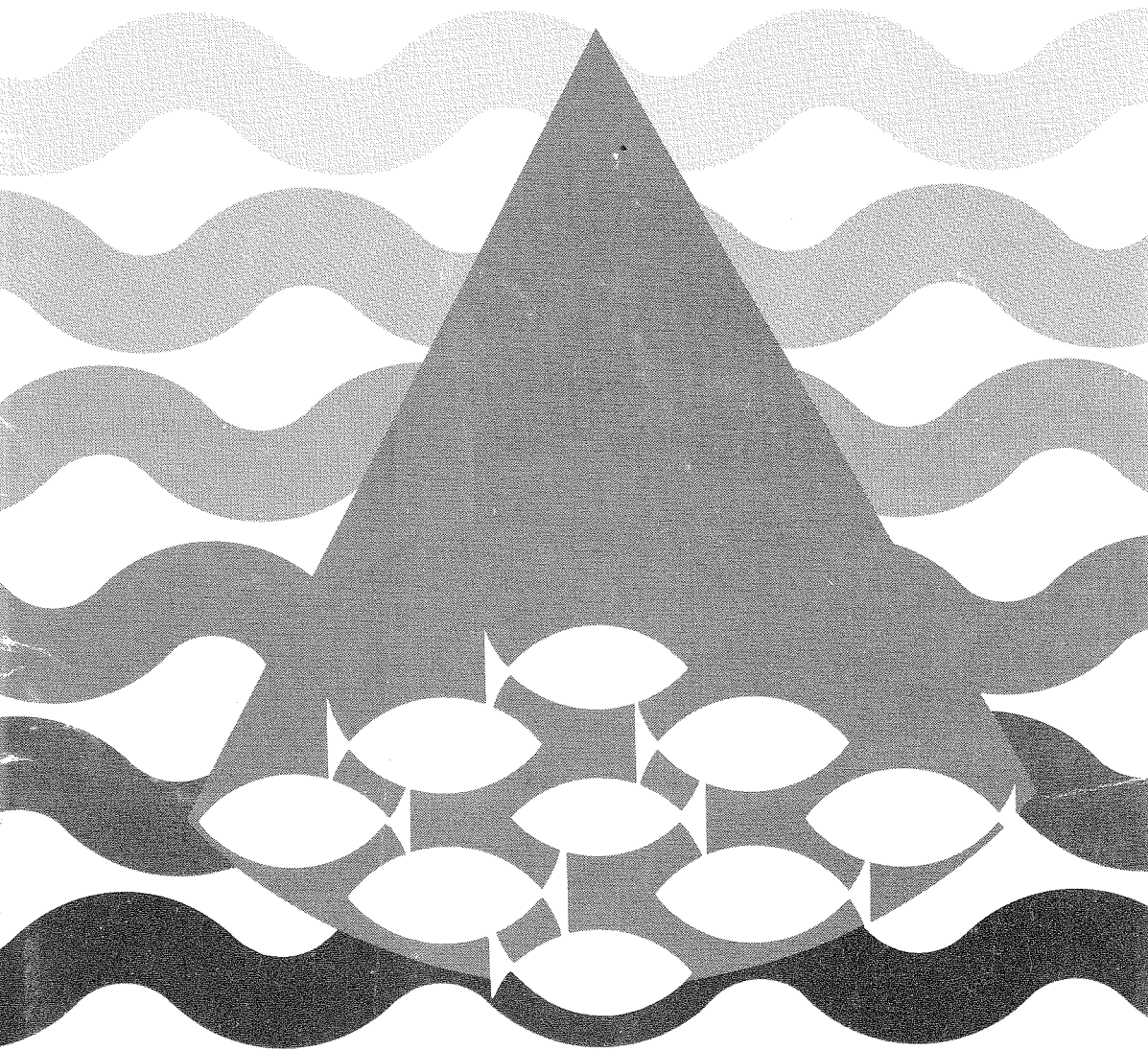


FISKERIDIREKTORATETS SKRIFTER  
SERIE HAVUNDERSØKELSER

VOL. 18. No. 3



DIRECTORATE OF FISHERIES, BERGEN, NORWAY  
1986

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

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ABSTRACT

FERNÖ, A., SOLEMDAL, P. and TILSETH, S. 1986. Field studies on the behaviour of whiting (*Gadus merlangus* L.) towards baited books. *FiskDir. Skr. Ser. HavUnders., 18: 83-95.*

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.

\* This paper was first presented at the national symposium «Behaviour of marine animals» held at Solstrand, Os, Norway, 9–10 February 1983.

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-angle 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 artificial 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

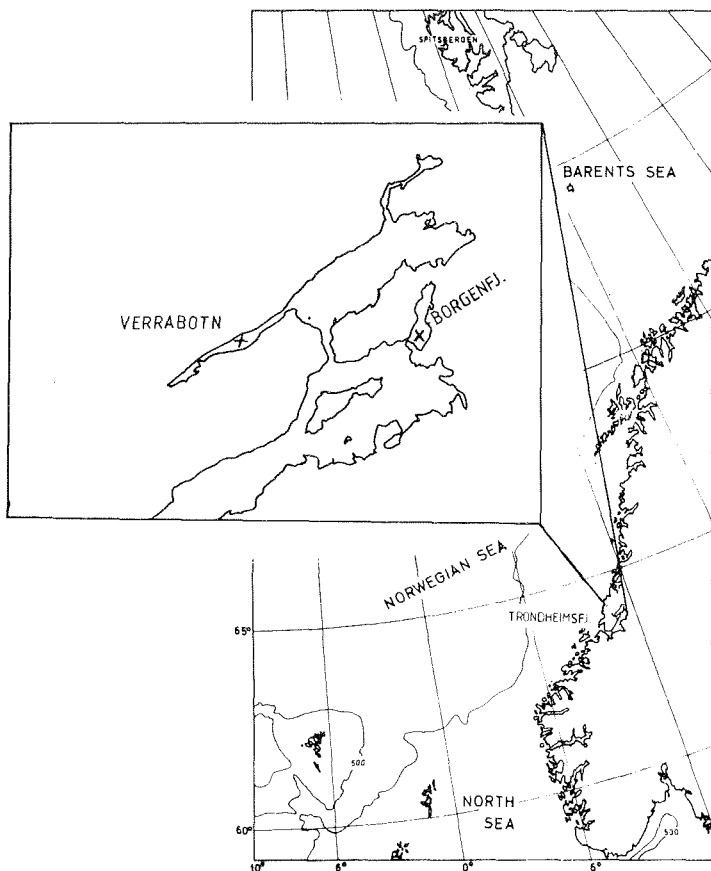


Fig. 1. The study area. Eksperimental sites are marked with x.

large ( $\frac{1}{2}$  cross-section of a large mackerel, one cm thick) or small ( $\frac{1}{4}$  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 distinguished 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 and 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 simultaneously, 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.

Period	Taste	Behaviour pattern						Total
		Incomplete			Complete			
		Bite	Jerk and Shake	Rush	Bite	Jerk and Shake	Rush	
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

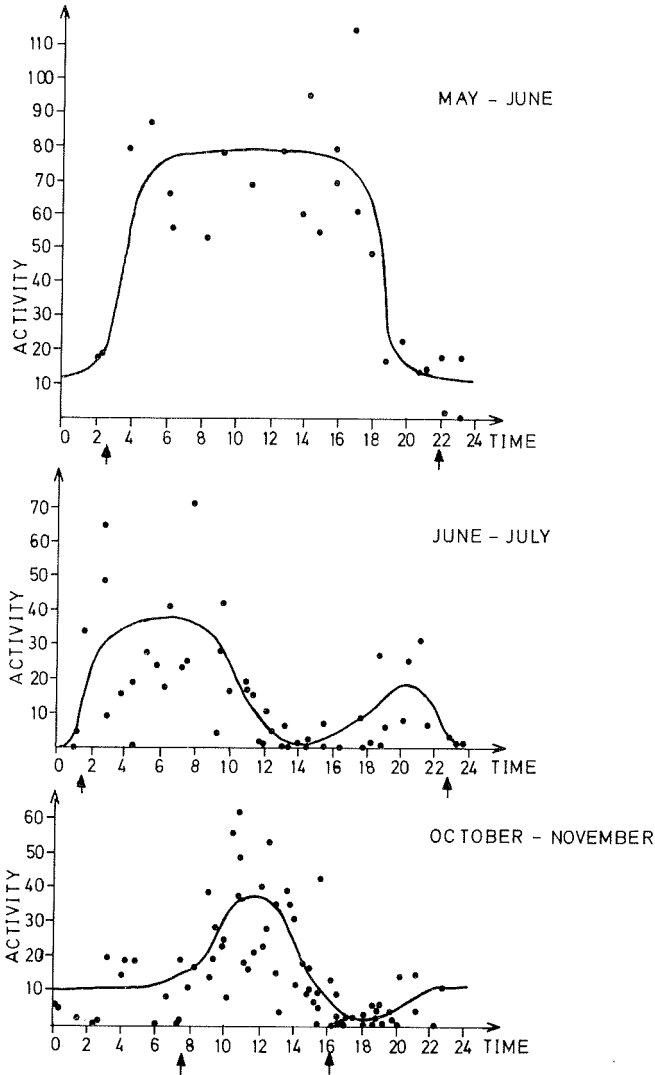


Fig. 2. The diel variation in activity of whiting towards a test line in three seasons given as the sum of all behaviour patterns towards the baited hooks. Each point represents one trial weighted to a 60-min observation time. The curves are drawn by hand. Sunrise and sunset are indicated by arrows.

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 occurrence of the different behaviour patterns was found within a trial.

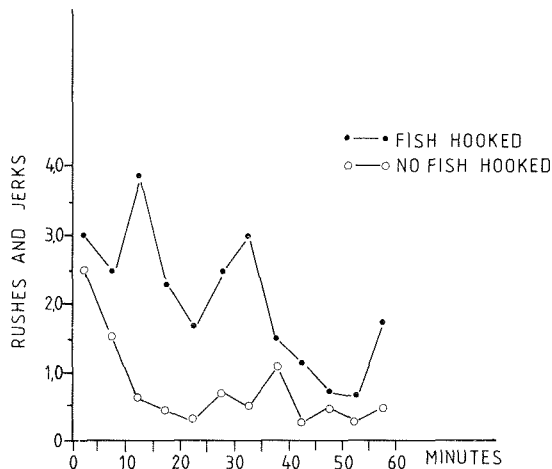


Fig. 3. The mean number of rushes and jerks in successive 5-min intervals of the trials. The activity when no hooked fish were present on the test line is compared with the activity when at least one fish was struggling on the line. Each point represents the mean of from 3 to 30 5-min intervals. Data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

Time of year	Bait					
	Small		Hook		Large	
	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 seasons. (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 rhythm 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 rhythm 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 rhythm.

Superimposed on the diurnal rhythm 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 JOHANNESSEN 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 whittings 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.

#### ACKNOWLEDGEMENT

We thank Miss Karin Pittman for remarks on the manuscript.

