries was twice as high. The pattern was different for the other selectivity parameters (see tables 33-35).

For simplicity the model was fitted with an assumption of the same between-set variation within each of the four trials as well as equal variance between countries within each period.

Relative Population Structure

Relative population structures were derived from the observed catches. These were based on the total catches and the mean curves fitted by the Laird-Ware model. As mentioned above the catch structures showed a profound difference between the Danish and the Swedish trials for both trial periods, whereas the selectivity curves were effectively the same (for the same twine and hanging ratio). This is reflected in the different population structures. See figure 11.

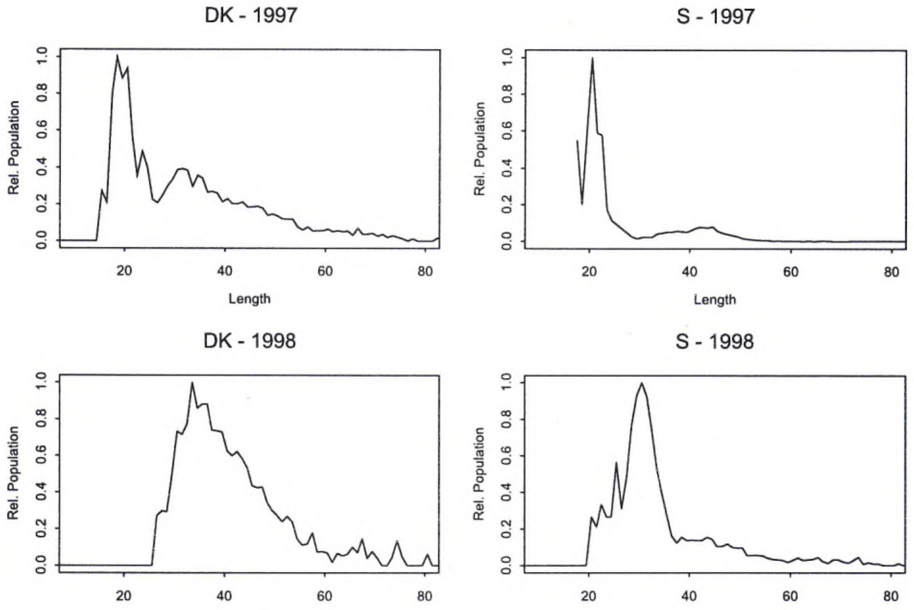


***Figure 11.** Relative population structures derived from catch data and mean selectivity curves.*

Conclusion

The data collected in the project have been analysed by a number of different approaches. Initial analyses of individual sets constituted the basis for the entire analysis. Subsequent analyses were directed to

· answering the questions of interest

· building models that reflected all relevant physical aspects of the experiments.

The objectives of this study included

- estimation of the selectivity parameters for a number of different gears
- comparison of these parameter estimates
- estimation of the relative fishing power of different gears
- comparison between seasons (or trials periods)

The analyses described here have addressed these questions by building and estimating appropriate models. These models have been derived by using common statistical assumptions (e.g. fish arrive at a gear according to a Poisson process) and using well accepted axioms (e.g. Baranov's principle of geometrical similarity) and constraints imposed by the actual experimental conditions (e.g. nets of the two different twine thickness were fished on the same population).

It appears that the selectivity is very robust to changes in gear parameters. It also appears relatively unchanged between the two seasons that were investigated. One of the objectives of the project was to assess the influence of changes in gear parameters on the efficiency of the nets. The conclusion here is that, at fixed mesh sizes, the efficiency is reduced by ca. one third when going from twine thickness 1.5*4 to 1.5*6. It was not possible to detect any difference in efficiency between the two hanging ratios tested (50% and 40%).

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Many people have been involved in the planning and conduction of experiments related to this project. In particular we wish to thank

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- Our colleagues Mogens Andersen, Svend Koppetsch and Thomas Moth-Poulsen who worked so hard during the conduction of the sea trials and P.O. Larsson and Anne Kamp Nielsen who helped design the experiments and carry out the gear surveys.

