Greenland halibut observed by video in front of survey trawl: behaviour, escapement, and spatial pattern

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Abstract

Video recordings of Greenland halibut (Reinhardtius hippoglossoides) were made at eight trawl stations in Svalbard waters in August 2002. The recordings were made down to 600 m depth using artificial light. A method for calculating actual fish length from the video image was established and the recordings were analysed with respect to length-dependent behaviour, escapement and spatial pattern. All Greenland halibut observed were either lying on the bottom or swimming in a horizontal position close to the bottom, and there was no tendency to schooling. Individual fish reacted in an ordered way to the approaching trawl and were herded along the ends of the ground-gear. Escapement under the ground-gear was higher for smaller fish, while some larger individuals were apparently able to escape the trawl ahead of the observed region.

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Keywords: Greenland halibut; Trawl video; Behaviour; Escapement; Catchability

1. Introduction

Fish behaviour in relation to sampling gear has long been anticipated as an important factor for inferences in resource biology and stock assessments (Fréon et al., 1993). For Greenland halibut (Reinhardtius hippoglossoides) inferences about population structure (length and age composition), biological rates (growth and maturation) and spatial dynamics (distribution and migration) all rely heavily on data from research surveys using some sort of sampling trawl. The behaviour of fish towards an approaching trawl has attracted much research during the last few decades (Wardle and Hollingworth, 1993; Fernö and Olsen, 1994; Fréon and Misund, 1999). However, most of this research has been on roundfish, both demersal and pelagic. Studies on flatfish behaviour in front of the trawl have mainly been done in shallow water and mostly during day (Main and Sangster, 1981; Walsh and Hickey, 1993; Bublitz, 1996). These results may not be directly relevant for Greenland halibut living at low light levels below 500 m depth.

This paper is part of a comprehensive effort to study distribution and migration of Greenland halibut in the Northeast Arctic region, i.e. the Norwegian Sea, Barents Sea and Svalbard area, throughout the year and during ontogeny. The objective of this paper is to describe behaviour in front of the trawl, with empha-
sis on the extent of schooling behaviour, herding effects and escapement under the ground-gear with respect to fish size.

2. Material and methods

2.1. Recording and sampling at sea

Video recordings were made in the trawl opening during a bottom trawl survey with RV ‘Jan Mayen’ west of Svalbard in August 2002. The hauls were made using Campelen 1800 with Rockhopper ground-gear (Engås and Godø, 1989), a modified shrimp trawl used as the standard Norwegian survey trawl. Towing speed was 1.5 m s\(^{-1}\) (3 knots). The video recorder was mounted on the headline and directed towards the mid-section of the ground-gear. Artificial light was mounted in the net roof, 2 m behind the camera. Eight recordings were made with identical settings. Table 1 lists position, depth and catch from the eight stations and Fig. 1 (upper panel) gives a schematic description of the set-up. The camera used was a SIMRAD osprey oe1324 s.i.t. camera with a ±30 degrees horizontal opening angle in water. The light source was 9W fluorescent lamp of type Ralux /E with average luminance 2.8 cd cm\(^{-2}\).

Although Greenland halibut abundance in these areas peaks at depths between 600 and 700 m, the recordings were limited by the video equipment, which was not certified for depth greater than 600 m. The observed behaviour patterns may thus not be representative for areas with higher abundance. In addition to video recordings, each trawl catch of Greenland halibut was also retained and analysed for length composition. The mean length was 40 cm, which is slightly (5 cm) below that of trawl catches from a broader depth range in the same area (Albert, 2003).

