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# FIELD STUDIES ON THE BEHAVIOUR OF WHITING (*GADUS MERLANGUS* L.) TOWARDS BAITED HOOKS *

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ABSTRACT

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The responses of whiting to a test line with baited hooks were studied during three cruises in the Trondheimsfjord area in three seasons. The activity of the fish directed towards the baited hooks increased at sunrise and decreased at sunset in all seasons. In October–November and May–June there was only one peak of activity, with durations of 8 and 14 hours, respectively, whereas in June–July there was a period of low activity around noon between two peaks in the morning and evening. Higher activity was observed in periods of higher, rather than lower, current, and 80–90% of the fish swam upstream into the field of observation. There was a decrease in activity over the course of trials of 60 minutes duration, and hooked fish seemed to increase the responses of unhooked fish. The intensity of response was lowest in May–June when all fish were ripe, increasing in June–July and October–November when the fish were spent. The seasonal hooking probability of different combinations of hook and bait, calculated as the ratio between the number of hooked fish and the number of rushes, was highest in October–November. Treble hooks were about twice as effective as single hooks.

## INTRODUCTION

The outcome of a fishing operation is determined by the interaction between the fishing gear and the fish. Fish behaviour is of special importance for the catching process with passive fishing gears, such as longlines and traps.

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The design and use of longlines have evolved over centuries, but it is presumably still possible to improve the efficiency of the gear. A prerequisite for this is a deeper understanding of the relationship between the fish and the gear. Direct observations of fish reactions to longlines under natural conditions are important in this connection, and are a valuable complement to laboratory studies on fish behaviour towards baits and hooks (SOLEMDAL and TILSETH 1974, FERNÖ and HUSE 1983) and comparative fishing experiments (BJORDAL 1983). Until now, few field studies on fish behaviour in relation to longlines have been made (but see JOHNSTONE and HAWKINS 1981), hence the present study was undertaken.

Although several species of fish were seen during this investigation, whiting was the most abundant and was thus studied in greater detail. Our three main objectives were the following: to give a general description of the behaviour of whiting towards baited hooks; to record the daily and seasonal variations in the level of activity around the baited hooks, including the influence of current strength and direction; and to compare the hooking probabilities (catch efficiency) of various combinations of baits and hooks.

## MATERIALS AND METHODS

Three cruises were made in the Trondheimsfjord area with a 60-foot vessel, the R/V Harry Borten II. During Cruise 1, the observations were carried out in the Borgen fjord (Fig. 1) in two adjacent localities at depths of 25 and 42 m between 27 June and 1 July 1977. During the second cruise (26 October–3 November 1977) fish abundance was too low in the Borgen fjord, hence the cruise was conducted in the Verrabotn at 40 m depth. Cruise 3 (31 May–2 June 1978) was also conducted in Verrabotn at 40 m.

Prior to the observations, an aluminium frame was placed on the bottom in a set-up similar to that shown in SUTTERLIN, SOLEMDAL and TILSETH (1981). A light-sensitive underwater television camera with a wide-angel lens (Hydro Products TC – 125 SIT–W) was mounted horizontally in the frame. A 500 W halogen lamp with a Kodak Wratten 92 red filter was also mounted and switched on when light conditions made this necessary. The filter was used because preliminary tests had shown that artifical white light could frighten the fish. A test longline about 2 m length was attached to two aluminium poles on the frame and positioned about 1 m above the bottom and 1.5 m from the camera. The visible distance was 3–5 m.