## REFERENCES

- ARANOV, M.P. 1959. The role of the sense organs in the finding of food by the Black Sea whiting. *Trudy Sevastopol' biol. Sta.*, 11: 229-237.
- BAILEY, R.S. 1975. Observations on diel behaviour patterns of North Sea gadoids in the pelagic phase. *J. mar. biol. Ass. U.K.*, 55: 133-142.
- BJORDAL, Å. 1983. Effects of different longline baits (mackerel, squid) on catch rates and selectivity for tusk and ling. *Coun. Meet. int. Coun. Explor. Sea, 1983* (B:31): 1-9. [Mimeo.]
- BLAXTER, J.H.S. and PARRISH, B.B. 1958. The effect of artificial light on fish. *Mar. Res.*, 2: 1-24.
- FERNÖ, A., TILSETH, S. and SOLEMDAL, P. 1977. The behaviour of whiting (*Gadus merlangus*) in relation to longlines. *Coun. Meet. int. Explor. Sea, 1977* (B:44):1-11. [Mimeo.]
- FERNÖ, A., SOLEMDAL, P. and TILSETH, S. 1981. Factors influencing the attraction and hooking of fish in longline fishing. *Int. Coun. Explor. Sea Working group on reactions of fish to fishing operations*, Nantes 1981: 1-10. [Mimeo.]
- FERNÖ, A. and HUSE, I. 1983. The effect of experience on the behaviour of cod (*Gadus morhua* L.) towards a baited hook. *Fisheries Research*, 2: 19-28.
- GORDON, J.D.M. 1977. The fish populations in inshore waters of the West coast of Scotland. The distribution, abundance and growth of whiting (*Merlangius merlangus* L.) *J. Fish. Biol.*, 10: 587-596.
- HUSE, I. 1979. Fish behaviour studies as an aid to cod and haddock longline hook design. *Coun. Meet. int. Coun. Explor. Sea, 1979* (B:43): 1-12. [Mimeo.]
- JOHANNESSEN, T. 1983. Betydning av krok- og agnstørrelse for fangsteffektivitet og lengdeseleksjon i linelisket etter torsk (*Gadus morhua* L.) og hyse (*Melanogammus aeglefinus* L.) Thesis, University of Bergen. 109 p.
- JOHNSTONE, A.D.F. and HAWKINS, A.D. 1981. A method for testing the effectiveness of different fishing baits in the sea. *Scottish Fisheries Information Pamphlet, ( 1981)* 3:1-7.
- MÜLLER, K. 1978. Locomotor activity of fish and environmental oscillations. p. 1-19 in THORPE, J.E. ed. *Rhythmic activity of fishes*. Academic Press, London.
- PAWSON, M.G. 1977. Analysis of a natural chemical attractant for whiting, *Merlangius merlangus* L. and cod, *Gadus morhua* L., using a behavioural bioassay. *Comp. Biochem. Physiol.*, 56 A: 129-135.
- RAE, B.B. 1967. The food of cod in the North Sea and on west of Scotland grounds. *Mar. Res.*, 1967 1:1-68.
- SOLEMDAL, P. 1984. Individual variation in response from smell stimuli by cod (*Gadus morhua* L.). *Int. Coun. Explor. Sea Ad hoc working group on artificial bait and bait attraction, Hirtshals, May 2-4 1984*: 1-20. [Mimeo.]
- SOLEMDAL, P. and TILSETH, S. 1974. Reactions of cod (*Gadus morhua* L.) to smell stimuli from bait. *Coun. Meet. int. Coun. Explor. Sea, 1974* (F:40): 1-20. [Mimeo.]
- SUTTERLIN, A.M. 1975. Chemical attraction of some marine fish in their natural habitat. *J. Fish. Res. Bd Can.*, 32: 729-738.
- SUTTERLIN, A.M., SOLEMDAL, P. and TILSETH, S. 1981. Baits in fisheries with emphasis on the North Atlantic cod fishing industry. P. 293-305 in HARA, T.J. ed. *Chemoreception in Fishes*. Elsevier scientific Publishing Company, Amsterdam.
- TILSETH, S., SOLEMDAL, P. and FERNÖ, A. 1978. Behaviour studies on fish reaction to longlines. *Coun. Meet. int. Coun. Explor. Sea, 1978* (B:22): 1-9. [Mimeo.]
- VALDEMARSEN, J.W., FERNÖ, A. and JOHANNESSEN, A. 1977. Studies on the behaviour of some gadoid species in relation to traps. *Coun. Meet. int. Coun. Explor. Sea, 1977* (B:42): 1-9. [Mimeo.]



## AVOIDANCE OF PETROLEUM HYDROCARBONS BY THE COD (*GADUS MORHUA*) \*

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### ABSTRACT

BØHLE, B. 1986. Avoidance of petroleum hydrocarbons by the cod (*Gadus morhua*). *FiskDir. Skr. Ser. HavUnders.*, 18: 97–112.

The experimental fish were held in two different aquaria, one with three and one with two compartments. Water containing «water soluble fraction» of Fuel Oil No. 2 was introduced in one of the compartments. By means of light- and sound-based detectors, the amount of time spent by the fish in the various compartments was recorded. Although the results were somewhat contradictory, it seems that the fish avoided water containing more than 100 µg/l of the petroleum hydrocarbons.

### INTRODUCTION

Concern over marine pollution by crude oil and refinery products has increased steadily over the last few decades. The risk for and occurrence of oil spills in the open sea and chronic oil pollution in inshore waters has increased considerably as the utilization of petroleum products has increased. The increase of petroleum hydrocarbons in the oceans has been estimated to be 4.5 mill tons per year, with the largest increase resulting from transportation and river run-off (ANON. 1975).

In spite of the relatively high chronic increase and occasionally heavy spill of crude oil and oil products, the concentrations of petroleum hydrocarbons in offshore waters are reportedly very low (ANON. 1975). In the open ocean, the concentration of petroleum hydrocarbons at the surface is generally less than 10 µg/l. In subsurface waters, the concentration is even lower. However, in inshore waters close to large harbours, up to 1000 µg/l of total hydrocarbons may occur.

\* This paper was first presented at the national symposium «Behaviour of marine animals» held at Solstrand, Os, Norway, 9–10 February 1983.



Though extremely variable, the solubility of petroleum hydrocarbons in the sea water is low. Components with low boiling points evaporate quickly, however, depending on temperature, wind speed, and like influences. Petroleum products spilled on the sea surface may also be emulsified in the water column.

After an oil spill near Stavanger (Norway), concentrations of hydrocarbons were found up to 200 µg/l although concentrations of 20 000 µ/l were found close to areas where oil had gathered in bays (GRAHL-NIELSEN *et al.* 1976). The high values occurred as oil-in-water emulsions.

Several experiments have been performed to study possible effects of petroleum hydrocarbons on marine life. Many of these involved high oil concentrations that only very seldom might be found in the sea, for example, immediately after oil spills (KÜHNHOLD 1969).

RICE (1973) found that fry of Pink Salmon (*Onchorhynchus gorbuscha*) avoided Prudhoe Bay oil at a concentration of 1.6 µg/l. SUAZUKI (1964) found that some fish species (goby, perch, striped mullet) avoided «crude petroleum» at 0.7 µg/l. Other types of oil required much higher concentrations to give the same effects.

Earlier experiments on the behaviour of adult cod (*Gadus morhua* L.) in relation to hydrocarbons are lacking. HELLSTRØM and DØVING (1983) have estimated that cod can detect very low concentrations of petroleum hydrocarbons, of the order of 0.1 µg/l.

It is not known whether realistic concentrations, i.e., those less than 500 µg/l, of petroleum hydrocarbons in the sea may alter the natural pattern of fish behaviour, i.e., migration and catchability. The aim of this study was to investigate any avoidance effects of hydrocarbons due to chronic pollution or oil spills. The experiments were performed at the Institute of Marine Research, Flødevigen Biological Station, Norway, in the period 1979–1981.

## METHODS

The experiments were performed with two aquaria. One aquarium is cog-shaped, with three compartments and a hexagonal core. The other is rectangular, with two compartments.

### THE COG-SHAPED AQUARIUM

A sketch of a cog-shaped aquarium is given in Fig. 1. Except for the bottom in the central section, which was of acryl, the walls and bottom were made of glass, sealed to a steel frame with silicone glue. The water depth in the aquarium was 30 cm, giving a total volume of 55 l in each compartment.

Sea water was introduced separately in each compartment, and the flow was adjusted to maintain equal volumes. An overflow outlet was placed in the

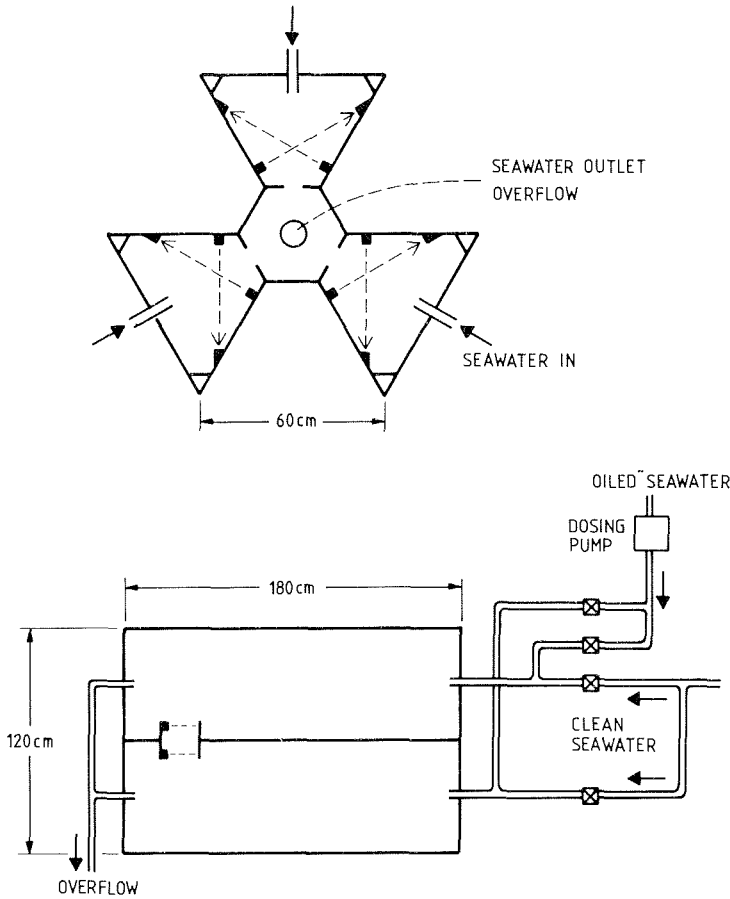


Fig. 1. The experimental aquaria. Top: the cog-shaped aquarium, Bottom: the two-compartment aquarium.

middle compartment. This was separated from the outer compartments by glass, except for openings, 11 cm x 8 cm, through which the experimental fish could move. To minimize the risk of water entering other compartments, the inflows to the several compartments were equalized. Water outlets were arranged as overflow in the middle compartment.

The aquarium was shield from daylight and the side walls covered with black cardboard. Six 25 W lamps above the aquarium and controlled by a dimmer provided equal illumination to each compartment.

In each compartment infrared light sources and photo detectors were mounted for recording where the fish stayed and moved. When the fish interrupted the light beam, an impulse was given to a counter. There were two detectors and two counters for each compartment. The detectors were mounted

identically in each compartment. The numbers on the counters, reflecting the swimming activity in each compartment, were most often logged every two hours.

The size of the aquarium was chosen so that the fish would experience the need for more space or water than was in a single compartment, i.e., the fish would be constantly motivated to move to another compartment. This was necessary to facilitate data-gathering.

The fish were considered to be acclimated to the experimental conditions and unstressed when their swimming mode was relaxed and their pigmentation was natural. This ensured that the fish had relieved any stress due to the capture, transportation, or transfer from the storage tank.

The oily sea water was prepared by letting clean sea water, at a rate of 1–1.5 l/min, flow through a diffusor and sink by gravity as small drops through a column of the lighter fuel oil (Fig. 2). In this way, a relatively large portion of the sea water came in direct contact with the oil. This resulted in a relatively high concentration of hydrocarbons; namely, 2000–3000  $\mu\text{g/l}$  in the outflowing water.

Initially, it was desired to use Ekofisk crude as a source in preparing a «water soluble fraction» (WSF). Because of technical problems in mixing the crude with sea water, this could not be performed. Therefore, the Fuel Oil No. 2 was selected as the pollutant. This is a refinery product which, compared to Ekofisk

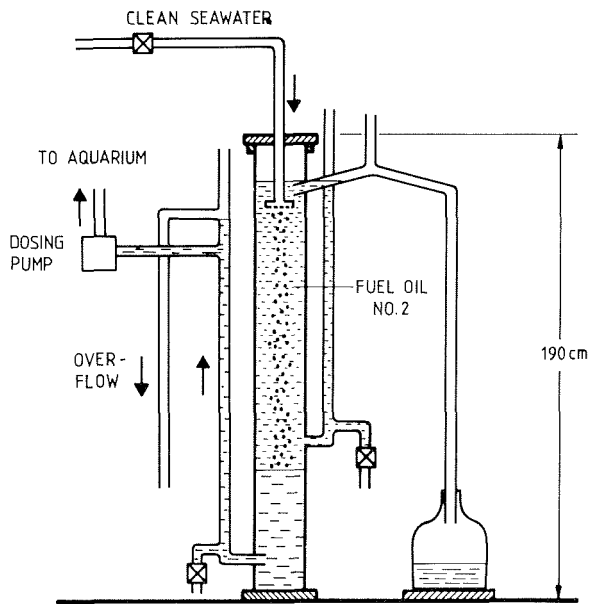


Fig. 2. The petroleum-water mixing arrangement.

crude, lacks only the lowest- and highest-boiling-point components (Fig. 3).

One of the experiences from the Ekofisk blowout in the North Sea in April 1977 was that the hydrocarbons introduced to the sea were both in true solution and in emulsified form (GRAHL-NIELSEN, WESTRHEIM and WILHELMSEN 1977). The oily water in the present study, as indicated on the chromatograph (Fig. 4), contained hydrocarbons both in solution and in emulsion. In this respect, at least, there is a similarity in chemical exposure compared to the Ekofisk blowout (GRAHL-NIELSEN *et al.* 1976).

The experiments lasted from a few days to four weeks. Usually one batch of oil was used throughout the same experiment, sometimes from one experiment to the next one.

It has been argued that the most soluble components of the oil might be «washed out» with time, and that the WSF in the aquarium could shift toward the less soluble components. Tests of the outflowing sea water from the column showed that the content of the most soluble components at the times of measurement was as high as at the beginning of the experiments.

The supply of oily sea water to the aquarium was taken from the outflow of the oil column and delivered at a constant rate by a dosing pump. The concentration of hydrocarbons in the aquarium was altered by adjustments to the dosing pump. The clean and the oily sea water were mixed in a glass funnel to ensure dilution before entering the aquarium.