<table>
<thead>
<tr>
<th>Station no</th>
<th>Latitude</th>
<th>Longitude</th>
<th>Depth (m)</th>
<th>Distance (m)</th>
<th>Catch (n)</th>
<th>Length measured</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>80°03’</td>
<td>17°16’</td>
<td>378</td>
<td>2700</td>
<td>21</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>78°36’</td>
<td>8°59’</td>
<td>600</td>
<td>2500</td>
<td>23</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>78°38’</td>
<td>9°20’</td>
<td>575</td>
<td>3200</td>
<td>36</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>80°27’</td>
<td>16°05’</td>
<td>435</td>
<td>3000</td>
<td>–</td>
<td>Catch lost</td>
</tr>
<tr>
<td>5</td>
<td>80°12’</td>
<td>10°04’</td>
<td>578</td>
<td>2500</td>
<td>13</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>78°32’</td>
<td>9°10’</td>
<td>580</td>
<td>2200</td>
<td>5</td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>78°11’</td>
<td>9°18’</td>
<td>589</td>
<td>2000</td>
<td>13</td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>79°53’</td>
<td>8°15’</td>
<td>595</td>
<td>2600</td>
<td>14</td>
<td></td>
</tr>
</tbody>
</table>

Fig. 1. Upper panel: Rigging of the gear. Schematic drawing of position and observation window of the video recorder and light source. Lower panel: Example of video image with (x,y) coordinate system for manual recording of image positions.
within four phases: at first detection, between first detection and crossing of the ground-gear, when crossing the ground-gear, and after having crossed the ground-gear.

Behaviour at first detection of a specimen was classified with respect to vertical position in the water, transverse (left-right) position on the screen, and horizontal orientation. Four different categories were used for vertical position in the water: (1) Resting on the bottom substrate, (2) Swimming close to the bottom (not above 35 cm off bottom, i.e. within the height of the rubber-discs of the Rockhopper ground-gear), (3) Swimming between 0.35 and approx. 1 m off the bottom and (4) Swimming more than 1 m off the bottom. The transverse position on the screen was recorded by dividing the screen from left to right in 7 adjacent vertical bins with equal width, coded by integer numbers from −3 to 3, with 0 corresponding to the central vertical bin (see Fig. 1, lower panel). These figures were in the later analysis divided by 3.5 in order to obtain standardised measures ranging from −1 to 1.

In addition, the orientation of the fish on the screen was recorded using a reference compass card with North pointing in the \( y_{im} \)-direction, corresponding to the direction into the trawl opening (see Fig. 1). For fish that took off from the bottom, orientation at take-off was used instead of orientation at first detection.

After first detection the fish was traced and classified into eight different behaviour categories (Table 2) with possibility to give more than one category to each observation. For fish that left the bottom, the along-trawl distance from the ground-gear at take-off was measured on the screen and the position of the fish at take-off was recorded using a scale from −3 to +3 in the \( x \)- and \( y \)-directions (Fig. 1, lower panel).

When the fish crossed the ground-gear, registrations of the screen position and orientation were recorded the same way as when first detected. Contact with the ground-gear or trawl opening was classified into seven different categories (Table 2). After crossing, the fate of the fish was classified to caught, lost or uncertain.

If possible, also the length of the fish was measured on the screen. This was only done for individuals that were seen in a horizontal position at or close to the bottom. Also the screen position and orientation of the fish when measured were recorded in order to calculate the real length from the length measured on the screen (see below). For each fish observed, the distance across the four central rubber-discs of the Rockhopper ground-gear was also measured as a reference length.

The spatial pattern of Greenland halibut along the trawl path was analysed using distance between succeeding individuals on the video recording. This inter-fish distance is not only a function of the spatial pattern per se (i.e. regular, random, or clumped distribution), but also by the fish density on the locality (i.e. number caught per nautical mile). For each trawl haul the inter-fish distances were therefore standardised by dividing with the mean inter-fish distance.