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Tables

1997 Trials

Danish trials 1.5*4

Table 1. *Estimated parameters for the 1.5*4 Danish Trials*

Parameter	*Estimate*	*Std. Dev.*	*t-Value*	*dof*	*p-Value*
α_1	4.45710	0.01310	340.20520	35	0.00000
β_1	0.27180	0.00876	31.01734	35	0.00000
α_2	5.67179	0.12754	44.47167	35	0.00000
β_2	1.41001	0.14378	9.80689	35	0.00000
ω	0.13108	0.01536	8.53432	35	0.00000

Table 2 *Between set-variation (Correlations below the diagonal)*

	α_1	β_1	α_2	β_2	ω
α_1	0.000974	-0.000289	0.000420	0.005998	-0.001066
β_1	-0.637927	0.000210	0.002138	0.002333	0.000161
α_2	0.056344	0.617737	0.056968	0.085385	-0.003164
β_2	0.457119	0.382654	0.850706	0.176838	-0.011637
ω	-0.925599	0.299859	-0.359207	-0.749789	0.001362

Table 3. *Estimated Covariance on the parameters(Correlations below the diagonal*

	α_1	β_1	α_2	β_2	ω
α_1	0.000172	-0.000007	0.000104	0.000612	-0.000096
β_1	-0.057837	0.000077	0.000354	0.000275	0.000016
α_2	0.062393	0.317063	0.016266	0.011308	-0.000318
β_2	0.325067	0.218216	0.616675	0.020672	-0.001004
ω	-0.477864	0.117348	-0.162328	-0.454817	0.000236

Danish trials 1.5*6

Table 4. *Estimated parameters for the 1.5*6 Danish Trials*

Parameter	*Estimate*	*Std. Dev.*	*t-Value*	*dof*	*p-Value*
α_1	4.36110	0.02452	177.89000	45	0.00000
β_1	0.28961	0.01100	26.32000	45	0.00000
α_2	5.46910	0.14260	38.35300	45	0.00000
β_2	1.03330	0.09646	10.71200	45	0.00000
ω	0.09323	0.00992	9.39740	45	0.00000

Table 5. *Between set-variation (Correlations below the diagonal*

	α_1	β_1	α_2	β_2	ω
α_1	0.006399	-0.000299	0.019553	0.000087	-0.000212
β_1	-0.142858	0.000685	0.006185	-0.006697	0.000389
α_2	0.659810	0.637810	0.137240	-0.071245	0.003478
β_2	0.004178	-0.988514	-0.743091	0.066981	-0.003823
ω	-0.176131	0.987229	0.622971	-0.980184	0.000227

Table 6. *Estimated Covariance on the parameters(Correlations below the diagonal)*

	α_1	β_1	α_2	β_2	ω
α_1	0.000601	-0.000015	0.001539	-0.000001	-0.000019
β_1	-0.055637	0.000121	0.000647	-0.000560	0.000030
α_2	0.440079	0.412565	0.020335	-0.005491	0.000315
β_2	-0.000602	-0.527263	-0.399230	0.009304	-0.000386
ω	-0.079927	0.277968	0.222351	-0.402975	0.000098

Swedish trials HR 50%

Table 7. *Estimated parameters for the 1.5*4 Swedish Trials*

Parameter	*Estimate*	*Std. Dev.*	*t-Value*	*dof*	*p-Value*
α_1	4.47540	0.01326	337.54652	50	0.00000
β_1	0.26309	0.00884	29.75131	50	0.00000
α_2	6.04377	0.23807	25.38621	50	0.00000
β_2	1.23251	0.07620	16.17490	50	0.00000
ω	0.16290	0.02045	7.96501	50	0.00000