Four snoods of 40 cm length were attached to the test line 40 cm apart. Various combinations of hooks and baits were attached to the snoods, using either two combinations on alternating snoods or four different combinations. The hooks were both large and small single hooks (Mustad No. 8 and 10) and large and small treble hooks (Mustad No. 5/0 and 3/0). The baits were either

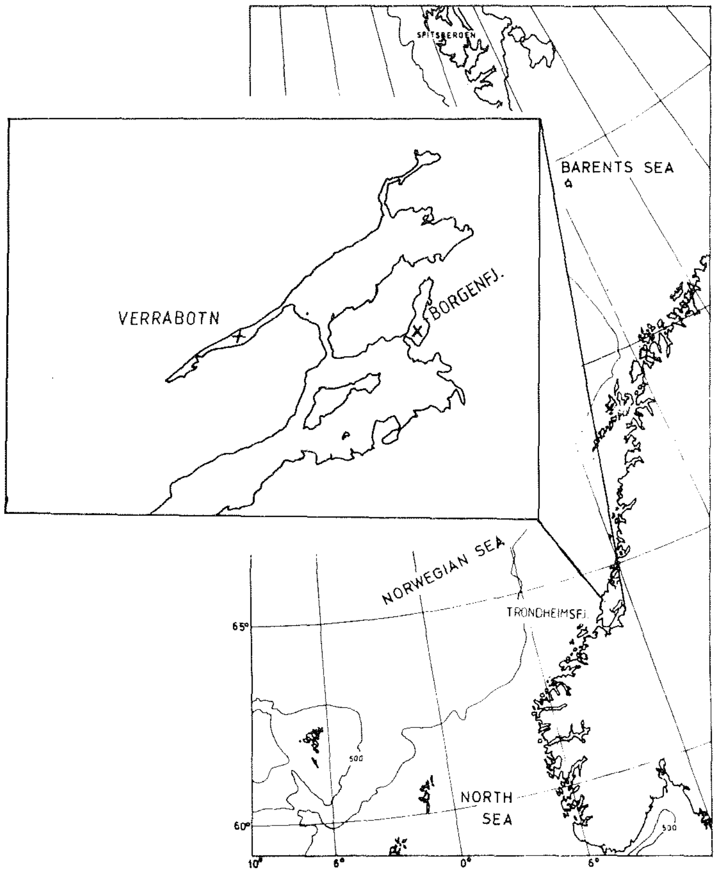


Fig. 1. The study area. Eksperimental sites are marked with x.

large (½ cross-section of a large mackerel, one cm thick) or small (¼ cross-section, same thickness). A single hook was baited by penetrating the mackerel skin twice, and a treble hook was baited by penetrating the skin once on two of the three hooks.

At the beginning of each trial, the hooks were baited afresh and the frame allowed to sink to the bottom. The observation period started when the frame had reached the bottom, and lasted 30–60 minutes or until there were no free, baited hooks left, due to hooking or bait loss. The frame was then hauled to the surface and, generally, another trial was started at once. During Cruises 1, 2 and 3, there were 51, 75 and 27 trials, respectively.

The behaviour of the observed fish was recorded according to defined behaviour patterns (see results). In addition to this, the swimming direction of fish entering the field of observation was recorded as either upstream, downstream or perpendicular (directly at right angle) to the current. Some of the trials were also videotaped for more detailed study.

During Cruise 1, the current velocity was recorded by a current meter once per trial. However, as both the direction and strength of the current often changed rapidly during a trial, the velocity during the trials in Cruises 2 and 3 was classified every five minutes into the categories (1) little or no planktonic particle movement and (2) medium to strong particle movement.

Hooked fish brought to the surface were investigated with regard to hooking position, length, total weight, liver weight, and stomach and gut content.

## RESULTS

### *BEHAVIOUR OF WHITING TOWARDS THE BAITED HOOKS*

Of the several species of fish observed to react to the baited hooks in this study, whiting was the most abundant. With the exception of haddock, other species such as cod and dogfish could easily be distinguised from whiting during the observations. Haddock were observed only occasionally during Cruises 1 and 3, but more frequently during Cruise 2, when they comprised about 10% of the hooked fish. As whiting and haddock could not be separated with certainty, all fish of these species were recorded as whiting, and the hooked haddock were included when calculating the hooking probability. As the majority of fish were whiting, this was not considered to significantly influence the main results.