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**Table 2**

<table>
<thead>
<tr>
<th>Code</th>
<th>Behaviour observed after first detection of the fish</th>
<th>Contact with ground-gear or trawl opening</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Take-off from bottom</td>
<td>Moving in above the ground-gear and further back in trawl</td>
</tr>
<tr>
<td>2</td>
<td>Swimming in front of the ground-gear at the bottom</td>
<td>Moving in above the ground-gear, keep position and coming back</td>
</tr>
<tr>
<td>3</td>
<td>Swimming with the ground-gear, between 0.35 and 1 m above the bottom</td>
<td>Hit by the ground-gear</td>
</tr>
<tr>
<td>4</td>
<td>Swimming higher up in the water</td>
<td>Overrun by the ground-gear</td>
</tr>
<tr>
<td>5</td>
<td>Swimming towards the trawl opening</td>
<td>Swimming actively towards the ground-gear (between the discs or under the ground-gear)</td>
</tr>
<tr>
<td>6</td>
<td>Swimming across trawl direction</td>
<td>Moving in through the ground-gear and coming back through the ground-gear</td>
</tr>
<tr>
<td>7</td>
<td>Disappearing from video image at the sides</td>
<td>Bend towards the roof of the trawl (turning, upward orientation)</td>
</tr>
<tr>
<td>8</td>
<td>Disappearing from video image ahead of the ground-gear</td>
<td></td>
</tr>
</tbody>
</table>
2.3. Estimation of fish length from video

Let $x_{im}$ and $y_{im}$ denote the normalised co-ordinates of the horizontal and vertical positions in the video frame, i.e. ranging from $-1$ to $1$. The correspondence between these image co-ordinates and the co-ordinates $x$, $y$ and $z$ in the water (see Fig. 1) can then be deduced by translation and rotation of co-ordinate systems (Harbitz, 1990)

$$
x = \frac{0.8 \cdot x_{im} \cdot \tan(\phi)}{\sin(\theta) - \cos(\theta) \cdot y_{im} \cdot \tan(\phi)} \cdot (h - z)
$$

$$
y = \frac{\cos(\theta) + \sin(\theta) \cdot y_{im} \cdot \tan(\phi)}{\sin(\theta) - \cos(\theta) \cdot y_{im} \cdot \tan(\phi)} \cdot (h - z)
$$

where $\phi \approx 30$ degrees is (half) the horizontal opening angle of the camera, corresponding to technical specifications, and $\theta \approx 70$ degrees is the tilt angle between the horizontal plane and the main camera direction. The factor 0.8 in the $x$-formula is due to the difference between the width and the height of the screen. A more general and rigorous work on perspective transformations is given by Haralick (1980).

The vertical distance, $h$, between the camera (lens) and the seabed was determined directly from measurements by a Scanmar sensor mounted close to the camera when these measurements were available. Based on 5 such measurements, a reference length defined by the distance across the four central rubber-discs of the Rockhopper groundgear was estimated to 1.05 m. Unfortunately the reference length could not be verified, because the entire trawl along with the video equipment were lost in a later haul. When the reference length was known, this was used to estimate $h$ for each fish measurement by manipulation of Eq. (1) using the image co-ordinates (left and right points) of the reference length.

Finally, Eqs. (1) and (2) were applied to measure fish length. Because only fish very close to the bottom were measured, it is a good approximation to set $z = 0$. The fish length was calculated as the distance between the endpoints of a straight line with centre at the fish position and the appropriate length and orientation corresponding to the video frame measurements.

3. Results

3.1. Length composition from catch and video

In total, 80 Greenland halibut were classified as caught based on the video recordings from the seven trawl hauls where catch was retained. Additionally, for nine individuals it was not possible to determine whether they were caught or lost under the groundgear. This corresponded to 63% and 70%, respectively, of the actual catch from these seven trawl hauls.

The lengths estimated from the video recordings were generally in good agreement with the length composition from the catch (Fig. 2). The difference between the mean length of those individuals that were classified as caught and the mean length from the real catch was less than eight percent in any of the six trawl hauls where Greenland halibut were measured from the catch. The frequency distributions based on video and catch were of similar range and with similar modes. However, for individual trawls the video-mode was either similar or one 5 cm length-group below the catch-mode.