Table 8. *Between set-variation (Correlations below the diagonal)*

	α_1	β_1	α_2	β_2	ω
α_1	0.001349	0.000023	0.004200	0.001037	0.001200
β_1	0.033966	0.000339	0.010452	0.000608	0.000332
α_2	0.169488	0.841352	0.455321	0.048216	0.028279
β_2	0.322648	0.376991	0.816153	0.007665	0.004720
ω	0.580540	0.320184	0.744497	0.957631	0.003169

Table 9. *Estimated Covariance on the parameters(Correlations below the diagonal)*

	α_1	β_1	α_2	β_2	ω
α_1	0.000176	0.000020	0.000488	0.000143	0.000094
β_1	0.172759	0.000078	0.001014	0.000105	0.000023
α_2	0.154562	0.481507	0.056679	0.011535	0.002504
β_2	0.141988	0.156059	0.635859	0.005806	0.000385
ω	0.344770	0.128576	0.514278	0.247327	0.000418

Direct modelling of the Danish trials 1.5*4 & 1.5*6 - Including efficiency

***Table 10.** Estimated parameters for the 1.5*4 & 1.5*6 Danish trials - Direct modeling including efficiency*

Parameter	*Estimate*	*Std. Dev.*	*t-Value*	*dof*	*p-Value*
α_1	4.45500	0.0131	338.9654	60	0.0000
β_1	0.28261	0.0069	41.1129	60	0.0000
α_2	5.51784	0.0845	65.2897	60	0.0000
β_2	1.26931	0.0787	16.1252	60	0.0000
ω	0.12653	0.0124	10.2125	60	0.0000
offset(α_1)	-0.08452	0.0206	-4.1100	60	0.0001
offset(ω)	-0.04273	0.0119	-3.5995	60	0.0006
q	0.70541	0.0415	16.9784	60	0.0000

***Table 11.** Between set-variation (Correlations below the diagonal)*

	α_1	β_1	α_2	β_2	ω	offset(α_1)	Offset(ω)	q
α_1	0.0012415	-0.0000392	-0.0032089	-0.0009457	-0.0009645	0.0003120	0.0004375	-0.0034034
β_1	-0.0777584	0.0002049	0.0004096	0.0004750	0.0000327	-0.0008661	0.0000125	0.0008945
α_2	-0.8012107	0.2517176	0.0129205	-0.0098027	0.0026361	-0.0027906	-0.0004130	0.0104552
β_2	-0.1300474	0.1607831	-0.4178550	0.0425948	0.0002968	0.0000737	-0.0024142	0.0028477
ω	-0.9967712	0.0831438	0.8444496	0.0523583	0.0007542	-0.0002753	-0.0003165	0.0026687
offset(α_1)	0.1437325	-0.9821465	-0.3985246	0.0057989	-0.1627540	0.0037948	-0.0001148	-0.0042423
offset(ω)	0.7563268	0.0532390	-0.2213473	-0.7125502	-0.7019972	-0.1135677	0.0002695	-0.0010209
q	-0.8665625	0.5605938	0.8251729	0.1237869	0.8717718	-0.6178100	-0.5579309	0.0124249

***Table 12.** Estimated Covariance on the parameters(Correlations below the diagonal)*

Variance of parameters

	α_1	β_1	α_2	β_2	ω	offset(α_1)	offset(ω)	q
α_1	0.0001727	0.0000106	-0.0001906	-0.0000058	-0.0000892	-0.0000410	0.0000434	-0.0002958
β_1	0.1176010	0.0000473	0.0001387	0.0000882	-0.0000017	-0.0000689	0.0000017	0.0000632
α_2	-0.1715948	0.2387434	0.0071425	0.0012224	0.0001417	-0.0002112	-0.0000110	0.0007115
β_2	-0.0055661	0.1629692	0.1837430	0.0061962	-0.0002047	-0.0000222	-0.0000776	0.0001415
ω	-0.5480424	-0.0200405	0.1353613	-0.2099142	0.0001535	-0.0000237	-0.0001026	0.0003130
Offset(α_1)	-0.1515940	-0.4874947	-0.1215034	-0.0137219	-0.0931950	0.0004229	-0.0000258	-0.0002672
Offset(ω)	0.2784164	0.0204423	-0.0109457	-0.0830269	-0.6976367	-0.1055240	0.0001409	-0.0002525
q	-0.5416240	0.2213055	0.2026337	0.0432798	0.6079809	-0.3127869	-0.5119694	0.0017262