The behaviour of whiting towards the baited hooks was divided into the following behaviour patterns:

| | |
|---|---|
| Taste | – touching the bait with the mouth. Tasting followed by bite or incomplete bite was not recorded. |
| Complete bite | – sucking the entire bait into the mouth and then spitting it out. |
| Incomplete bite | – differs from complete bite in that the fish takes only a part of the bait in the mouth. |
| Jerk | – a rapid, typically lateral movement of the head with the bait in the mouth. |
| Shake | – several rapid lateral movements with head and body while the bait is in the mouth. |
| Rush | – swimming rapidly forward with bait in the mouth. |
| Bait ejection | – the bait is spat or pulled out of the mouth. |
| Hooking | – the hook is retained in the mouth for at least 20 seconds while the fish fights violently. |

In addition to these behaviour patterns, during the latter part of Cruise 2 and the whole of Cruise 3, jerks, shakes und rushes following complete and incomplete bites were distinguished. Tasting, incomplete bite and reactions following incomplete bites were regarded as the least intensive behaviour patterns.

Whiting generally approached the line quickly and decelerated in the immediate vicinity of a baited hook. The fish could then change the reaction and turn away, but they generally touched the bait with the mouth. In May–June, however, many reactions were terminated without physical contact. The response could then continue with the fish taking all or part of the bait into the mouth, leading to either bait ejection or more active behaviour patterns, e.g., rushing. Several active behaviour patterns could follow each other until the bait was spat or pulled out of the mouth, or the fish was hooked. If the fish was not hooked, it renewed its efforts or left the field of observation. As several fish were often observed simultanously, it was not always possible to tell if the same fish made several attempts if it left the field of observation for a time. All fish that entered the field of observation were therefore regarded as «new» fish.

Table 1. The relative frequency of the different behaviour patterns in each season given as percentages of all behaviour patterns.

| | | Behaviour pattern | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | Incomplete | | | Complete | | | |
| Period | Taste | Bite | Jerk and Shake | Rush | Bite | Jerk and Shake | Rush | Total |
| May–June | 18.1 | 40.6 | 11.5 | 7.8 | 2.0 | 4.5 | 15.4 | 1772 |
| June–July | 9.8 | 21.2 | 8.2 | 12.2 | 0.8 | 2.8 | 45.1 | 255 |
| Oct–Nov | 31.7 | 12.9 | 2.7 | 0.5 | 2.2 | 16.7 | 33.3 | 186 |

*SEASONAL VARIATION IN THE INTENSITY OF RESPONSE*

The relative occurrence of the different behaviour patterns in different seasons can be used as a measure of the seasonal variation in the intensity of response (Table 1). As jerks, shakes and rushes following complete and incomplete bites were not differentiated for the whole study, the comparison is made with recorded data from the last part of Cruise 2, the whole of Cruise 3, and from a video-analysis of Cruise 1. To increase the size of the material, data for all single hooks were lumped together. This was justifiable because only one barely significant difference was found in the relative frequency of different behaviour patterns among the different combinations of single hooks and baits within seasons. The jerk and shake reactions were combined to form one category.

There were marked seasonal differences in the relative occurrence of the different behaviour patterns ($p<0.001$, $\chi^2$-test). The ratio between the number of complete and incomplete bites and the ratio between the number of jerks, shakes and rushes following complete and incomplete bites (complete versus incomplete jerks, shakes and rushes in Table 1) were lowest in May–June and highest in October–November. Rush was least frequent in May–June and tasting least frequent in June–July. Generally speaking, the intensity of response was lowest in May–June and rose to about the same level in June–July and October–November.

*DIEL VARIATION IN ACTIVITY*

The diel variation in the activity of whiting towards the baited hooks in different seasons is shown in Fig. 2 as the sum of all behaviour patterns except