From all eight videos, 127 Greenland halibut were recorded as either caught or lost under the
3.2. Behaviour patterns

In total 138 Greenland halibut were identified from the video recordings, 126 of which could be followed until crossing the ground-gear, either beneath or above. All individuals were swimming with the blind side facing down. At first detection, 53% of the fish started swimming from a resting position on the bottom substrate, 11% were swimming along with the trawl, while 36% were swimming towards the trawl opening. The two largest groups did not differ substantially in terms of length composition or in proportion lost under the ground-gear (Fig. 5). Those swimming along with the trawl at first detection included only individuals at or

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Fig. 3. Estimated length distributions of Greenland halibut from video recordings. Individuals observed going into the trawl compared with fish lost under the ground-gear.

Fig. 4. Catchability by size of Greenland halibut in trawl estimated from video recordings. Symbol size indicates number of observations; the leftmost and the two rightmost values were based on less than ten observations. The first and last groups are plusgroups and the line is fitted using a cubic function.

Fig. 5. Estimated length distributions of Greenland halibut at first detection when entering the picture frame. a: fish resting on the substrate, b: fish swimming in the trawl direction in front of the ground-gear, and c: fish swimming towards the trawl opening.
above the mean length of the other two groups. Descriptions of behaviour for each of the three groups follow.

The individuals lying on the bottom were first detected when they started to swim. They started off with a burst, usually generating a mud cloud that was seen in the water for a few seconds. Often subsequent tail bursts also curled up mud, thus generating a track of clouds. Most individuals remained on the bottom until the ground-gear was less than 1.5 m away. At take-off the fish were usually well within the observation window and mud-clouds from a take-off ahead of the camera field of view were only occasionally seen. Fig. 6 shows the distance from the gear at take-off. All individuals waiting with take-off until the ground-gear was less than 30 cm away were caught. This is a significantly higher catching proportion ($\chi^2$, df=1, $p<0.02$) than for those that took off at greater distance from the ground-gear. Otherwise, there was no clear indication that the probability of being captured decreased with increasing distance at take-off.

For fish that start to swim from a resting position on the bottom, Fig. 7 shows the transverse position on the screen at take-off (lower panel) and when crossing the ground-gear (upper panel). The probability of being caught did not appear to be dependent on transverse position neither at take-off nor crossing. The individuals were mostly detected for the first time in front of the mid-section of the ground-gear, while the transverse position when crossing the ground-gear was more uniformly distributed. This corresponds with the bearing of the fish changing markedly in this process (Fig. 8). Nearly all individuals took off in a direction away from the trawl, while their direction was predomi-

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**Fig. 6.** Greenland halibut resting on the bottom when first detected: Frequency distribution of distance from the ground-gear at take-off, related to whether they were eventually going into the trawl or under the ground-gear.

**Fig. 7.** Greenland halibut resting on the bottom when first detected. Transverse position in the picture frame at first detection (b) and when fish crossing the ground-gear (a).

**Fig. 8.** Greenland halibut resting on the bottom when first detected. The orientation at take-off (bottom) and when crossing the ground-gear (top) relative to the transverse position in the picture frame when first detected. Trawl direction is downwards. The radius represents 14 observations.
nantly transverse to the trawl path when they crossed the ground-gear. Most swam close to the seabed, 65% were below approx. 35 cm (the diameter of the rubber discs of the Rockhopper ground-gear) and only 6% swam more than ca. 1 m above the bottom. About half of the observed individuals swam in front of the trawl for some time before turning to the sides and approaching the ground-gear. These had the longest observation time, with a mean and maximum of 6 and 18 s, respectively. The other half turned directly after take-off and the mean observation time was less than 2 s (Table 3).

The Greenland halibut that were first observed swimming along with the trawl had a rather uniformly distributed transverse position in the video image at first detection as well as when crossing the ground-gear (Fig. 9). After detection they behaved similarly to those that were observed starting off from the bottom. They crossed the ground-gear heading sideways, and were tracked for 2–14 s with a mean of 4. Table 3 summarises the different types of behaviour from detection to crossing of the ground-gear.