1998 Trials

Danish trials 1.5*4

Table 13. *Estimated parameters for the 1.5*4 Danish Trials*

Parameter	*Estimate*	*Std. Dev.*	*t-Value*	*dof*	*p-Value*
α_1	4.351100	0.018862	230.680000	50	0.00000
β_1	0.261720	0.010802	24.230000	50	0.00000
α_2	5.512900	0.178640	30.860000	50	0.00000
β_2	0.797860	0.082911	9.623200	50	0.00000
ω	0.087305	0.010282	8.490900	50	0.00000

Table 14. *Between set-variation (Correlations below the diagonal)*

	α_1	β_1	α_2	β_2	ω
α_1	0.003786	0.000334	0.011626	-0.002944	-0.000189
β_1	0.195287	0.000773	0.013904	-0.002085	-0.000079
α_2	0.357939	0.947471	0.278668	-0.015897	-0.002953
β_2	-0.245363	-0.384550	-0.154435	0.038024	-0.001329
ω	-0.306787	-0.284579	-0.559057	-0.681245	0.000100

Table 15. *Estimated Covariance on the parameters(Correlations below the diagonal)*

	α_1	β_1	α_2	β_2	ω
α_1	0.000356	0.000043	0.000878	-0.000215	-0.000020
β_1	0.211705	0.000117	0.001100	-0.000162	-0.000007
α_2	0.260683	0.569910	0.031912	0.001206	-0.000046
β_2	-0.137390	-0.181301	0.081443	0.006874	-0.000199
ω	-0.102987	-0.065170	-0.025159	-0.233628	0.000106

Danish trials 1.5*6

***Table 16.** Estimated parameters for the 1.5*6 Danish Trials*

Parameter	*Estimate*	*Std. Dev.*	*t-Value*	*dof*	*p-Value*
α_1	4.33740	0.018227	237.97000	50	0.00000
β_1	0.26309	0.017135	15.35400	50	0.00000
α_2	6.05630	0.14721	41.14200	50	0.00000
β_2	0.34479	0.074532	4.62600	50	0.00003
ω	0.11987	0.017646	6.79300	50	0.00000

***Table 17.** Between set-variation (Correlations below the diagonal)*

	α_1	β_1	α_2	β_2	ω
α_1	0.002994	-0.002812	-0.017341	0.0023238	-0.0009046
β_1	-0.908860	0.003198	0.019702	-0.0043107	0.0010059
α_2	-0.637280	0.700552	0.247318	-0.0917733	0.0093757
β_2	0.182316	-0.327241	-0.792215	0.0542614	-0.003754
ω	-0.768490	0.826851	0.876322	-0.7490954	0.0004628

***Table 18.** Estimated Covariance on the parameters(Correlations below the diagonal)*

	α_1	β_1	α_2	β_2	ω
α_1	0.000332	-0.000185	-0.001133	0.000129	-0.000073
β_1	-0.591854	0.000294	0.001477	-0.000345	0.000084
α_2	-0.422191	0.585675	0.021669	-0.007372	0.000865
β_2	0.095054	-0.269910	-0.671917	0.005555	-0.000404
ω	-0.226627	0.276352	0.332797	-0.306854	0.000311

Swedish trials HR 40%

Table 19. *Estimated parameters for the 1.5*4 Swedish Trials*

Parameter	*Estimate*	*Std. Dev.*	*t-Value*	*dof*	*p-Value*
α_1	4.52490	0.02071	218.45000	45	0.00000
β_1	0.28127	0.01835	15.32500	45	0.00000
α_2	5.83460	0.13816	42.23000	45	0.00000
β_2	0.95079	0.12047	7.89240	45	0.00000
ω	0.09981	0.01881	5.30530	45	0.00000