#### THE TWO-COMPARTMENT AQUARIUM

The two-compartment aquarium was rectangular, with dimensions 180 cm × 120 cm × 80 cm (Fig. 1). The aquarium was divided into two equal compartments by means of a partition wall of shaded glass. The aquarium was constructed from a steel frame, with bottom and side walls of glass. The end-walls were made from acryl. The aquarium was covered by black cardboard, shaded from daylight, and illuminated from above by a single 60 W lamp.

The inlets of the sea water were placed at the end walls, one in each compartment. The flow was adjusted by valves and controlled separately by flow meters. Two overflow outlets were placed in the opposite end-walls, one in each compartment. There was an opening in the partition wall near the outlets. This opening, 20 cm × 20 cm, was made as small as possible to minimize penetration of water from one compartment to the other, while being large enough to let the fish swim through easily.

Sea water with hydrocarbons was prepared in the oil column (Fig. 2) and delivered by a dosing pump. The pipeline from the oil column was connected directly to the pipeline with clean sea water. The oily sea water was directed to

only one of the two compartments at any one time, but could be shifted from one to the other.

It was not possible to prevent sea water from entering the other compartment. Thus, the fish had the «choice» between oily and less oily sea water.

For monitoring and recording the compartment in which the fish stayed, two ultrasound transmitters were placed in the opening in the partition wall. These were connected to an electronic unit. When the fish moved through the opening, the two sound beams were interrupted. The sequence of interruptions indicated the direction the fish moved, and consequently where the fish had been. A strip chart recorder indicated where the fish stayed. To obtain a quantitative measure of the durations of residence of the fish in the different compartments, the recordings on the chart paper were measured by means of a line meter and computed to give fish distributions in percent of time between the two compartments.

The sea water used in all experiments was taken from 75 m depth, through the Biological Station's sea water system. The salinity range was 30–32 ‰, the temperature varied between 6 and 12° C, though very little within each experiment. In the last two experiments with the two-compartment aquarium, the temperature was held constant at 10° C. To some extent, different temperature levels might explain different levels of total swimming activity and may have influenced how fast a response to changes in water quality could be recorded.

Water samples of 0.8–0.9 l were taken from the aquaria by siphoning into a 1 l separator funnel. Hydrocarbons were extracted by shaking twice for 3 min with 20 ml of distilled dichloromethane. Of the extract, 10–30 ml was evaporated in a Rotavapor to 0.5–1.0 ml. The hydrocarbons with  $C_n < 10$  were to a large extent lost during this procedure. This volume was transferred to a 1 ml Microvessel where it was concentrated further by blowing nitrogen. In the first experimental period, the volume was adjusted to 15  $\mu$ l. Later on, 40  $\mu$ l was used as a standard volume. When the injection in the gas chromatograph was to be performed by an autosampler, the concentrate was transferred to a 0.1 ml V-shaped vial and the volume adjusted to 40  $\mu$ l.

The quantification of hydrocarbons in the sea water was performed by gas chromatography (GC). Water samples from the first five experiments with the cog-shaped aquarium were analyzed on a Perkin Elmer 900. The GC was equipped with a 1/4 inch  $\times$  10 feet glass column, packed with 3% SP 2100 on 80/100 Supelcoport. The temperature profile was 80–295° C, at 8° C/min. Carrier gas was nitrogen at 50 ml/min. The GC was equipped with flame ionization detector (FID).

For the quantitative estimates, the area below the chromatographic curve, measured by means of a planimeter, was subtracted from the area below the

chromatographic curve resulting from injection of the same volume of solvent (dichloromethane). As a standard, a solution of Fuel Oil No. 2 in dichloromethane was used. The injection volume was standardized to 2  $\mu$ l.

Water samples from the last four experiments with the cog-shaped aquarium and from all the experiments with the two-compartment aquarium were analyzed on a Hewlett-Packard 5880A gas chromatograph. Most of these samples were injected by an automatic sampler. This GC was equipped with FID and 1/4 inch  $\times$  6 feet glass column, packed with 10% SP2100 on 80/100 Supelcoport. The temperature profile was 40–250° C, at 8° C/min. The carrier gas was nitrogen, at 40 ml/min.

From the last experiment with the cog-shaped aquarium and all the experiments with the two-compartment aquarium, the quantitative estimations were performed by the electronic integrator in the HP 5880 system. The calculations were based on the standard of Fuel Oil No. 2 and dichloromethane as solvent as before.

Chromatograms of the Fuel Oil No. 2 standard and a sea water extract are shown in Figs. 3 and 4, respectively. The precision of the analysis is judged to

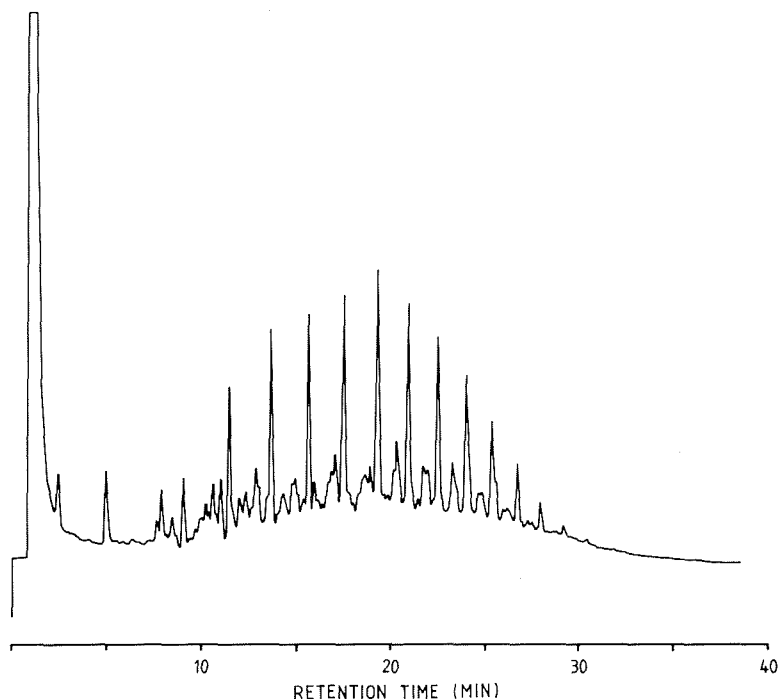


Fig. 3. Chromatogram of the Fuel Oil No. 2, diluted in methylene-chloride. Hewlett-Packard 5880 A.

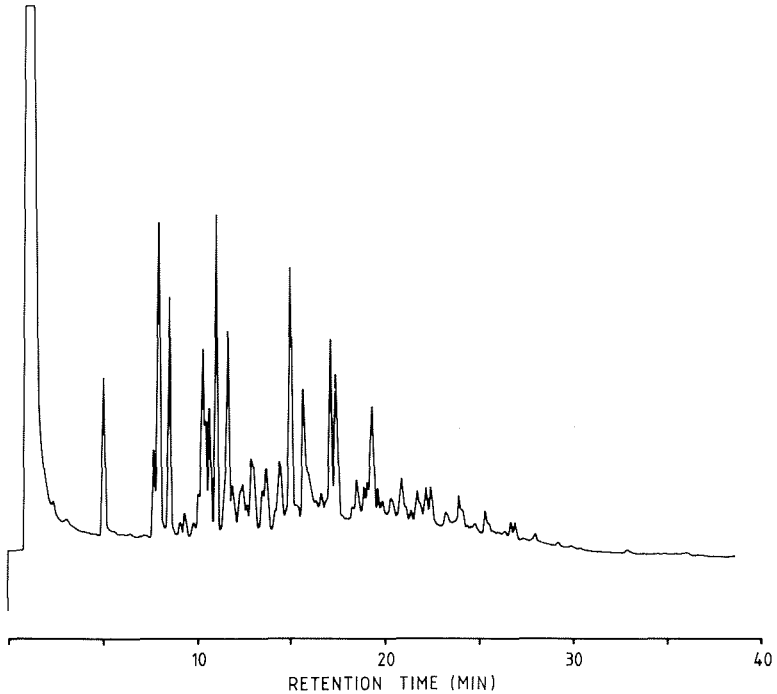


Fig. 4. Chromatogram of the «water soluble fraction» of the Fuel Oil No. 2, introduced to the experimental aquaria. Hewlett-Packard 5880 A.

be of the order of  $\pm 20\%$ . For several reasons, the sensitivity of the analytical method is judged to be about  $10 \mu\text{g/l}$ .

By increasing or decreasing the flow of oily water and by recording the fish movements, the fish reaction to different concentrations of hydrocarbons could be studied. With a water flow of  $1.5 \text{ l/min}$  and volume of each compartment of  $675 \text{ l}$ , 20 hr elapsed before the hydrocarbon concentration in the aquarium was in balance with the last adjustment.

Most of the fish used in this study were caught in traps along the coast between Arendal and Grimstad (southeastern Norway). In a few experiments one-year-old fish, which had been hatched and bred at the Biological Station in Flødevigen, were used.

The fish held in clean sea water in tanks before being transferred to the experimental aquaria. This should have constituted adequate acclimation to laboratory conditions. The fish needed different time periods to be accustomed to the conditions in the experimental aquaria. This included finding the small opening between the compartments. Some of the fish found these openings rapidly. Later, these same fish could find and move through the openings very easily. Other fish «learned» very slowly to move through the openings. Some

fish apparently were stressed or frightened and never succeeded in moving between the compartments. These were taken out and discarded.

Before introducing the oily sea water, it was desirable that the fish should have an active, but relaxed swimming behaviour, be able to find the opening easily, and spend approximately equal periods of time in the two compartments. The last item was difficult to achieve. Therefore, in most cases, hydrocarbons were introduced to that compartment where the fish apparently preferred to stay.

The time period needed to adaptation and acclimatization varied from 2 days to 3 weeks. There were large differences among the individual fish. Only one fish was used at a time.

Data on swimming activity is not included in this paper. However, in some periods, the activity could be extremely low, and the fish hardly moved from one compartment to the other. In such periods, food items were sometimes introduced to the aquarium divided equally among the several compartments. This usually resulted in increased activity, also between the compartments.

During the study, 30 experiments were performed. However, some of these were pilot experiments and had to be terminated due to stressed fish or to other reasons. Altogether, 16 experiments were executed, 10 with the cog-shaped aquarium and 6 with the two-compartment aquarium.

## RESULTS

Recordings of the percentage distribution of the fish among the three compartments are summarized in Table 1 and Fig. 5. Fig. 5 shows that at very low concentrations, below 50  $\mu\text{g/l}$ , the fish showed distribution percentages from 5 to close to 100. This reinforces the impression that the fish only to a very small extent noticed the petroleum at concentrations below 50  $\mu\text{g/l}$ .

When the fish were offered concentrations 50–100  $\mu\text{g/l}$ , they most often stayed for less than 35% of the time. When the fish were offered 100–200  $\mu\text{g/l}$ , they stayed there always less than 30% of the time.

Table 1. Number of recordings at each concentration range giving different rates of activity in the cog-shaped aquarium.

Concentration of petroleum hydrocarbons ( $\mu\text{g/l}$ )	Activity (%)			
	0–15	16–35	36–75	76–100
100–	24	13	4	0
50–99	19	8	4	0
0–49	9	13	15	7



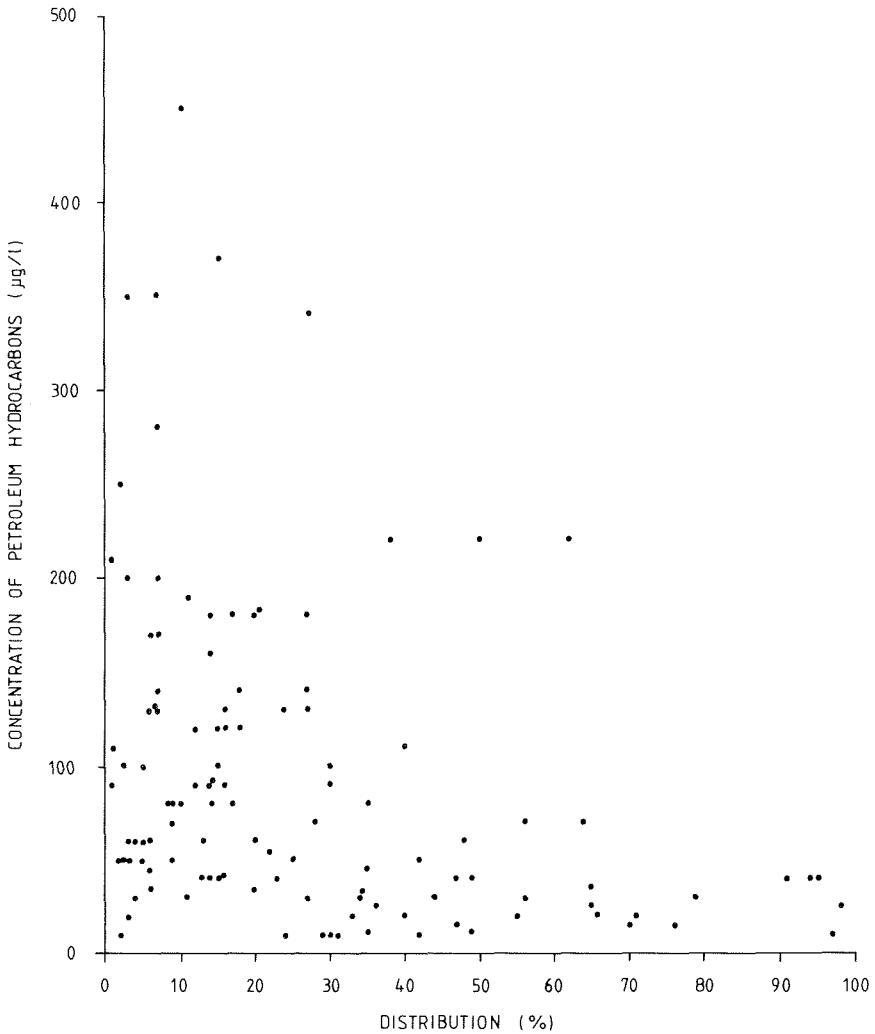


Fig. 5. Recordings of the time spent in water with different concentrations of petroleum hydrocarbons in the cog-shaped aquarium.