Table 3

<table>
<thead>
<tr>
<th>Behaviour from detection to crossing of the ground-gear</th>
<th>n</th>
<th>p</th>
<th>t</th>
<th>L</th>
<th>SE</th>
<th>C</th>
</tr>
</thead>
<tbody>
<tr>
<td>Up from bottom, swimming in front, turning to the side</td>
<td>32</td>
<td>29</td>
<td>5,9</td>
<td>35,2</td>
<td>1,3</td>
<td>68</td>
</tr>
<tr>
<td>Up from bottom, turning to the side</td>
<td>29</td>
<td>26</td>
<td>1,9</td>
<td>38,3</td>
<td>2,5</td>
<td>65</td>
</tr>
<tr>
<td>Swimming in front, turning to the side</td>
<td>10</td>
<td>9</td>
<td>4,4</td>
<td>42,0</td>
<td>2,2</td>
<td>73</td>
</tr>
<tr>
<td>Swimming along the ground-gear ends towards the trawl</td>
<td>36</td>
<td>33</td>
<td>1,4</td>
<td>38,2</td>
<td>1,7</td>
<td>78</td>
</tr>
<tr>
<td>Swimming along the ground-gear ends towards the trawl, swimming in front</td>
<td>3</td>
<td>3</td>
<td>9,1</td>
<td>38,6</td>
<td>4,4</td>
<td>100</td>
</tr>
</tbody>
</table>

n: Number of observations, p: Percentage of all observations classified, t: Mean time in sec. from detection to crossing of the ground-gear, L and SE: Mean length with standard error, C: Proportion being caught.

Fig. 9. Greenland halibut swimming along with the trawl when first detected. Transverse position in the picture frame at first detection (b) and when crossing the ground-gear (a).

The individuals that were heading towards the trawl opening after first detection were first observed at the lateral sides of the screen (Fig. 10). They were

Fig. 10. Greenland halibut swimming towards the trawl opening when first detected. Transverse position in the picture frame at first detection (b) and when crossing the ground-gear (a).
following either side of the ground-gear in the same direction as the sweeps (Fig. 11) and crossed the ground-gear in its mid-section. They were mainly swimming close to the seabed: 80% were less than approx. 35 cm above the bottom and only 4% were above approx. 1 m. These individuals were usually seen for less than two seconds, except for three individuals that turned in front of the mid-section of the ground-gear and swam along with the trawl for up to 17 s before crossing the ground-gear (Table 3).

When crossing the ground-gear, most fish were either swimming above or were hit and/or overrun by the ground-gear. A few individuals seemed to actively position themselves heading towards the ground-gear and moving between the rubber discs. The mean length and the previous behaviour patterns were not significantly different for these three types of contact with the ground-gear (p>0.1).

3.3. Spatial pattern throughout the haul

The catch rate of Greenland halibut was highest during the first 100–200 m after the ground-gear hit the bottom. Fig. 12 (upper panel) shows the number observed per 100 m for all trawls combined, for the first 2000 m, which was the length of the shortest haul. The mean length of the individuals observed within the first 200 m was significantly larger than for later encounters (p < 0.001) and included the two largest individuals (>70 cm) observed. Neither catchability (percentage going above the ground-gear) nor previous behaviour (percentage within the different behaviour types recognised) of these first few individuals of each haul was different from that of those that were caught later in the hauls ($\chi^2$, p>0.1).

The frequency distribution of relative distance between successive observations of Greenland halibut (Fig. 12, lower panel) was not significantly different from the fitted exponential distribution (Kolmogorov–Smirnov D, p>0.1). Thus, there is no reason to reject the null hypothesis that the spatial pattern conforms to a random Poisson process.

Fig. 11. Greenland halibut swimming towards the trawl opening when first detected. Orientation when first detected (b) and when crossing the ground-gear (a) relative to the transverse position in the picture frame when first detected. Trawl direction is downwards. The radius represents 14 observations.