Table 20. *Between set-variation (Corelations belw the diagonal)*

	α_1	β_1	α_2	β_2	ω
α_1	0.004230	0.002293	0.010317	-0.005915	-0.000853
β_1	0.580755	0.003686	0.022463	-0.017682	0.001858
α_2	0.402773	0.939524	0.155101	-0.085638	0.011974
β_2	-0.230369	-0.737753	-0.550809	0.155853	-0.016796
ω	-0.253866	0.592598	0.588751	-0.823849	0.002667

Table 21. *Estimated Covariance on the parameters (Correlations below the diagonal)*

	α_1	β_1	α_2	β_2	ω
α_1	0.000429	0.000206	0.000868	-0.000437	-0.000071
β_1	0.541161	0.000337	0.001790	-0.001339	0.000144
α_2	0.303220	0.706016	0.019089	-0.004633	0.000914
β_2	-0.174979	-0.605440	-0.278346	0.014513	-0.001136
ω	-0.181120	0.415894	0.351703	-0.501205	0.000354

Swedish trials HR 50%

Table 22. *Estimated parameters for the 1.5*4 Swedish Trials*

Parameter	*Estimate*	*Std. Dev.*	*t-Value*	*dof*	*p-Value*
α_1	4.46960	0.01374	325.23000	40	0.00000
β_1	0.25007	0.01015	24.62600	40	0.00000
α_2	5.84330	0.15264	38.28000	40	0.00000
β_2	1.26170	0.09005	14.01100	40	0.00000
ω	0.12514	0.01974	6.34090	40	0.00000

Table 23. *Between set-variation (Corelations belw the diagonal)*

	α_1	β_1	α_2	β_2	ω
α_1	0.001252	0.000676	0.011228	0.007310	-0.000571
β_1	0.737207	0.000672	0.006928	0.002813	-0.000577
α_2	0.978406	0.824073	0.105203	0.060500	-0.003644
β_2	0.930374	0.488714	0.839952	0.049314	-0.004776
ω	-0.286224	-0.395083	-0.199231	-0.381414	0.003179

Table 24. *Estimated Covariance on the parameters (Correlations below the diagonal)*

	α_1	β_1	α_2	β_2	ω
α_1	0.000189	0.000083	0.001052	0.000657	-0.000043
β_1	0.595024	0.000103	0.000687	0.000293	-0.000047
α_2	0.501504	0.443359	0.023301	0.009250	-0.000408
β_2	0.530764	0.320632	0.672923	0.008109	-0.000375
ω	-0.160153	-0.232208	-0.135554	-0.210922	0.000390

Direct modelling of the Danish trials 1.5*4 & 1.5*6 - Including efficiency

Table 25. *Estimated parameters for the 1.5*4 & 1.5*6 Danish Trials- Direct modelling including efficiency*

Parameter	*Estimate*	*Std. Dev.*	*t-Value*	*dof*	*p-Value*
α_1	4.35440	0.01469	296.42000	56	0.00000
β_1	0.26564	0.01062	25.02500	56	0.00000
α_2	6.05120	0.15421	39.24100	56	0.00000
β_2	1.13640	0.14960	7.59600	56	0.00000
ω	0.09157	0.01108	8.26500	56	0.00000
Offset(β_2)	-0.46689	0.18331	-2.54700	56	0.01364
q	0.64123	0.03660	17.51900	56	0.00000

Table 26. *Between set-variation (Corelations belw the diagonal)*

	α_1	β_1	α_2	β_2	ω	offset(β_2)	q
α_1	0.002110	-0.000024	-0.013075	-0.014619	-0.000168	0.015637	-0.000861
β_1	-0.016356	0.001006	0.006646	-0.007401	0.000199	0.004842	-0.000520
α_2	-0.575350	0.423554	0.244779	0.101715	0.009473	-0.204273	0.025791
β_2	-0.696612	-0.510743	0.449985	0.208736	0.002142	-0.201561	0.022072
ω	-0.159516	0.272530	0.833369	0.204026	0.000528	-0.009175	0.001351
offset(β_2)	0.611336	0.274153	-0.741436	-0.792242	-0.717130	0.310099	-0.036214
q	-0.256863	-0.224756	0.714668	0.662320	0.806210	-0.891566	0.005321