A few times the concentrations were increased to 200–400 µg/l. With some exceptions, the fish stayed in such concentrations not more than 10–15% of the experimental periods.

The results from the 10 experiments in the cog-shaped aquarium show that avoidance of petroleum hydrocarbons was observed in all of the experiments (Table 2). Also, responses named «indifference» and «attraction» were observed, though far more scarce. In one case, the avoidance response was recorded at concentrations as low as 30 µg/l. Petroleum concentrations were, to

Table 2. Effects of exposure to petroleum hydrocarbons in the cog-shaped aquarium.

Experiment no.	Concentration of hydrocarbons ( $\mu\text{g/l}$ )	Behavioural response
8	190-600	Avoidance
11	160-550	Avoidance
	220	Attraction
12	30- 50	Avoidance
	100	(Avoidance)
	200	Avvoidance
13	140-370	Avoidance
	70- 90	Avoidance
	180	(Indifference)
	50- 60	Avoidance
14	80-100	Avoidance
16	50- 70	Avoidance
	90	Avoidance
18	40- 60	Avoidance
	170	Avoidance
	30	Indifference
19	60	Avoidance
	90-120	Avoidance
20	60-100	Avoidance
	30	Avoidance
	10	Attraction
	10	Indifference
21	100-130	Avoidance
	20- 30	(Avoidance)
	20- 40	Indifference

a large extent, maintained in the range 50-100  $\mu\text{g/l}$  during the experiments. A majority of recordings within that range showed the avoidance response.

With one exception, the indifference response was recorded only at concentrations below 50  $\mu\text{g/l}$ . From the 10 experiments with the cog-shaped aquarium, it seems that the concentration range of 50-100  $\mu\text{g/l}$  of petroleum hydrocarbons is a border zone between avoidance and indifference.

Recordings of the percentage distribution of the fish between the three compartments are summarized in Table 3 and Fig. 6. Not even at high levels of hydrocarbons did the fish show any distinct response. As seen from Table 4, both avoidance, attraction and indifference were recorded, also at hydrocarbons levels above 100  $\mu\text{g/l}$ .

#### DISCUSSION

The aquaria were constructed in order to separate different types of water without to much intermixing. Hydrocarbons to some extent did penetrate the

Table 3. Number of recordings at each concentration range of petroleum hydrocarbons giving different rates of activity in the two-compartment aquarium.

Concentration of petroleum hydrocarbons ( $\mu\text{g/l}$ )	Activity (%)			
	0-15	16-35	36-75	76-100
100-	3	6	7	5
50-99	2	5	13	3
0-49	1	8	16	6

other compartments. The situation for the fish was thus most often a «choice» between not quite clean water and water containing a higher concentration of hydrocarbons. Because of the small opening between the compartments, an artificially elevated threshold of stimulus may have had to be exceeded before the fish moved to another compartment. However, in most experiments the fish moved freely through the openings, and it seemed that the openings presented no major hindrance.

The results are variable. Within one estimated level of concentration between different experiments or within one experiment with the same fish, the behavioural responses were observed to vary. This could be explained from natural variation between specimens or from variation or instability in the experimental conditions. How rapidly the fish «learned» or «accepted» the experimental situation in the aquaria seemed to vary from fish to fish. Although obviously stressed fish had been sorted out, some slightly stressed fish may have been included in the experiments.

To some extent, the classification of the behavioural responses was based on subjective judgement. Sometimes, it seemed reasonable to classify the behaviour from a change in fish distribution. In other cases, the classification was based on the actual fish distribution.

Very often a response to a change in the hydrocarbon supply was apparently delayed. This could be due to the need for a period of 20-24 hr to stabilize a new concentration, combined with a possible period for the fish to combine different stimuli («think over») before taking action, i.e., swimming away from the oily water. Such a period would be parallel to what ATEMA and STEIN (1974) called «alert phase» in experiments with lobsters.

A delayed reaction could also be explained by «habitual behaviour», in which the fish continued to stay or maintained a swimming pattern they were used to, despite the environmental conditions becoming unfavourable. Despite such uncertainties, it is concluded that the results support the conclusions below.

A response has been characterized as «avoidance» if the fish stayed away from the concentration to be studied 60-100% of the time. This does not imply that the fish stayed away continuously; the fish could inspect the water or could

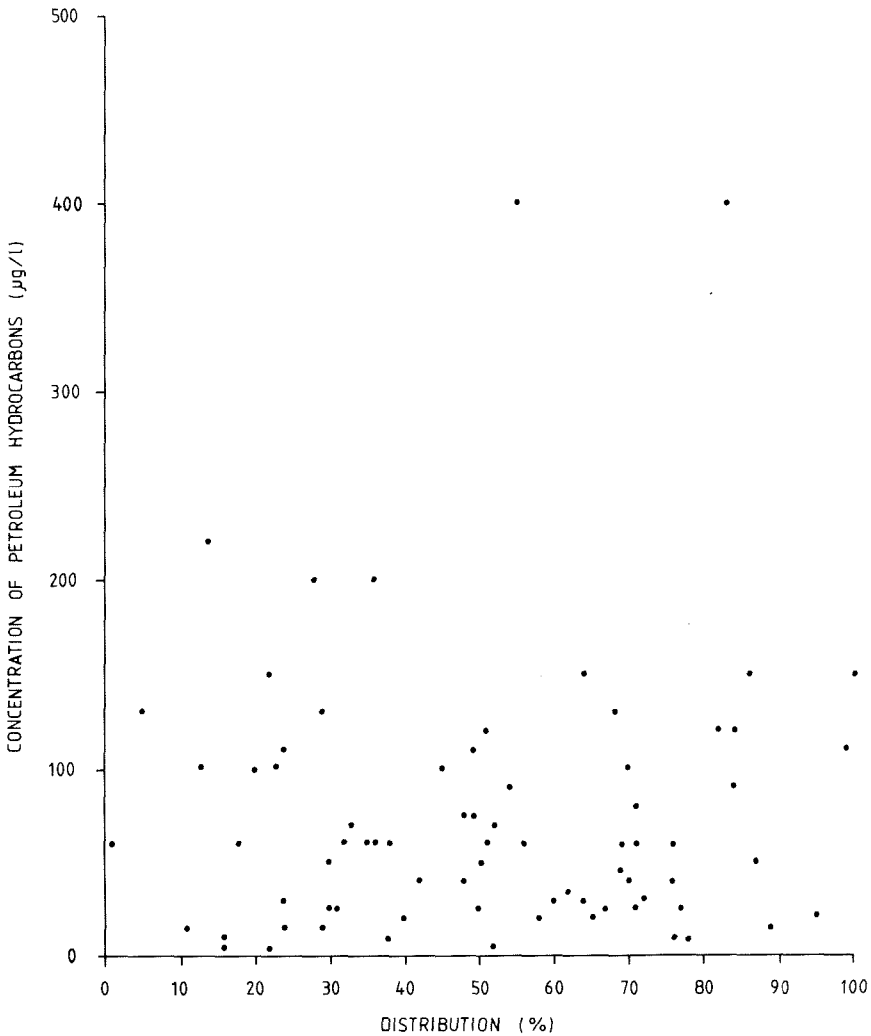


Fig. 6. Recordings of the time spent in water with different concentrations of petroleum hydrocarbons in the two-compartment aquarium.

accept to stay in the water of adverse quality for some time before searching activity for better water quality increased and the fish succeeded or happened to reach water of an acceptable quality. To facilitate data collection, the fish had to have a requirement for movement (and probably food-searching) which resulted in the fish moving into a compartment of adverse water quality.

The fish were not observed to react at concentrations of 10–15 µg/l. Indifference was also noted at 100–130 µg/l. In one of the experiments with the two-compartment aquarium, the fish did not respond to concentrations up to

Table 4. Effects of exposure to petroleum hydrocarbons in the two-compartment aquarium.

Experiment no.	Concentration of hydrocarbons ( $\mu\text{g/l}$ )	Behavioural response
103	130	Avoidance
	90	Attraction
	90-110	Indifference
	100	Avoidance
104	30- 40	Indifference
	110-150	Attraction
	220	Avoidance
105	110-200	Avoidance
106	25- 60	Attraction
	70- 75	Indifference
	120	Attraction
107	60- 70	Avoidance
	50	Indifference
108	40- 60	Indifference
	130	Avoidance
	100-120	Indifference
	120-130	Attraction
	400	Indifference
	400	Attraction

400  $\mu\text{g/l}$ . However, at the end of that experiment, the fish was stressed and exhibited very low activity, hence this recording is doubtful.

The behavioural response characterized as «attraction» was noticed mostly at high concentrations. This characterization is judged to be doubtful when it appeared suddenly during the experiment. However, it has been reported that fish schools have been attracted to oil spilled on the sea surface; it is possible that certain components in the fuel oil may give rise to food-searching activity. Thus, under special conditions, fish may be attracted to petroleum, but this is probably not a «normal» response.

In the two-compartment aquarium, the experimental fish displayed the indifferent response more often than in the cog-shaped aquarium. The reason for this cannot be fully explained. In the two-compartment experiments, larger fish were used. It may be that these fish were less sensitive to petroleum hydrocarbons. It may also be that the size proportions of the two-compartment aquarium were unsuitable for the larger fish.

Despite variable results, the main conclusion is that the cod in these experiments avoided concentrations of total petroleum hydrocarbons down to 50-100  $\mu\text{g/l}$ . The question is how these results can be applied for conditions at sea.

It is obvious that the fish's life in an experimental aquarium is different from that in the sea where the fish may be influenced by varying stimuli, for

example, salinity, temperature, current, and light. The total fish behaviour is also a result of feeding activity or food searching, sexual activity, migration, social activity (schooling), and avoidance of predators.

In the sea, behavioural responses due to a pollutant may be overwhelmed by responses due to other stimuli or environmental conditions. In the laboratory experiments, such changing conditions were eliminated, hence the responses which were observed in the aquaria should derive from the concentration of petroleum hydrocarbons alone.

It is impossible to simulate completely in a laboratory what will happen in the sea after an oil spill or during chronic pollution by petroleum hydrocarbons. The hydrographic and atmospheric state to a large extent influences the quality and composition of hydrocarbons entering the water column. In addition, there are almost an infinite number of crudes and petroleum products that may be spilled into the sea.

Within these limitations, then, it seems reasonable to conclude that cod avoid petroleum hydrocarbons at concentrations down to 50–100  $\mu\text{g/l}$ , whether these are in true solution or emulsified as droplets. This may also happen in the sea unless other stimuli should be stronger.

The observed threshold concentrations are well below the concentrations recorded after oil spills in the sea, for example, the Ekofisk blowout in 1977 (GRAHL-NIELSEN *et al.* 1977), where recordings in excess of 300  $\mu\text{g/l}$  were made. As judged from the present results, it seems that the cod would leave or avoid such an area of pollution.

If such concentrations are to have any noticeable effect on fisheries, the concentrations would have to last for weeks or months. Mortality among large fish with high swimming performance is very improbable because these will move away. Mortality on free-swimming fish due to oil spills has hardly ever been recorded. It is also likely that the fish density would have to be very high before any severe effects in practical fisheries could occur.

#### ACKNOWLEDGEMENT

The author expresses his thanks to the staff at the Department of Biological Oceanography at the Institute of Marine Research, Bergen, for advices and guidance. Thanks are also due to the staff at the Biological Station Flødevigen. Leiv Nilsen developed and constructed most of the sensoric and electronic equipment.

#### REFERENCES

- ANON. 1975. *Petroleum in the marine environment*. National Academy of Sciences, Washington D.C. 1975. 107 pp.