Fig. 12. Encounters of Greenland halibut along the trawl path during the hauls. All eight hauls combined. Upper panel: Number of fish observed relative to towed distance after the ground-ground-gear hit the bottom. Data for the first 2000 m of each haul, as this was the length of the shortest haul. Lower panel: Distance between successive observations relative to the mean distance between observations within each trawl. Dots represent observed frequencies and the line represents the fitted exponential distribution.
4. Discussion

4.1. Influence of methods used

The reaction of fish to an approaching trawl varies according to light levels (Blaxter and Parrish, 1965; Glass and Wardle, 1989). Therefore, it seems feasible that the use of artificial light in the otherwise dark environment of Greenland halibut might impact the observed behaviour. Previous studies of flatfish behaviour in front of trawls have not found clear differences attributable to neither ambient light (Beamish, 1969; Walsh and Hickey, 1993) nor artificial light (Weinberg and Munro, 1999). However, such effects cannot be ruled out. Therefore artificial light was used only in lack of alternative methods for direct observation at these depths of a bottom living flatfish with low acoustic contrast. Supplementing with flash photos and video recordings using time intervals on the light source might indicate the realism of the constant light recordings.

About 30% of the Greenland halibut caught were not observed on the video recordings. Since the recordings were of high quality, most of these other individuals must have entered the trawl outside the camera field of view. This could either be at the same swimming height as those observed, but close to the net wall, or higher up in the water where the width of the visual field was very limited. However, the upper limit of vertical distribution seemed well defined in our study, and Greenland halibut entering towards the roof of the trawl would have represented a behaviour pattern distinctly different from those observed. On the other hand, for Greenland halibut swimming towards the trawl, the frequency of transverse position increased towards the lateral edge of the observation field. It seems probable that those not observed were individuals swimming along the net towards the trawl opening. Increasing the visual angle or adjusting the tilt may thus decrease the discrepancy between observations and catch.

Taking into account the lack of precise reference measures (i.e. width of Rockhopper disks), the length frequency distributions based on estimated and measured lengths were reasonably similar. The discrepancy increased from zero to one 5-cm length interval for individuals from 20 to 50 cm. However, error in the estimated reference measure will give increasing absolute error in estimated length for larger fish. Since there was little evidence of strong length-dependent behaviour, it is reasonable to assume that the discrepancy was mainly due to imprecise estimate of the reference length.

4.2. Greenland halibut behaviour in front of trawl

Most Greenland halibut observed could be classified in two distinct main types of behaviour: either leaving the bottom and swimming with the ground-gear or swimming towards the trawl along the ground-gear ends. These two main types may not be attributable to different phases of the same general pattern of reaction, as very few individuals were observed changing from one to the other. Also very few were swimming out of sight in such a way that they would be able to make such a change. If those that were caught without being observed on the video represent the latter behaviour type, then the two types were equally represented. Both main behaviour patterns indicate horizontal herding. Those swimming along the ground-gear ends towards the opening were herded to the mid-section of the ground-gear before crossing, and those that took off from the bottom were mainly located in front of the mid-section of the ground-gear and may thus have been herded before being detected by the video.

The take-off behaviour was similar to the way other flatfishes react in front of a trawl. Main and Sangster (1981) found that several flatfish species were herded by the sweeps towards the centre of the ground-gear. They reacted and swam away at right angles when the sweeps were close, and lay down again after 0.5–5 m. This behaviour was repeated until they were swimming in front of the ground-gear. This is consistent with our observations, where fish that left the bottom were already concentrated to the mid-section of the ground-gear section when first detected in the video image. The observations by Main and Sangster (1981) were made in shallow water during daylight, but Walsh and Hickey (1993) found little difference in flatfish reaction to the trawl during day and night. If our observations were not affected by the use of artificial light, they suggest that Greenland halibut at 600 m depth are able to react to the approaching trawl in a way similar to that observed by Main and Sangster (op cit.). In that case, herding may
be effective also along the sweeps and the associated sand clouds from the doors. The low swimming height of Greenland halibut would also facilitate herding along the sweeps.