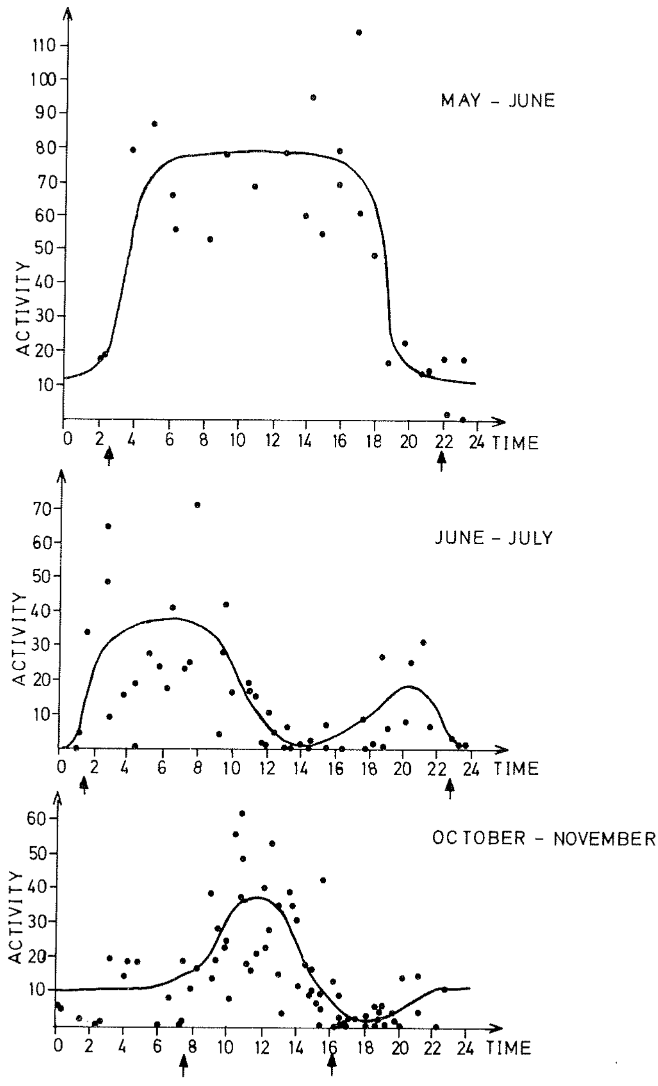


Fig. 2. The diel variation in activity of whiting towards a test line in three seasons given as the sum of all behaviour patterns towards the baited hooks. Each point represents one trial weighted to a 60-min observation time. The curves are drawn by hand. Sunrise and sunset are indicated by arrows.

for bait ejection and hooking. In May–June the fish were diurnally active for about 14 hours, the activity increasing at dawn and decreasing at dusk. The activity was relatively low during the night. In June–July, there were peaks of activity at dawn and dusk with periods of low activity around noon and midnight. In October–November, there was again only one peak of activity during daytime, lasting about eight hours.

Table 2. The influence of the current on the number of fish responding to the baited hooks, fish activity (sum of all behaviour patterns), and number of hooked fish in periods of high and low activity. The mean values for the first 30 minutes of trials with a relatively constant current are given.
Trials lasting for 10–30 minutes are weighted to 30 minutes and trials lasting less than 10 minutes are disregarded.

| | High-activity period | | Low-activity period | |
|---|---|---|---|---|
| | Current | No current | Current | No current |
| No. of fish responding | 24.7 | 16.7 | 5.4 | 2.2 |
| Fish activity | 33.6 | 17.7 | 9.2 | 3.8 |
| No. of hooked fish | 2.6 | 1.5 | 0.7 | 0.4 |

*ACTIVITY AND SWIMMING DIRECTION RELATIVE TO CURRENT*

The influence of the current on fish activity was investigated using the data from Cruise 2 in October–November. The strength of the current was not estimated in the same way in Cruise 1, and the amount of data from Cruise 3 was too small to permit this analysis. The trials in the period of high activity (8 a.m.–4 p.m.) were treated separately from trials in the period of low activity (the rest of the 24-hour cycle), as the pronounced diel variation in activity could otherwise conceal any effect of the current. Trials without current generally occurred either at high or low tide. The amount of data did not permit any comparison between ebb and flow.