- ATEMA, S. and STEIN, L.S. 1974. Effects of crude oil on the feeding behaviour of the lobster *Homarus americanus*. *Environ. Pollut.*, 6: 77-86.
- GRAHL-NIELSEN, O., NEPPELBERG, T., PALMORK, K.H., WESTRHEIM, K. og WILHELMSEN, S. 1976. Oljespillet fra T/T «Drupa»: Undersøkelser vedrørende olje, vann og fisk. *Fisken og Havet Ser. B*, 1976 (12): 1-24.
- GRAHL-NIELSEN, O., WESTRHEIM, K. and WILHELMSEN, S. 1977. Determination of petroleum in the water. P. 3.1-3.13 in ANON. (BERGE, G.) ed. *The Ekofisk Bravo Blowout. Coun. Meet. int. Coun. Explor. Sea*, 1977 (E:55): 1.1-11.13.
- HELLSTRØM, T. and DØVING, K.B. 1983. Perception of diesel oil by cod (*Gadus morhua* L.) *Aquatic Toxicology*, 4: 303-315.
- KÜHNHOLD, W.W. 1969. Der Einfluss wasserlöslicher Bestandteile von Rohölen und Rohölfraktionen auf die Entwicklung von Heringsbrut. *Ber.dt.wiss. Kommn.Meeresforsch.*, 20: 165-171.
- RICE, S.T. 1973. Toxicity and avoidance tests with Prudhoe Bay oil and Pink Salmon fry. P. 667-670 in ANON. ed. Proc. Joint Conf. Prevention and Control of Oil Spills. American Petroleum Institute, Washington D.C.
- SYAZUKI, K. 1964. Studies on the toxic effects of industrial waste on fish and shellfish. *J. Shimonoseki Coll. Fish.* 13: 157-211. Referenced in MALINS, D.C. 1977, ed. *Effects of Petroleum on Arctic and Subarctic Marine Environments on Organisms. Vol. II*. Academic Press, Inc. N.Y. 500 p.

AGGRESSION AND GROWTH OF  
ATLANTIC SALMON PARR.\*  
I. DIFFERENT STOCKING  
DENSITIES AND SIZE GROUPS

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ABSTRACT

FERNÖ, A. and HOLM, M. 1986. Aggression and growth of Atlantic salmon parr. I. Different stocking densities and size groups. *FiskDir. Skr. Ser. HavUnders., 18: 113–122.*

The aggressive behaviour and growth of salmon parr under crowded rearing conditions was studied at four different densities. One or several fish per aquarium was dominant, displaying a kind of territorial defence and committing a significant part of the observed aggressive acts. Large subordinate fish were more aggressive than small fish at all densities. The ratio between the number of performed and received aggressive actions was about the same for large and small subordinate fish at the lowest density, but with increasing density this ratio became higher for large parr. Small fish grew slower than large fish at the highest density and suffered generally from a higher mortality. Factors other than aggression also seemed to influence growth, as both the growth rate and number of aggressive acts per fish decreased with increasing density.

INTRODUCTION

Parr of the Atlantic salmon (*Salmo salar* L.) are territorial under natural conditions (KEENLEYSIDE and YAMAMOTO 1962). The aggressive behaviour might be a negative factor in the cultivation of salmon parr.

A negative correlation between growth rate and density under crowded rearing conditions has been found in salmon (LINDROTH 1972, REFSTIE and KITTELSEN 1976), rainbow trout (BRAUHN, SIMON and BRIDGES 1976, KILAMBI,

\* This paper was first presented at the national symposium «Behaviour of marine animals» held at Solstrand, Os, Norway, 9–10 February 1983.



ADAMS, BROWN and WICKIZER 1977, REFSTIE 1977), and coho salmon (FAGERLUND, McBRIDE and STONE 1981). It has often been assumed (e.g. REFSTIE and KITTELSEN 1976) that suppression of growth by aggressive behaviour was involved. BROWN (1946a) demonstrated that maximum growth in early stages of brown trout took place under moderate densities. Low densities led to suppressed growth of the smallest individuals, presumably due to some kind of social hierarchy, whereas there was a general suppression of growth at high densities. An optimum degree of crowding was also found in 2-year-old trout (BROWN 1946b).

The aggressive behaviour of salmon parr has earlier been studied in the laboratory (e.g. KEENLEYSIDE and YAMOMOTO 1962, FENDERSON and CARPENTER 1971), but until now, there has been no systematic study on the aggressive behaviour of salmon parr under the crowded conditions typical in aquaculture. The present study was therefore undertaken. The aggressive behaviour at different densities was investigated, and the aggressive activity of large and small parr was compared. The relationship between the aggressive behaviour and the growth rate was also studied.

#### MATERIALS AND METHODS

Second-generation hatchery-reared fish were used in the experiment. The eggs came from a commercial fish farmer at Hitra in middle Norway, and the parent fish originated from a river in the same area. The eggs were hatched in January 1975 at the field experiment station in Matre, near Bergen. The fish were about one year old at the start of the experiment in January 1976.

The aquaria were semi-oval fiber glass tanks with a glass front. The water inlet was on the backside, with an inflow of about 4 l/min, and the outlet was on the concave bottom. The bottom was covered with a perforated aluminium plate providing a horizontal floor of 4820 cm<sup>2</sup> level with the bottom of the window. The water depth was 40 cm, giving a volume of about 200 l. The temperature was around 10° C, and the oxygen saturation varied between 82 and 94%. The source of illumination was 100 W white fluorescent lights placed on top of each aquarium, and the photoperiod was 12 hrs starting at 0800 hours. The fish were fed to satiation by hand three times a day during week days, at 0830, 1200, and 1500 hours. On Saturdays the fish were fed only once, at 1200. No feeding was done on Sundays.

The aquaria were stocked at initial densities of 255 g (120 parr) at density A, 505 g (229 parr) at density B, 1005 g (393 parr) at density C, and 2000 g (878 parr) at density D. The initial length of the parr varied between 40 and 94 mm.

In order to distinguish large fish from small fish, all fish of the least 71 mm length were freeze-branded with liquid nitrogen on both sides of the body under the adipose fin. The estimation of growth rate of large and small parr

was based directly on the freeze-branding. When comparing the aggressive activity, the fact that some of the unmarked fish had outgrown some of the marked fish, during the course of the experiment, had to be considered. The number of large fish in each aquarium was therefore defined as the mean between number of marked fish at the beginning of the experiment and number of marked fish plus number of unmarked fish larger than the smallest marked fish at the end of the experiment. Unmarked fish clearly larger than the smallest marked fish were recorded as «large» during the observations.

The observations of fish behaviour started three days after stocking. Observations were made four days a week for eight weeks. The experiment was then terminated, and the length and weight of the fish were recorded.

During the observations, the laboratory was in darkness. The observations began at 1000 hours. The aquaria were observed in rotation to avoid systematic errors. The observation time was 15 min/aquarium/observation day. This was divided into two periods: 10 min for observation of the whole aquarium and 5 min for observation of the special observation volume. This volume was delineated by two parallel lines 20 cm apart on the window pane and bottom at the center of each aquarium. All fish could be observed with reasonable accuracy in this restricted volume, and the reliability of the observations from the whole aquarium could in this way be estimated. The number of fish in the special observation volume was recorded before an observation. The observations were recorded on magnetic tape and later transcribed. The following aggressive behaviour patterns were recorded:

- Attack* – an approach towards another fish followed by a bite
- Charge* – an approach not followed by bite
- Nip* – a bite not preceded by an approach
- Chase* – at least two successive attacks towards a fleeing fish

Frontal and lateral displays (KEENLEYSIDE and YAMOMOTO 1962) were also observed, but it was not possible to record these behaviour patterns systematically under the high densities in the experiment.

## RESULTS

### AGGRESSIVE BEHAVIOUR

Aggressive behaviour patterns were observed relatively frequently with no systematic change in aggressive activity during the eight weeks of observation. The total number of aggressive acts per aquarium increased somewhat with increasing density (Table 1). The aggressive activity per fish was, however, highest at the lowest density and decreased markedly with increasing density.

Table 1. The aggressive activity at densities A–D (initial densities 255–2000 g per 200 l).

Density	Whole aquarium				Special observation volume			
	A	B	C	D	A	B	C	D
Total no. of aggressive acts	779	820	972	1279	220	236	224	314
Aggressive acts per fish per minute observation	0,023	0,012	0,008	0,005	0,067	0,040	0,021	0,017

Table 1 also shows the results from the observations in the special observation volume. The number of aggressive acts per fish in this volume was at all densities higher than in the observations from the whole aquarium. This was probably because passive fish had a tendency to cluster along the tank walls, but unrecorded aggression during observations of the whole aquarium may also contribute to this difference. The observation technique was, however, regarded as valid since similar tendencies were found for both types of observation.

A large number of fish could be observed simultaneously with reasonable accuracy because most fish kept their position, quietly tail-beating against the current. This made movements of single fish easily detectable. Only the observations of the total water volume are considered hereafter.

One or several dominant fish per aquarium could be distinguished during most observations. One fish could be dominant for several weeks, but could also be displaced by a challenger. Dominant fish were generally large and had a pale overall colouration with black vertical bands through the eyes. They defended a kind of territory in which the density of other fish was lower than elsewhere in the aquarium. A dominant often patrolled its territory from a position 5–10 cm above the bottom, but could also defend a territory higher up. In the lowest density, the dominant fish often defended the whole bottom area as its territory, but at higher densities some fish were usually present in the vicinity of a dominant without being attacked. Dominants seemed to selectively attack fish that moved.

At the lowest densities, there was usually one dominant fish (mean per observation = 1.1 in both A and B) committing 47% (A) and 17% (B) of the aggressive acts. At densities C ( $\bar{x}$  = 1.7) and D ( $\bar{x}$  = 1.9) there were often several dominants (up to four) committing respectively 7% and 25% of the aggressive acts.

Table 2 shows all observed aggressive acts by both dominant and subordinate fish. Of the different aggressive behaviour patterns, attacks were observed most frequently, followed by charges, nips and chases. With increasing density, attacks became relatively more frequent ( $p < 0.001$ , chi-square test) and charges less frequent ( $p < 0.001$ ). The proportion of chases was highest at the lowest density ( $p < 0.001$ ). The mean intensity of the aggressive

Table 2. The number of different aggressive behaviour patterns between different categories of fish at densities A-D (initial densities 250-2000g per 200 l)

Aggressor-Target	Attack				Charge				Nip				Chase				Total			
	A	B	C	D	A	B	C	D	A	B	C	D	A	B	C	D	A	B	C	D
Dom.-Dom.	12														1		12			1
Dom.-Large	55	29	25	65	23	36	15	20	2				4	4		1	84	69	40	86
Dom.-Small	116	24	17	116	126	44	5	99	1	3		1	27	3		25	270	74	22	241
Large-Dom.	7	2	5	6	1		1										8	2	6	6
Small-Dom.	14	4	1	9			1		1		1						15	4	3	9
Large-Large	10	88	199	116	2	30	38	11	1	19	27	5		4	5	2	13	141	269	134
Large-Small	34	108	159	188	11	41	53	23	6	16	23	10		3	4	5	51	168	239	226
Small-Large	14	66	86	83	7	15	13	5	4	7	19	12	1	1	2	1	26	89	120	101
Small-Small	193	190	191	381	54	46	28	41	37	34	53	46	16	3		8	300	273	272	476
Sum	455	511	683	964	224	212	154	199	52	79	123	74	48	18	12	42	779	820	972	1279
% of total	58,4	62,3	70,3	75,4	28,8	25,9	15,8	15,6	6,7	9,6	12,7	5,8	6,2	2,2	1,2	3,3				

behaviour (regarding chase as the most intensive and charge as the least intensive behaviour patterns) was therefore not systematically changed with an increase in density.

Dominant fish had a tendency to make relatively more charges and chases (41% and 7% of all aggressive acts) than subordinate fish (14% and 2%,  $p < 0.001$ , chi-square test), whereas the reverse was true for attacks and nips (dominant fish 51% and 1%, subordinate fish 73% and 11%,  $p < 0.001$ ).

There was also a significant difference between large and small subordinate parr in the relative occurrence of different behaviour patterns ( $p < 0.001$ ), with large parr performing more charges and small parr more nips. There was also a difference in the target of the aggressive actions of the different categories ( $p < 0.05$ ), with large parr receiving more attacks and small parr more chases and charges. All aggressive behaviour patterns will, in the following, generally be treated together.

Large fish constituted 13% (A), 24% (B), 41% (C) and 31% (D) of the total number of subordinate fish in the different densities. Large fish were generally more aggressive than small fish, and made 17% of the total number of aggressive acts of subordinate fish at density A ( $p > 0.10$ , chi-square test), 46% at density B ( $p < 0.001$ ), 57% at density C ( $p < 0.001$ ), and 38% at density D ( $p < 0.001$ ).

Of the total number of aggressive acts aimed at subordinate fish at the different densities, large fish were the targets in 17% (A), 37% (B), 45% (C) and 25% (D). This means that large fish were attacked more than small fish at density B ( $p < 0.001$ ) and less at density D ( $p < 0.01$ ), whereas no significant difference was found at densities A and C. When all densities are regarded together, large and small fish were observed equally often to be the object of aggression, but there also seemed to be a tendency for small fish to be attacked relatively more with increasing density.

Table 3 shows the ratios between the number of performed and received aggressive acts of large and small fish. At the highest densities, small parr seemed to have a less favourable situation than large parr.