Even though Greenland halibut that took off from the bottom were heading away from the trawl, they may not all have reacted to the trawl before lying down. Flatfish may change horizontal heading when lying on the bottom and when leaving the bottom they tend to head away from disturbing objects (Stickney et al., 1973). When facing an approaching danger flatfish may also seek to the bottom to change heading before take-off in the new direction. This facilitates fast start in the new direction (Webb, 1981). Thus, it is not possible from our observations to estimate how many of the observed individuals had previously been herded towards the trawl path. The width and efficiency of the herding process remains to be evaluated.

If individual Greenland halibut were herded by the action of doors and sweeps, one would expect to observe more and more individuals during the first few minutes of the hauls. Our results, however, showed the opposite effect, with significantly higher encounter rates at the very start than further on during in the hauls. This result may be related to some sort of surprise effect (Godø et al., 1990) on individuals encountered just after the ground-gear hit the bottom. Such effects will probably be related to signals that change abruptly rather than gradually. The visual stimuli from the artificial light source will increase gradually also for fish encountered early in the haul, as the trawl approaches obliquely from above. The sound patterns, on the other hand, will change abruptly as the ground-gear hits the bottom. It is also probable that Greenland halibut can detect the sounds generated from the ground-gear, as can other flatfishes (Karlsen, 1992; Lagardère and Vilotte, 1990). However, also some visual cues will increase abruptly at bottom contact, e.g. the lighted dust-cloud from behind the ground-gear, and it is not possible from the present study to infer which sensory systems are most important in determining the reaction to the trawl.

Our observations indicate that for smaller fish catchability increases with fish length due to reduced escapement beneath the ground-gear. Huse et al. (1999) found a bell-shaped selection curve for Greenland halibut caught by sampling trawl, including reduced catchability with increased size for the largest individuals. This seems consistent with our finding of reduced catch rates, especially of the largest individuals, during the main part of the hauls compared with the probable confusion area at the very start of the hauls. The larger Greenland halibut were probably to some degree able to avoid the trawl at distances ahead of the visual range of the camera. This is also consistent with the observation that the individuals where the tail part was the first part entering the video-frame (i.e. those that were observed reacting at greater distance from the ground-gear) constituted the upper part of the length composition in this study. A bell-shaped selection curve will seriously reduce estimates of maturation at age and the female portion of the spawning stock (Albert, 2003). The present results indicate that reducing haul duration might improve sampling of larger Greenland halibut.

4.3. General discussion and further research

Though previous direct observations of Greenland halibut are virtually non-existent, the species has often been described as a vigorous swimmer, possibly swimming in a vertical position and probably behaving more like a roundfish (Smidt, 1969; De Groot, 1970; Jørgensen, 1997; Huse et al., 1999). Our observations do not support this general view of the species. Although we do not know for how long the individuals had used energy to avoid the trawl, it is noteworthy that none of those entering our observation range were able to keep up with the trawl for more than 20 s. The swimming position was exclusively horizontal, also at more than 1 m above the bottom. Most individuals were lying on the bottom and they were apparently to a large degree, relying on the bottom for changing direction in the horizontal plane. This behaviour is in accordance with some previous circumstantial observations of Greenland halibut held in experimental tanks (Albert et al., 1999), passing over a sorting grid in demersal trawl (R. Larsen, University of Tromsø, pers. comm., 2003), and some Russian observations by video and flash camera (M. Zaferman, PINRO, Murmansk, pers. comm., 2003). Further, the spatial distribution was in accordance with a random Poisson distribution, and thus no evidence was found for schooling or shoaling behaviour. It seems that Greenland halibut is more flatfish-like than previously anticipated.
However, our observations were restricted with respect to coverage of the natural environment of Greenland halibut. First, the bottom depths were shallower than where the highest catch rates are found (Albert et al., 1998). Secondly, only the demersal region was covered, while several studies indicate that the species also may occur pelagically (Jørgensen, 1997; Bowering and Lilly, 1992; Hovde et al., 2002). Future research on availability of Greenland halibut to survey trawls should focus on behaviour at higher abundance levels and during other time periods (e.g. spawning season), and also on the extent of pelagic occurrence. In addition, the effects of artificial light on catching performance of the trawl with respect to Greenland halibut need to be addressed.

References