Table 3. Swimming direction of fish relative to current, given separately for fish with and without response towards the baited hooks. The number of fish and percentage of total (within brackets) are given for the different swimming directions.

| *Swimming direction* | Fish with response | Fish without response |
|---|---|---|
| *Upstream* | 589 (89.0) | 420 (78.0) |
| Downstream | 22 (3.3) | 34 (6.5) |
| Perpendicular to the current | 51 (7.7) | 81 (15.5) |

Table 2 shows that the number of fish responding, in any one of the defined behaviour patterns, to the baited hooks was higher in trials with current than in trials without current in periods of both high ($p<0.10$, Mann-Whitney U test) and low ($p<0.05$) activity. The same tendencies were observed for fish activity and the number of hooked fish (high-activity period $p<0.05$, low-activity period n. s.).

The swimming direction of whiting relative to the direction of current is given in Table 3. Data are presented from the cruise in May–June. The majority of fish swam upstream whether they made a response or not ($p<0.001, \chi^2$-test). However, fish which responded to the baited hooks swam upstream more often than fish that made no response ($p<0.001$).

*CHANGES IN ACTIVITY WITHIN TRIALS AND THE EFFECT OF HOOKED FISH*

The decrease in the level of activity during a 60-min trial is illustrated in Fig. 3 by the reduction in the number of jerks and rushes. No clear change in the relative occurence of the different behaviour patterns was found within a trial.

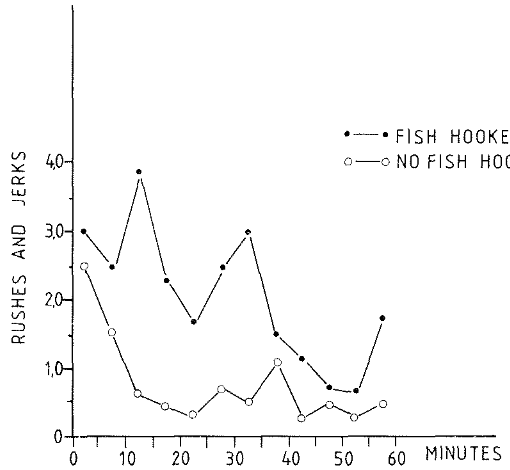


Fig. 3. The mean number of rushes and jerks in successive 5-min intervals of the trials. The activity when no hooked fish were present on the test line is compared with the activity when at least one fish was struggling on the line. Each point represents the mean of from 3 to 30 5-min intervals. Data were taken from the cruise in June–July.

Fig. 3 also compares the number of rushes and jerks in 5-min intervals in the presence and absence of hooked fish. A decrease in activity over time was found under both conditions, but the mean number of rushes and jerks was about twice as high in the presence of hooked fish. A similar, although somewhat smaller, difference was found if those 5-min intervals when fish became hooked were disregarded. This shows that the difference cannot be explained simply by a correlation between high activity and hooking, and indicates that there is actually a positive effect on general activity by fish hooked on the line.

*HOOKING*

As the vast majority of hookings took place in connection with a rush, cf. Discussion below, the hooking probability was calculated as the number of hooked fish divided by the number of rushes. The hooking probability differed

Table 4. The probability of hooking whiting with various combinations of hook and bait, calculated as the ratio between numbers of hooked fish and rushes in each season. The number of hooked fish is given within brackets.

| | Bait | | | | | |
|---|---|---|---|---|---|---|
| | Small | | | Large | | |
| | Hook | | | | | |
| Time of year | Small single | Large single | Small treble | Small single | Large single | Large treble |
| May–June | 0.11(21) | 0.14(23) | | 0.14(5) | 0.19(5) | |
| June–July | 0.13(20) | | | | 0.08(18) | |
| Oct–Nov | 0.28(13) | | 0.52(15) | | 0.19(15) | 0.40(18) |

with the combination of hook and bait (Table 4) and was about twice as high for treble hooks than for single hooks ($p<0.01, \chi^2$-test, regardless of size of hook or bait). No significant difference in hooking probability between any combination of single hook and bait or between any combination of treble hook and bait was found within one season.

Seasonal differences were also found in the hooking probability. The hooking probability of a small single hook with small bait was significantly higher in October–November than in May–June ($p<0.01$) or June–July ($p<0.05$). A large single hook with large bait also had a higher hooking probability in October–November than in June–July ($p<0.01$).