To get a better idea of the dominance relationship in the aquaria, it is important to know between which categories of fish aggression occurred most frequently (see Table 2). Dominant fish were seldom aggressive towards each other. Dominants directed more aggression towards large than small subordi-

Table 3. The ratio between the number of performed and received aggressive acts of large and small fish at densities A–D (initial densities 255–2000 g per 200 l).

	Density			
	A	B	C	D
Large fish	0.59	1.04	1.20	1.14
Small fish	0.55	0.71	0.74	0.62

Table 4. Growth and food utilization at densities A-D (initial densities 255-2000 g per 200 l).

$$\text{Food conversion factor} = \frac{\text{weight of feed (g)}}{\text{growth (g)}}$$

	Density			
	A	B	C	D
Total weight gain (g)	188	285	545	683
Relative weight gain (% of original weight)	73.7	56.4	54.2	34.2
Food conversion factor	2.0	2.4	1.7	2.1

nate fish at the three lowest densities (A: 24%,  $p < 0.05$ , B: 48%,  $p < 0.001$  and C: 65%,  $p < 0.001$ ). No difference was found at the highest density (26%,  $p > 0.10$ ). Dominants also had a tendency to make more attacks towards large fish and more charges towards small fish ( $p < 0.01$ ).

Large subordinate fish were significantly more aggressive towards large fish at three of four densities, and directed 20% ( $p > 0.20$ ), 46% ( $p < 0.001$ ), 53% ( $p < 0.001$ ) and 37% ( $p < 0.05$ ) of the aggressive acts towards them at densities A-D. Small fish were generally more aggressive towards small fish, while directing only 8% ( $p < 0.05$ ), 25% ( $p > 0.90$ ), 31% ( $p < 0.001$ ) and 18% ( $p < 0.001$ ) of their aggression towards large fish at densities A-D, respectively.

#### GROWTH RATE AND MORTALITY

The total weight gain was highest at the highest density, and decreased with decreasing density (Table 4). When the growth is considered relative to the original weight (relative weight gain), the most rapid growth was found in the lowest density.

The specific growth rate of large and small fish is presented in Table 5. The growth rate was dependent on density ( $p < 0.001$ , chi-square test), with small fish growing relatively slower with increasing density.

Table 5. The specific growth rate (G) of salmon parr at densities A-D (initial densities 255-2000 g per 200 l).

$$G = \frac{\ln Y_T - \ln Y_t}{T - t}$$

where  $Y_t$  = weight (g) at start of experiment,  $Y_T$  = weight (g) at end of experiment and  $T-t$  = time of experiment in days.

	Density			
	A	B	C	D
Large fish	0.93	0.78	0.76	0.56
Small fish	1.00	0.82	0.74	0.50

Table 6. The percent mortality of large and small parr at densities A–D (initial densities 250–2000 g per 200 l).

Density	Small fish	Mortality, %	
		Large fish	Total
A	9.4	7.1	9.2
B	11.1	5.0	10.0
C	6.3	0.9	4.8
D	9.6	2.2	8.1

The total mortality was not significantly influenced by density (chi-square test, Table 6). Small fish suffered generally from a higher mortality than large fish, and a significant difference was found at densities C ( $p < 0.05$ ) and D ( $p < 0.001$ ). It was also the smallest fish within the group that died (mean length of dead unmarked fish was 50.1 mm versus 59.6 mm for the mean length of the whole group during the period). The eyes of small fish were often damaged, indicating aggression as the cause of death.

#### DISCUSSION

A relatively high rate of aggressive activity of salmon parr under crowded rearing conditions was found in this study. One or several fish per aquarium showed a kind of territorial defence although, with increasing density, other fish were accepted in the vicinity of the dominant. This finding is not in accordance with the observation by KALLEBERG (1958), who states that territoriality of salmon parr as a rule is not observed under crowded rearing conditions. The territorial defence observed in the present study may be enhanced by the small size of the aquaria. In larger tanks, the scarcity of points of reference could hinder establishment of territories.

Non-territorial fish also showed aggressive behaviour. Small parr displayed generally less aggressive activity than large parr. If the ratio between the number of performed and received aggressive acts is taken as a measure of the position of the fish in the social hierarchy, the results clearly show that the situation for small parr became less favourable with increasing density. A relationship between the aggressive behaviour and growth is indicated by the finding that, compared to large parr, the growth of small parr became slower with increasing density. Small parr also had a higher mortality than large parr. These observations are in agreement with a study on coho salmon (FAGERLUND *et al.* 1981), where crowding stress particularly affected the growth and stress level (measured as interrenal cell diameter) of small fish. This contrasts with the findings for brown trout (BROWN 1946a), where suppressed growth of small individuals appeared especially at low densities.

Although the total number of observed aggressive acts might seem to be high in the study, an individual fish was seldom the object of aggression due to the high number of fish (a mean of once every 44 to 204 min at the different densities). It could be questioned whether such a low frequency can influence growth, in view of the few aggressive encounters during feeding, an observation which invalidates direct competition for food when food is abundant. However, even such a low level of aggression could induce a level of stress leading to a decreased growth rate – mere visual contact with another fish could in fact influence growth, as demonstrated in *Blennius pholis* (WIRTZ 1975). Another possibility is that physical injuries from aggression depressed growth and increased mortality.

In this study both growth rate and the frequency of aggression per fish were highest at the lowest density. The decrease in growth rate with increasing density found in other studies (e.g. LINDROTH 1972, FAGERLUND *et al.* 1981) was therefore probably not caused by an increase in the level of aggression with increasing density. Factors other than the aggressive behaviour could suppress growth at high densities. One explanation for the present observations is that the water quality was negatively influenced by increases in density, as the inflow of water was the same in all aquaria. The oxygen saturation was, however, never below 82%, and should therefore not be a limiting factor for growth (SMART 1981). The concentration of ammonia nitrogen in the water was not measured. Another explanation is that high densities could have made it difficult for the fish to move and reach the food, as proposed by REFSTIE and KITTELSEN (1976). In the present study, the food utilization was not negatively influenced by an increase in density. Although the fish were fed «to satiation», feeding could apparently have continued for a longer time if food had been given in smaller quantities. This may apply especially to the highest stocking densities. The feeding procedure could therefore have influenced the difference in growth between the densities.

#### ACKNOWLEDGEMENT

We thank Miss Karin Pittman for remarks on the manuscript.

#### REFERENCES

- BRAUHN, J.L., SIMON, R.C. and BRIDGES, W.R. 1976. Rainbow trout growth in circular tanks: Consequences of different loading densities. *Techn. Pap. Fish Wildl. Serv. U.S.*, 86: 1–16.
- BROWN, M.E. 1946a. The growth of brown trout (*Salmo trutta* Linn.). I. Factors influencing the growth of trout fry. *J. exp. Biol.*, 22: 118–129.
- BROWN, M.E. 1946b. The growth of brown trout (*Salmo trutta* Linn.). II. The growth of two-year-old trout at a constant temperature of 11.5. *J. exp. Biol.*, 22: 130–144.



- FAGERDLUND, U.H.M., MCBRIDE, J.R. and STONE, E.T. 1981. Stress-related effects of hatchery rearing density on coho salmon. *Trans. Am. Fish. Soc.*, 110: 644-649.
- FENDERSON, O.C. and CARPENTER, M.R. 1971. Effects of crowding on the behaviour of juvenile hatchery and wild landlocked Atlantic salmon (*Salmo salar* L.). *Anim. Behav.*, 19: 439-447.
- KALLEBERG, H. 1958. Observations in a stream tank of territoriality and competition in juvenile salmon and trout (*Salmo salar* L. and *Salmo trutta* L.). *Rep. Inst. Freshwat. Res. Drottningholm*, 39: 55-98.
- KEENLEYSIDE, M.H.A. and YAMAMOTO, F.T. 1962. Territorial behaviour of juvenile Atlantic salmon (*Salmo salar* L.). *Behaviour*, 19: 139-169.
- KILAMBI, R.V., ADAMS, J.C., BROWN, A.V. and WICKIZER, W.A. 1977. Effects of stocking density and cage size on growth, feed conversion, and production of rainbow trout and channel catfish. *Prog. Fish. Cult.*, 39 (2): 62-66.
- LINDROTH, A. 1972. Heritability estimates of growth in fish. *Aquilo, Ser. Zool.*, 13: 77-80.
- REFSTIE, T. 1977. Effect of density on growth and survival of rainbow trout. *Aquaculture*, 11: 329-334.
- REFSTIE, T. and KITTELSEN, A. 1976. Effect of density on growth and survival of artificially reared Atlantic salmon. *Aquaculture*, 8: 319-326.
- SMART, G.R. 1981. Aspects of water quality producing stress in intensive fish culture. P. 277-293 in PICKERING, A.D. ed. *Stress and fish*. Academic Press, London.
- WIRTZ, P. 1975. Physiological effects of visual contact to a conspecific in *Blennius pholis* (Pisces, Teleostei). *J. comp. Physiol.*, 101: 237-242.

AGGRESSION AND GROWTH OF  
ATLANTIC SALMON PARR.\*  
II. DIFFERENT POPULATIONS IN PURE  
AND MIXED GROUPS

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ABSTRACT

HOLM, M. and FERNÖ, A. 1986. Aggression and growth of Atlantic salmon parr. II. Different populations in pure and mixed groups. *FiskDir. Skr. Ser. HavUnders.*, 18: 123–129.

The aggressive behaviour and growth of different populations of Atlantic salmon parr and the possible effect of fin-clipping on these traits were studied. Each of three 200 l aquaria was stocked with 90 unmarked hatchery parr from one of three different populations (one Swedish, two Norwegian). Three other aquaria were stocked with mixed groups consisting of 30 parr from each population. To enable identification, two of the three groups were alternately fin-clipped (adipose fin or pelvic fins). Significant differences in aggressive activity and growth were found between the populations. The population with the most aggressive parr had the slowest growth in both pure and mixed groups. Parr with cut pelvic fins both performed and received fewer aggressive acts than parr with cut adipose fin or unmarked parr. The results suggest a negative correlation between aggression and growth, and indicate that growth differences between populations to some extent may be mediated by genetically determined differences in behaviour.

INTRODUCTION

Salmon parr are territorial under natural conditions (KEENLEYSIDE and YAMAMOTO 1962). Resulting aggressive behaviour could have a negative influence on growth under crowded rearing conditions. In experiments at high densities (FERNÖ and HOLM 1986), salmon parr showed a relatively high

\* This paper was first presented at the national symposium «Behaviour of marine animals» held at Solstrand, Os, Norway, 9–10 February 1983.

aggressive activity, and dominant individuals with territorial defence were established. There were also indications of a relationship between the aggressive behaviour and slow growth of small parr at the highest stocking densities.

In the present study, the growth and aggressive behaviour of different populations of salmon parr have been studied in both pure and mixed groups using fin-clipping as a marking technique. Behavioural differences between populations could be relevant to selection experiments for growth (e.g. NÆVDAL, HOLM, MØLLER and ØSTHUS 1975), and, since fin-clipping is a common means of identification in such studies, its possible influence on behaviour and growth is investigated.

#### MATERIALS AND METHODS

The salmon parr (*Salmo salar* L.) used in the experiment were second-generation hatchery-reared fish originating from three different rivers; namely, the Lonevåg River and Etne River in southwestern Norway and the Skellefte River in northeast Sweden. The Lonevåg River is a typical grilse river whereas the Etne and Skellefte Rivers produce big salmon.

The parents of the parr were all selected for good individual growth rate. The eggs were hatched in January 1977 at the field experiment station in Matre, near Bergen, where this experiment was performed. All parr had been reared under the standard rearing conditions at the field station. The fish were about one year old at the start of the experiment in January 1978.

The six aquaria in the experiment were 200 l semioval fibre glass tanks with a window pane of the same type as described by FERNÖ and HOLM (1986). The water inflow was about 1.0 l/min and the temperature was  $10 \pm 1^\circ$  C. The aquaria were illuminated from above with 100 W white fluorescent lights, and the photoperiod was 12 hrs starting 0730 hours. The fish were fed to satiation by hand with commercial dry pellets three times a day. The fish were in a healthy state throughout the experiment except for a short period with bacterial gill disease, which was cured by antibiotics. Each aquarium was stocked with 90 parr, a density that was favourable for observing, yet not unrealistically low for rearing conditions. Lengths and weights of the fish were measured at the start and end of the experiment. Initially the fish were 50–99 mm long and the total weight per aquarium was 200–250 g.

Aquaria 1–3 were stocked with single-population groups, viz. 90 unmarked parr from one population in each aquarium, and aquaria 4–6 were stocked with mixed-population groups, viz. 30 parr from each of the three populations. The fish from two of the populations in the mixed groups were fin-clipped (adipose fin and pelvic fins, respectively) to enable identification of the populations during the observations. The clipped fin of the populations was alternated

between the aquaria in order to avoid systematic error and to detect possible effects of fin-clipping on behaviour and growth.

The observations were begun four days after stocking. The laboratory was in darkness during the observations to prevent disturbances. Observations were made on three aquaria for 15 min per aquarium between 1100 and 1200 hours, and on three aquaria between 1600 and 1700 hours, with the order of observation rotated between the aquaria. There were 30 observation days for the uniform groups and 28 for the mixed groups during a total experimental period of 60 days.