Table 27. *Estimated Covariance on the parameters (Correlations below the diagonal)*

	α_1	β_1	α_2	β_2	ω	offset(β_2)	q
α_1	0.000216	0.000007	-0.000959	-0.001100	-0.000019	0.001180	-0.000070
β_1	0.044410	0.000113	0.000582	-0.000616	0.000013	0.000414	-0.000051
α_2	-0.423422	0.355458	0.023780	0.009628	0.000679	-0.017349	0.001988
β_2	-0.500449	-0.387835	0.417337	0.022380	-0.000067	-0.021502	0.002156
ω	-0.119014	0.109472	0.397344	-0.040152	0.000123	-0.000582	0.000118
offset(β_2)	0.438095	0.212793	-0.613734	-0.784098	-0.286643	0.033602	-0.003595
q	-0.130348	-0.131929	0.352224	0.393812	0.290099	-0.535811	0.001340

Direct modelling of the Swedish trials HR 40% & HR 50%

Table 28. *Estimated parameters for the HR 50% and HR 40% Swedish trials*

Parameter	*Estimate*	*Std. Dev.*	*t-Value*	*dof*	*p-Value*
α_1	4.50130	0.01259	357.47000	63	0.00000
β_1	0.25854	0.00620	41.70700	63	0.00000
α_2	5.90410	0.12328	47.89100	63	0.00000
β_2	1.35450	0.08465	16.00200	63	0.00000
ω	0.09828	0.01169	8.40670	63	0.00000
offset(β_2)	-0.15352	0.04892	-3.13800	63	0.00259

Table 29. *Between set-variation (Corelations belw the diagonal)*

	α_1	β_1	α_2	β_2	ω	offset(β_2)
α_1	0.001750	0.000171	0.010390	0.007595	-0.000956	0.000427
β_1	0.264139	0.000238	0.003922	-0.000797	0.000102	0.001401
α_2	0.774689	0.792271	0.102795	0.028351	-0.003109	0.021241
β_2	0.730849	-0.207681	0.355966	0.061710	-0.004429	-0.006165
ω	-0.821050	0.237322	-0.348607	-0.640895	0.000774	0.000993
offset(β_2)	0.109482	0.972336	0.709962	-0.265933	0.382565	0.008708

Table 30. *Estimated Covariance on the parameters (Correlations below the diagonal)*

	α_1	β_1	α_2	β_2	ω	offset(β_2)
α_1	0.000159	0.000025	0.000760	0.000542	-0.000072	0.000017
β_1	0.325086	0.000038	0.000337	-0.000015	0.000005	0.000082
α_2	0.489862	0.441415	0.015199	0.004795	-0.000125	0.001493
β_2	0.508228	-0.028186	0.459492	0.007165	-0.000466	-0.001500
ω	-0.487420	0.062810	-0.086979	-0.471237	0.000137	0.000106
offset(β_2)	0.027466	0.269402	0.247585	-0.362274	0.185147	0.002393

Overall indirect model - All trials

Table 31. *Estimated parameters for the HR 50% and HR 40% Swedish trials*

Parameter	*Estimate*	*Std. Dev.*	*t-Value*	*dof*	*p-Value*
α_1	4.4537969	0.00937	475.26144	422	0.00000
β_1	0.2646808	0.00377	70.22317	422	0.00000
α_2	5.9230868	0.07254	81.65702	422	0.00000
β_2	1.2292782	0.04404	27.90989	422	0.00000
ω	0.1366112	0.00731	18.68479	422	0.00000
Offset($\alpha_{1,Twine}$)	-0.1050921	0.01748	-6.01241	422	0.00000
Offset($\beta_{2,Twine}$)	-0.5062592	0.07811	-6.48160	422	0.00000
Offset($\alpha_{1,Hang.-ratio}$)	0.0605533	0.0185781	3.2594009	422	0.00121