Table 5. Data from the hooked whiting in different sesons. (The weight was not recorded during the cruise in June–July).

| | May–June | June–July | Oct–Nov |
|---|---|---|---|
| No. hooked in mouth | 44 | 39 | 42 |
| No. hooked in stomach or throat | 3 | 6 | 13 |
| Mean length in cm (range) | 37.8(26–50) | 36.1(29–56) | 38.2(30–47) |
| Mean total weight in g (range) | 446(131–987) | – | 435(166–1008) |
| Mean liver weight in g (range) | 13.1(1.5–40.0) | – | 10.4(1.7–71.0) |

Data from the hooked whiting that were brought to the surface are presented in Table 5. Most fish were caught in the mouth. Swallowed hooks in the stomach or throat were seldom found, although these cases were more common in October–November than in May–June ($p < 0.05$, $\chi^2$-test).

Whiting caught in October–November were longer than whiting caught in June–July ($p < 0.05$, t-test). However, in the autumn, in addition to single hooks, treble hooks were used and tended to catch larger fish (single-hooks' mean captured length 36.7 cm and mean total weight 375 g versus treble hooks' mean length 39.5 cm, $p < 0.01$ and mean total weight 474 g, $p < 0.05$). No seasonal difference was found for fish caught with single hooks. Therefore, the size distribution of whiting is the same in all cruises. No other significant differences in length, total weight, or liver weight were found for the different combinations of hook and bait within or between seasons.

Fish caught in the stomach or throat were not significantly different from fish caught in the mouth with regard to length or total weight. Fish with swallowed hooks had, however, a lower liver weight ($m = 4.9$ g) than fish caught in the mouth ($m = 12.9$, $p < 0.001$, Mann-Whitney U test, data from Cruise 2). A condition factor, based on gutted weight, was also calculated from Cruise 2 according to the formula

$$Q = \frac{\text{gutted weight in g} \times 100}{(\text{length in cm})^3}$$

and showed that fish caught in the stomach or throat had a lower mean condition factor (0.62) than fish caught in the mouth (0.69, $p < 0.01$).

The majority of fish had no stomach content, but as hooked whiting was observed to regurgitate, there were no reliable data on stomach contents prior to hooking. Generally the gut was 1/3–2/3 full.

Approximately equal numbers of male and female fish were caught. In May–June all mature fish were ripe, in June–July all but one fish were spent, and in October–November all fish were spent.

*DISCUSSION*

There was a diurnal rhytm in the activity of whiting towards baited hooks that varied seasonally, increasing at sunrise and decreasing at sunset. Differences between seasons in time of sunrise and sunset may therefore explain, to a large extent, the seasonal variation in the daily rhytm of activity. In May–June and October–November there was only one peak of activity, which lasted longer in May–June than in October–November, corresponding to the period of daylight. However, in June–July there was a period of low activity around noon between two peaks of activity in the morning and evening. Similar shifts between one and two peaks of activity, in connection with an increase and decrease of the light cycle, have been observed in laboratory studies for several species of fish (Müller 1978).

The observed diel variation in activity could be explained by both a diel variation in the feeding tendency and a daily vertical migration. It is known that whiting migrate vertically and can adjust the vertical distribution according to the prevailing amount of light (Blaxter and Parrish 1958, Bailey 1975, Gordon 1977). There are no data about vertical migration in the present study, but a descent at sunrise could partly explain the generally high daytime response to the baited hooks. However, the low noontime activity found in June–July is not easily explained by vertical migration. We also observed relatively large numbers of whiting in the field of observation even during the periods of low activity. Therefore, it seems likely that a variation in feeding tendency may be partly responsible for this recorded diurnal activity rhytm.

Superimposed on the diurnal rhytm was the current, whose presence led to increased activity and a higher number of hooked fish (cf. TILSETH, SOLEMDAL and FERNÖ 1978). It is known that whiting have a well-developed sense of smell (ARANOV 1959), and, as 80–90% of the whiting swam upstream to enter the field of observation, there is good reason to believe that a strong current can carry the olfactory stimuli over a greater distance and thus attract more fish. Upstream movement towards smell stimuli has also been observed in other fish species (SUTTERLIN 1975, VALDEMARSEN, FERNÖ and JOHANNESEN 1977).