A dictaphone was used for recording the observations. The aggressive behaviour was defined as the four different categories of attack, charge, nip and chase (cf. FERNÖ and HOLM 1985 for definitions). In this paper, only the sum of all behaviour patterns is considered because no significant differences were found in the relative occurrence of any one behaviour pattern either between different populations or between different marking methods.

## RESULTS

The aggressive activity of the fish was low at the beginning of the experiment, but then increased. One fish generally became dominant (see FERNÖ and HOLM 1986) in each aquarium, defending a kind of territory which could vary in size and position from day to day. A dominant fish generally remained dominant throughout the experiment, but sometimes challengers became dominant, and in some observations there were up to three dominant fish. The dominant fish in the aquaria with mixed groups were, with few exceptions (four observations), Etne parr.

Table 1 shows the aggressive activity of dominant and subordinate fish in the different aquaria. There were significant differences between the aquaria concerning the proportion of the aggressive acts made by dominants ( $p < 0.001$ , chi-square test), there being least aggression by dominants in the aquaria with highest aggressive activity. Regarding the total number of aggressive acts, Etne parr had the highest aggressive activity of the uniform groups, followed by Lonevåg parr and Skellefte parr. Significant differences were observed between Etne and Skellefte and between Lonevåg and Skellefte

Table 1. The number of aggressive acts made by dominant and subordinate fish in the different aquaria.

	Pure groups			Mixed groups		
	1 (Lonevåg)	2 (Etne)	3 (Skellef.)	4	5	6
Dominant fish	107	70	186	239	114	116
Subordinate fish	1018	1311	581	580	522	321
Total	1125	1381	767	819	636	437

Table 2. Mixed groups. Number of aggressive acts (n) made by the different categories of fish and the percentage of total in each aquarium. Aquarium number in brackets. (Dominants are excluded).

Marking	Etne		Population Lonevåg		Skellefte		Sum
	n	%	n	%	n	%	
Unmarked	165	51.4 (6)	158	30.3 (5)	159	27.4 (4)	482
Adipose fin	256	49.0 (5)	165	28.4 (4)	94	29.3 (6)	515
Pelvic fins	256	44.1 (4)	62	19.3 (6)	108	20.7 (5)	426
Sum	677		385		361		1423

( $p < 0.01$ , Wilcoxon matched-pairs signed-ranks test), although not between Etne and Lonevåg ( $p < 0.075$ ).

The number of aggressive actions made in the aquaria with mixed groups was generally lower than in the aquaria with pure groups. Table 2 shows the aggressive activity of the different populations in the mixed groups. There were significant differences between the populations ( $p < 0.001$ , ANOVA), with Etne parr being the most aggressive. (The aggressive activity of the dominant fish was excluded from the analysis, as this would otherwise bias the data). There was also an interaction between population and fin-clipping ( $p < 0.01$ ), with fish lacking pelvic fins being the least aggressive. The effect of fin-clipping alone on the aggressive behaviour was not significant.

There were also certain differences in the number of aggressive actions received by the different categories of fish (Table 3). The effect of fin-clipping ( $p < 0.05$ ) was more important than the population of origin. Fish with cut pelvic fins were least often the target of aggressive acts.

It is also of interest to see whether intra-population or inter-population aggression in the mixed groups was most frequent. Etne and Skellefte parr had a tendency to direct the aggressive behaviour toward members of their own population (44% and 55% respectively,  $p < 0.001$ , chi-square test). Lonevåg parr had no such tendency (37%).

Table 3. Mixed groups. The number of aggressive acts (n) received by the different categories of fish and the percentage of total in each aquarium. Aquarium number in brackets. (Dominants are excluded).

Marking	Etne		Population Lonevåg		Skellefte		Sum
	n	%	n	%	n	%	
Unmarked	163	38.0 (6)	187	29.9 (5)	313	39.8 (4)	663
Adipose fin	280	44.8 (5)	270	34.3 (4)	163	38.0 (6)	713
Pelvic fins	204	25.9 (4)	103	24.0 (6)	158	25.3 (5)	465
Sum	647		560		634		1841

There were also other differences in behaviour between the populations, which, although difficult to quantify, were apparent to the observer. Etne parr had a tendency to keep near the bottom. During feeding they generally lay on the bottom, making short bursts to take the food particles, whereas Lonevåg and Skellefte parr generally were positioned higher in the water volume, rushing to the surface when feeding started. Parr with cut pelvic fins seemed to be positioned higher above the bottom than unmarked parr and parr with cut adipose fin.

Another observation was that Skellefte parr seemed to be more easily frightened than the parr from the two other populations. At the beginning of the experiment, Skellefte parr with submissive colouration (cf. KEENLEYSIDE and YAMAMOTO 1962) often lay in rows on the bottom. Individual Skellefte parr often made rapid bursts around in the aquarium. The homogeneous Skellefte group displayed more (50 incidents) fright reactions, with the fish swimming violently around in the aquarium, than did the fish in the other aquaria (14–22 incidents).

Table 4. The growth and food utilization of different populations and markings of salmon parr. Mean weights with standard deviations, specific growth rates and food conversion factors are given (cf. FERNÖ and HOLM 1986 for definitions). UM = unmarked, AF = adipose fin, PF = pelvic fins.

Aqua- rium	Population	Marking	Initial mean weight (g)	Final mean weight (g)	Specific growth rate	Food conversion factor
1	Lonevåg	UM	2.8±1.3	5.2+2.6	1.03	1.5
2	Etne	»	2.1±1.1	3.3+2.1	0.73	2.5
3	Skellefte	»	2.8±1.3	5.0+2.6	0.94	1.6
	Skellefte	UM	2.6±1.2	4.4+2.1	0.88	
4	Lonevåg	AF	2.7±1.0	4.7+1.9	0.91	2.1
	Etne	PF	2.5±1.1	4.2+2.5	0.80	
	Lonevåg	UM	2.7±1.6	4.9+3.1	0.99	
5	Etne	AF	2.9±1.6	4.6+3.3	0.76	1.7
	Skellefte	PF	2.7±1.2	4.8+2.8	0.92	
	Etne	UM	2.9±1.9	4.7+3.7	0.83	
6	Skellefte	AF	2.7±1.4	4.7+3.1	0.91	2.0
	Lonevåg	PF	2.6±1.4	5.0+3.4	1.07	

The data on growth are presented in Table 4. In homogenous groups, the specific growth rate of Etne parr was lower than the growth rate of Lonevåg and Skellefte parr ( $p < 0.001$ , Students' t-test). Lonevåg parr had a somewhat better growth than Skellefte parr, but this difference was not significant. This trend also appeared in the mixed groups, as there were significant differences between the populations ( $p < 0.05$ , ANOVA), with Etne parr growing most slowly and Lonevåg parr growing most rapidly. There was no significant difference in growth with respect to the different markings and no interaction

between population and marking could be detected in the ANOVA. Table 4 also shows that the homogeneous Etne group had a poorer utilization of food than pure Lonevåg and Skellefte groups. The mortality in the experiment was generally low, with no systematic differences between populations or marking methods.

#### DISCUSSION

Parr from the Etne population grew slower than parr from the Lonevåg and Skellefte populations in both pure and mixed groups. The slow growth of Etne parr may be related to their frequent aggressive activity (see FERNÖ and HOLM 1986). Etne parr were more aggressive than Lonevåg and Skellefte parr in both pure and mixed groups, and the dominant parr in the mixed groups were generally from the Etne population. The high aggressive activity of this population could be genetically determined, although nothing is known about the aggressive activity under other conditions. Hereditary differences in aggressiveness are known in other fish species (see, for example, HOLZBERG and SCHRÖDER 1975).

A direct causal relationship between high aggressive activity and slow growth cannot, however, be clearly demonstrated in this study. It is also possible that the observed tendency of Etne parr to keep near the bottom could lead to a frequent occurrence of aggression as well as low utilization of food and a low growth rate. Most aggression seemed to occur near the bottom, and Etne parr were positioned near the bottom also during feeding time.

A connection between aggressive activity and position in relation to bottom is also indicated by the findings that parr with cut pelvic fins had a tendency to stay high in the water volume and to perform and receive fewer aggressive actions than unmarked parr and parr with cut adipose fin.

A negative correlation between aggressive activity and growth was, however, not always found in the study. In the pure groups, Skellefte parr were least aggressive, but Lonevåg parr had a somewhat higher growth rate. This may be the outcome of a generally higher level of stress in Skellefte parr, as indicated by their frequent fright reactions.

Even if the findings in this study are not wholly conclusive, the connection between population, growth, and aggressive activity suggests that genetically based differences in growth between salmon populations (NÆVDAL *et al.* 1975) to some extent may be mediated via genetically determined behavioural differences. The effect of fin-clipping must also be considered when evaluating experiments with marked fish.

#### ACKNOWLEDGEMENT

We thank Miss Karin Pittman for remarks on the manuscript.

## REFERENCES

- FERNÖ, A. and HOLM, 1986. Aggression and growth of Atlantic salmon parr. I. Different stocking densities and size groups. *FiskDir. Skr. Ser. HavUnders.*, 18: 113-122.
- HOLZBERG, S., and SCHRÖDER, H.J. 1975. The inheritance of aggressiveness in the convict cichlid fish, *Cichlasoma nigrofasciatum* (Pisces: Cichlidae). *Anim. Behav.*, 23: 625-631.
- KEENLEYSIDE, M.H.A. and YAMAMOTO, F.T. 1962. Territorial behaviour of juvenile Atlantic salmon (*Salmo salar* L. ). *Behaviour*, 19: 139-169.
- NAEVDAL, G., HOLM, M., MØLLER, D. and ØSTHUS, O.D. 1975. Experiments with selective breeding of Atlantic salmon. *Coun. Meet. int. Coun. Explor. Sea, 1975.* (M: 23): 1-7. [Mimeo.].

Printed 10. April 1986





## THE BEHAVIOUR OF NORWAY LOBSTER TOWARDS BAITED CREELS AND SIZE SELECTIVITY OF CREELS AND TRAWL \*

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### ABSTRACT

BJORDAL, Å. 1986. The behaviour of Norway lobster towards baited creels and size selectivity of creels and trawl. *FiskDir. Skr. Ser. HavUnders., 18: 131-137.*

The behaviour of Norway lobster (*Nephrops norvegicus* L.) towards baited creels was studied by underwater television at three different localities. A typical nocturnal activity pattern was observed. Most of the individuals approached the creel up current. The general behaviour in the vicinity of creels and lobster burrows is shortly described. The creels were found to have a fairly low catch rate, being less than ten per cent of the observed individuals. Catches of Norway lobster by creels and trawl have distinctly different length distributions. The possible reasons for this are discussed.

### INTRODUCTION

The Norway lobster (*Nephrops norvegicus* L.) lives mainly on or in muddy bottoms. During non-active periods, it lives in burrows in the bottom substrate (DYBERN and HØISETER 1965).

The European catch of Norway lobster is mainly taken by trawl. During the last 15 years, however, a fishery based on baited creels has been developed in Scotland (BJORDAL 1979), Faroe Islands (BJORDAL 1978) and Norway. The present behaviour studies are intended to assist development of this creel fishery in Norway.

\* This paper was first presented at the national symposium «Behaviour of marine animals» held at Solstrand, Os, Norway, 9-10 February 1983.

## MATERIALS AND METHODS

The behaviour studies were conducted at three different field localities along the coast of Norway over a two year period, from May 1978 to May 1980 (Table 1).

Field observations were accomplished by underwater television. The camera was mounted above a baited creel, facing down, with square field of view 2.5 m on the side, as shown in Fig. 1. The technical specifications are given in Table 2.

Table 1. Field observation localities.

Date	Locality	Depth (m)
12-16 May 1978	Lysefjorden	115
04-21 July 1978	Lysefjorden	115
13-15 Feb 1980	Nyleia	86
20-23 May 1980	Narøyfjorden	62

An artificial light source fitted with a red filter was used. According to previous investigations (LOEW 1976), the Norway lobster is not able to detect light of wave length greater than 500 nm, nor does it show behaviour effects at such long wavelengths (CHAPMAN and HOWARD 1979).

Table 2. Specification of observation equipment.

UTV-camera	Hydro Products, TC-125-Sit-W
Control unit/monitor	Hydro Products, SC 303
Video recorder	Sony AV-3420 CE
Light source	Effect, 0-500 Watt
Filter (red)	Kodak Wratten no. 29 (min. wave length: 605 nm)

Since the field of view was rather narrow, there was a risk of overestimating the number of Norway lobsters, as the same individual could enter and leave the area several times. To minimize this effect, an individual was regarded as «new» if the time interval between leaving and entering exceeded one minute, or if the individual that entered was distinctly different.

A strip of plastic, 1 cm × 20 cm, was mounted at the top of the creel to indicate the direction of the current. Entering and leaving directions of the individuals relative to the current direction, time spent in field of view, and observations of other species were recorded. Observations of special interest were recorded on videotape.