Table 32. *Estimated Covariance on the parameters(Correlations below the diagonal)*

Parameter	α_1	β_1	α_2	β_2	ω	Offs.($\alpha_{1,Tw}$)	Offs.($\beta_{2,Tw}$)	Offs.($\alpha_{1,HR}$)
α_1	0.000088	0.000001	0.000037	0.000022	0.000004	-0.000089	-0.0000307	-0.0000858
β_1	0.030620	0.000014	0.000052	-0.000002	0.000001	-0.0000032	-0.0000081	0.0000066
α_2	0.054151	0.189029	0.005262	0.001346	0.000086	0.000011	-0.000474	0.0000144
β_2	0.053973	-0.010625	0.421177	0.001940	-0.000063	0.000023	-0.0013934	0.0000835
ω	0.064064	0.018569	0.162385	-0.194503	0.000054	-0.000022	-0.0001084	-0.0000047
ffset($\alpha_{1,Twine}$)	-0.543272	-0.049076	0.008564	0.030224	-0.173765	0.000306	0.0000205	0.0000864
ffset($\beta_{2,Twine}$)	-0.041981	-0.027410	-0.083671	-0.405034	-0.189851	0.015045	0.0061007	-0.0000727
fset($\alpha_{1,Hang.-ratio}$)	-0.492774	0.0939127	0.010703	0.1020611	-0.0345138	0.2660723	-0.050132	0.0003451

Table 33. *Between-set variance*

	α_1	β_1	α_2	β_2	ω
α_1	0.003621	-0.000237	0.005815	0.006069	-0.000987
β_1	-0.196220	0.000402	-0.004252	0.001334	-0.000222
α_2	0.201520	-0.442297	0.229936	-0.078932	0.009454
β_2	0.261414	0.172439	-0.426645	0.148856	-0.013361
ω	-0.445655	-0.300813	0.535577	-0.940745	0.001355

Table 34. *Between-country variance*

	α_1	β_1	α_2	β_2	ω
α_1	0.0078312	-0.0004033	0.018437	0.0066727	0.0017781
β_1	-0.1218391	0.0013993	0.0089638	0.0053342	-0.0004682
α_2	0.2816249	0.3239155	0.5472769	0.164903	0.0119846
β_2	0.1759651	0.3327761	0.5201897	0.1836227	-0.002296
ω	0.4197004	-0.261464	0.3383925	-0.1119184	0.0022919

Table 35. *Between-season variance*

	α_1	β_1	α_2	β_2	ω
α_1	0.0035251	-0.0007074	-0.0109631	0.0174052	-0.0039911
β_1	-0.3614779	0.0010864	0.0134421	-0.0073779	0.002692
α_2	-0.1799975	0.397553	1.0523459	0.1911231	0.0228523
β_2	0.5551129	-0.4238713	0.352797	0.2788805	-0.0666628
ω	-0.4252331	0.5166517	0.1409186	-0.7985319	0.0249899

The institute's logo that can be seen on the title-page represents Bronze Age fishermen; from a rock-carving at Ödsmål, parish of Kville, Bohuslän, Sweden. From thousands of rock-carvings in western Sweden this is the only known scene showing fishing. Originally described by Åke Fredsjö, 1943: "En fiskescen på en bohuslänsk hällristning" - Göteborgs och Bohusläns Fornminnesförenings tidskrift 1943: 61-67. Later documentationby the same author in: "Hällristningar i Kville härad i Bohuslän. Kville socken. Del 1 och 2." - Studier i nordisk arkeologi 14/15, Göteborg 1981, 303 pp., Pl. 158 II. Published by Fornminnesföreningen i Göteborg.