The decreasing frequency of response to the baited hooks over a one-hour observation period may be due to a reduction of the smell stimuli from the bait in conjunction with a decrease in the number of available baits (cf. FERNÖ, TILSETH and SOLEMDAL 1977). Changes in the response of the fish after experience with baited hooks may also be involved in the decrease since aversive stimulation by contact with the point of the hook may give negative reinforcement and terminate the response. Such negative conditioning is known to take place in cod (FERNÖ and HUSE 1983). In this way, fish initially attracted may gradually leave the area if not caught.

When hooked fish were present on the test line, there were more responses towards the baited hooks than when no fish were hooked. This positive effect of hooked fish could be explained by the observation that fish often approached a struggling hooked fish and reacted to the free baits moving with the struggle. Whiting also react visually to moving food in the laboratory (ARANOV 1959, PAWSON 1977). No fright reactions were observed at the hooking of another fish in the present study.

Whiting showed an increased intensity of response to the test line from the spawning period in May–June, when all fish were ripe, to October–November, when all fish were spent. This may reflect a seasonal variation of the feeding tendency. In cod, the food intake is low during the spawning period both in the laboratory (SOLEMDAL 1984) and in the field (RAE 1967). A correlation between the feeding tendency and the behaviour towards the baited hooks is also indicated on the individual level by the finding that whiting with swallowed hooks had a lower liver weight and a lower condition factor than whiting caught in the mouth. A correlation between swallowing of the hook and low condition factor has also been found in cod (JOHANNESSEN 1983).

When investigating the efficiency of a particular combination of hook and bait, it is essential to know which behaviour pattern leads to hooking. Rush was chosen as the most important behaviour pattern, as it occurred in connection with the vast majority of hooking (cf. FERNÖ, SOLEMDAL and TILSETH 1981). However, as it was not possible to decide the exact moment of hooking, a fish may be caught during a previous behaviour pattern, e.g., a bite or jerk, and the rush could then be more the consequence than the cause of hooking. Whiting that swallowed the hook were presumably hooked before the rush. However, most whiting were caught in the mouth. Only a fraction of the fish were hooked after the rush, and many rushes were observed where only a part of the bait, and not the hook, was inside mouth. Therefore, we regard whiting as not generally being hooked prior to the rush, and the hooking probability was calculated as the number of hooked fish in relation to the number of rushes.

The proportion of fish hooked after a rush was relatively low (between 10 and 50%). The proportion of fish caught in connection with a rush may be determined by

1. The orientation of the point of the hook
2. The proportion of rushes based on a complete bite
3. The intensity or swimming speed of the rush.

The higher hooking probability of a treble hook compared to that of a single hook, demonstrates the importance of the orientation of the point of the hook. In order to hook efficiently, the point of the hook must have a certain position in the mouth and a certain angle to the direction of the snood during the rush (Huse 1979). The probability for this to occur obviously increases when several hooks aiming in different directions are present together.

The proportion of rushes following a complete bite may also influence the hooking probability, as the hook is probably seldom inside the mouth in a rush based on an incomplete bite. This proportion was highest in October–November, and the hooking probability was also highest during this time of the year.

No data exist concerning seasonal differences in the strength of the rush. The majority of observed rushes probably created enough power to allow the hook to penetrate the inside of the mouth cavity because of the sudden opposing force of the stretched snood. This sudden stop may, to a certain extent, differ from the situation in real longline fishing.

Some general observations of fish behaviour relevant to longline fishing could also be made from this study. When several whitings were in the vicinity of the test line, competition for the free baits was observed and could lead to aggressive interactions. Interspecific reactions were also observed. Cod sometimes chased away whiting from the test line and also directed bites at hooked whiting. The presence of one species could therefore influence the efficiency of a longline in catching another species. In conclusion, this study illustrates the importance of behavioural studies when attempting to comprehend the effective aspects of fishing gear.

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