## RESULTS

*DIURNAL ACTIVITY PATTERN*

The diurnal activity, expressed as the average number of individuals observed per hour, is shown in Fig. 2. During 214.5 hours of observation a total of 246

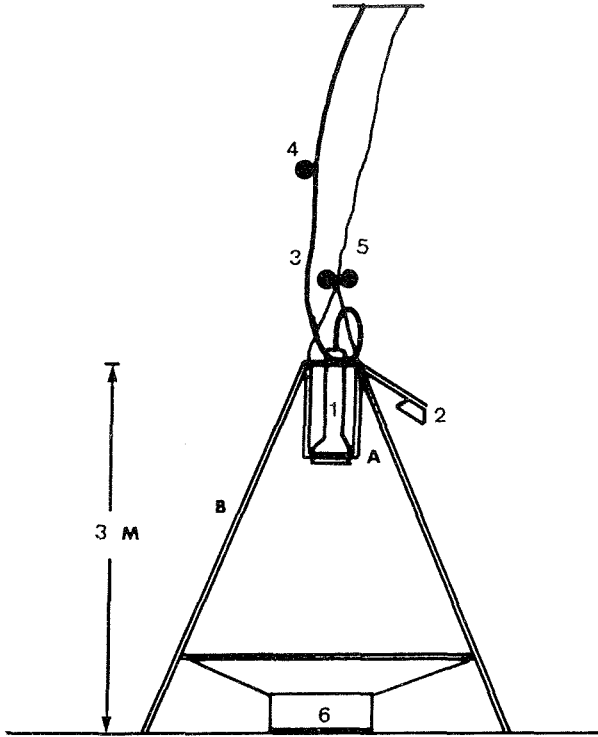


Fig. 1. Observation arrangement. A : camera frame, B : tripod, 1 : UTV-camera, 2 : light, 3 : cable, 4 : float, 5 : surface security line, 6 : creel.

Norway lobsters were seen, the majority of these in the period between dusk and dawn, with peak numbers observed between 2200–2300 hours and between 0100–0200 hours. Of these, a total of 15 individuals were caught in the creel, nine before and six after midnight.

#### *ATTRACTION TO BAITED CREEL VERSUS CURRENT DIRECTION*

Fig 3 shows the distribution of the approach-direction of the Norway lobsters relative to the direction of the current. The figure is based on 79 individuals from the Lysefjord observations. Most of the Norway lobsters approached the creel up current, in a sector  $30^\circ$  to either side of the current direction, while only one individual approached the creel down current.

#### *BEHAVIOUR IN VICINITY OF BAITED CREEL*

Norway lobsters that entered the field of observation generally approached the creel and searched around it. The duration of the search period varied from 1 to

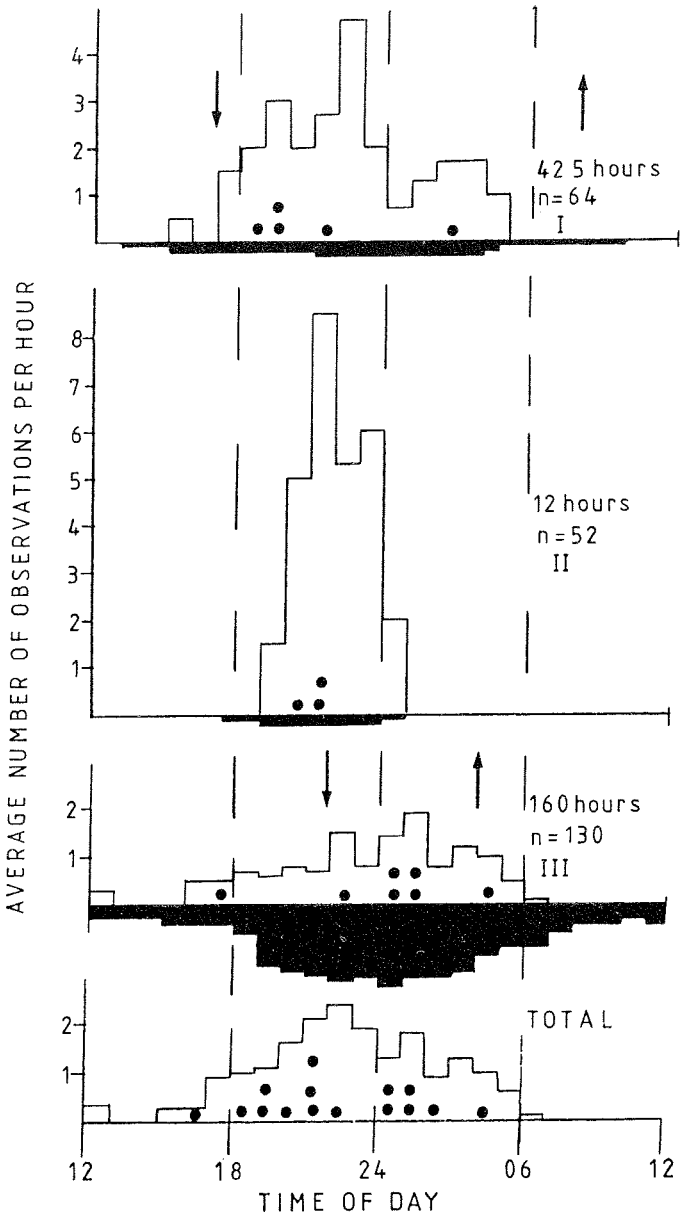
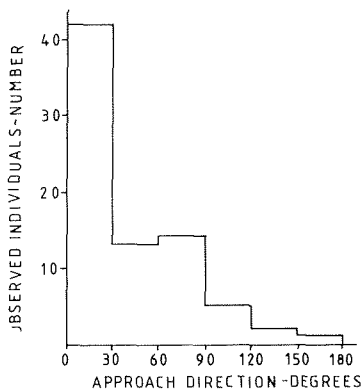


Fig. 2. Diurnal activity pattern. Number of Norway lobster observed per hour of observation at three different localities. I : Nyleia, II : Nærøysfjorden, III : Lysefjorden. Filled circles : catch of Norway lobster. Arrows indicate time of sunset and sunrise. Black area under the x-axis gives number of hours of observation (min.: 1 hr., max.: 17 hrs.).

40 minutes, when the individual either left the field of observation or entered the creel entrance. Only 65% of the observed individuals were in actual physical contact with the creel, while the rest either circled around it or passed at a distance. The catch rate, or proportion of observed animals that were captured was low, averaging 6.1 per cent.



#### *OBSERVATION OF NORWAY LOBSTER IN AND CLOSE TO BURROWS*

Occasionally the observation rig was positioned close to one or several burrows inhabited by relatively small Norway lobsters. These were observed to spend most of their time sitting in the burrow entrance, leaving only for short periods, and usually retreating to the burrow when other conspecifics or fish approached. Burrow systems with three different entrances were observed, and the Norway lobster could use these alternately.

#### *LENGTH DISTRIBUTION OF NORWAY LOBSTER CAUGHT BY TRAWL AND CREELS*

Fig. 4 gives the length distribution of Norway lobster caught by trawl and creels at a fishing ground, Sundene, in the Faroe Islands, and by creels at different fjord localities in Norway. Although the Faroese creel and trawl catches are taken at different times of the year, the length distributions should be representative of the distinct size difference of catches taken by the two types of gear. Trawl and creels seem to exploit the Norway lobster population over the same size range. The trawl catches contain a very high proportion of small individuals, whereas the creel catches show a more even length distribution.

#### DISCUSSION

This study has shown that the catch rates of Norway lobster can be low compared to the number of individuals attracted to the baited creel. This seems to be caused by following reasons:

Fig. 3. Approach direction of Norway lobster versus current direction (current direction : 0 degrees).

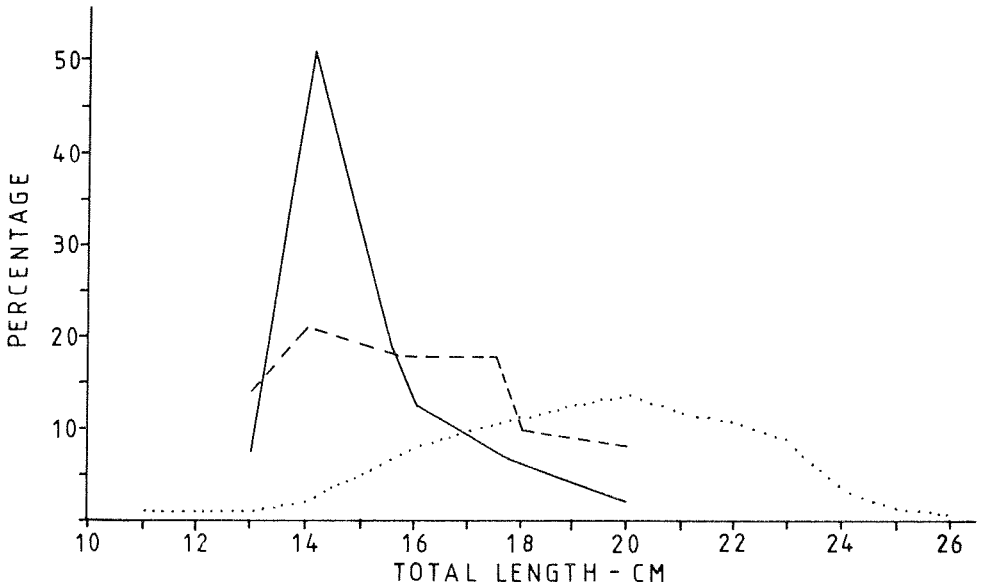


Fig. 4. Length distribution of Norway lobster, fished by:

- Trawl, Faroe Islands, (whole line). June and July 1977, n = 144 681.
- Creel, Faroe Islands, (broken line). January-June and October 1978, n = 90 231.
- Creel, three fjord localities, Norway, (dotted line). May-August 1977, n = 226.

The lengths in the Faroe Islands catches are recalculated from tailweights, and the size groups less than 13 cm and more than 20 cm are included in the 13 cm and 20 cm groups, respectively.

- The Norway lobster periodically shows low motivation for food search, especially towards dawn.
- The Norway lobster often seems to have difficulties in locating the creel entrance or entrances, even after extended search periods. A typical creel usually has two entrances, which occupy 10–15 per cent of the total circumference of the creel floor. Finding the entrance seems to depend on trial and error.
- Aggressive behaviour is frequent. Small individuals are usually chased off by bigger ones, thus having a negative impact on the catch possibility.
- The creel is an unnatural environmental factor, which might cause some degree of gear repulsion. This is supported by the observations, as one third of the observed individuals had no physical contact with the creel.

Furthermore, the creel catches are composed of a relatively high proportion of large individuals as compared to those of trawl catches. This seems to be caused by a difference in the selection process between the two types of gear.

Catching Norway lobster by creels can be divided into two stages: the attraction stage, which involves long-distance attraction by olfactory stimuli, and the gear stage, which operates in the proximity of the creel.

The selection process seems to start already in the attraction stage. CHAPMAN and HOWARD (1979) suggest that the bait stimulus does not induce the Norway lobster to leave its burrow, and that attraction only occurs when the animals are stimulated during a feeding excursion. The duration of the feeding excursion is positively correlated with the size of the animal.

Consequently, a small Norway lobster with a fairly restricted feeding range should have a low possibility of reaching the creel compared to that of a large individual. Thus, we can assume that even before the Norway lobster is in contact with the gear, there is a selection process exposing a relatively high proportion of large individuals to the gear stage.

In the gear stage, the critical factor is location of the creel entrance. Since this seems to depend on trial and error, the possibility of entering is somehow proportional to the search time. Small individuals were observed to be easily scared or disturbed during the gear stage, while larger individuals seemed to have a higher threshold for disturbances like gear repulsion and the appearance of conspecifics or other species. Thus, small Norway lobsters will spend less time searching for the entrance and make no or few trials to enter the creel, while larger individuals may make numerous trials.

The relatively high proportion of large individuals in the creel catches thus seems to be caused by a two-step behaviour-dependent selection process in the attraction and gear stages.

#### ACKNOWLEDGEMENTS

I want to thank Anders Fernø and Karin Pittman for helpful comments.

#### REFERENCES

- BJORDAL, Å. 1978. Description of the creel fishery for Norway lobster at the Farø Islands (in Norwegian). *Rep.Inst.Fish.Techn.Res.* 30.10.78: 1-6. [Mimeo.]
- BJORDAL, Å. 1979. Creel fishing for Norway lobster in Scotland (in Norwegian). *Fiskets Gang*, 63:p. 829.
- CHAPMAN, C.J. and HOWARD, F.G. 1979. Field observations on the emergence rhythm of the Norway lobster, *Nephrops norvegicus*, using different methods. *Mar.Biol.*, 51(2):157-165.
- DYBERN, B.I. and HØISÆTER, T. 195. The burrows of *Nephrops norvegicus* (L.). *Sarsia*, 21: 49-55.
- LOEW, E.R. 1976. Light and photoreceptor degeneration in Norway lobster, *Nephrops norvegicus* (L.). *Proc.R.Soc. Lond.B.*, 193: 31-44.