Vedl 69

Fish behaviour studies as an aid to improved longline hook design

Ingvar Huse[1,*] and Anders Fernö[2]
[1]Institute of Fisheries Technology Research, Gear and Methods Division, P.O. Box 1964, Nordnes N-5024, Bergen (Norway)
[2]Department of Fisheries Biology, University of Bergen, P. O. Box 1839, N-5024 Bergen (Norway)

(Accepted for publication 31 May 1990)

ELSEVIER

Fisheries Research, 9 (1990) 287–297
Elsevier Science Publishers B.V., Amsterdam

Fish behaviour studies as an aid to improved longline hook design

Ingvar Huse[1,*] and Anders Fernö[2]
[1]*Institute of Fisheries Technology Research, Gear and Methods Division, P.O. Box 1964, Nordnes N-5024, Bergen (Norway)*
[2]*Department of Fisheries Biology, University of Bergen, P. O. Box 1839, N-5024 Bergen (Norway)*

(Accepted for publication 31 May 1990)

ABSTRACT

Huse, I. and Fernö, A., 1990. Fish behaviour studies as an aid to improved longline hook design. *Fish. Res.*, 9: 287–297.

The responses of cod (*Gadus morhua* L.) and haddock (*Melanogrammus aeglefinus* L.) to baited hooks were analysed to determine behaviour patterns which could form the basis for improved longline hook design. The most important behaviour pattern observed for successful hooking of fish was when the fish accelerated rapidly with the baited hook in its mouth (termed "rush" behaviour). A hypothesis for hook design was formed, proposing that a longline hook with its point towards the line of pull would catch more fish than a typical Atlantic longline hook with its point parallel to the line of pull. Two experimental hooks conforming to this hypothesis were compared with a standard hook in fishing experiments. Altogether 19 500 hooks were fished. One experimental hook caught significantly ($P<0.01$ and $P<0.001$) more cod than the standard hook in two fishing experiments, with insignificant results in the third. It also caught significantly more haddock ($P<0.01$). The other experimental hook also caught significantly more cod and haddock than the standard hook ($P<0.001$ and $P<0.01$, respectively). Improved catch rates ranging from 10 to 33% were experienced.

INTRODUCTION

Two major basic development lines for fish hooks can be identified in different regions: the Pacific-type hook, e.g. the Ruvetus hook (Forster, 1973) and the Atlantic-type hook, e.g. the old Norwegian hooks described by Hurum (1977). Examples of ancient and modern versions of these basic hook types are shown in Fig. 1. The Atlantic hook was originally made of bone, and very primitive hooks from as early as 7000 BC are found in Norway (Hurum, 1977). As bronze was utilized as hook material around 200 BC the hook soon attained its present form, and has hardly developed at all since then. The hook

*Present address: Institute of Marine Research, Austevoll Marine Aquaculture Station, N-5392 Storebø, Norway.

0165-7836/90/$03.50

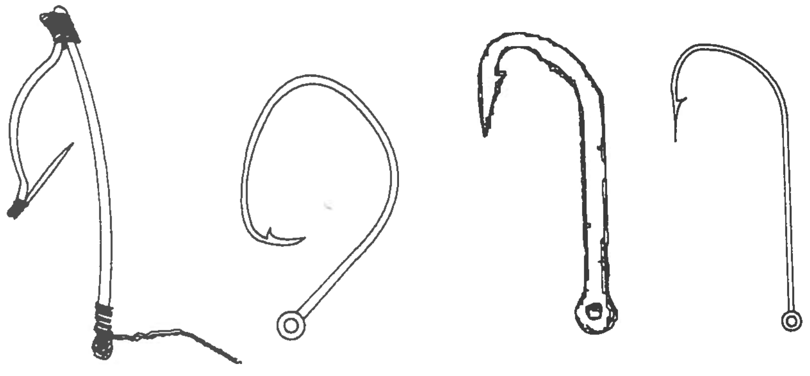

Fig. 1. Original and modern Pacific and Atlantic fish hooks. (a) Ancient Pacific wood and bone hook. (b) Modern Pacific tuna and halibut hook. (c) Ancient European bronze hook. (d) Modern European cod and haddock hook.

has a barb; the point is close to parallel with the shank, pointing in the same direction as the eye end of the hook, forming a semicircular hook head. The fish is secured as the point and barb penetrate the inside of the mouth, or the oesophagus or stomach if the hook is swallowed.

The original Pacific hooks were made out of wood and bone. They did not have or need a barb as the point itself filled the barb function of keeping the hook in place once fastened. The point was close to parallel with the shank, but pointing up along the shank rather than towards the eye, creating an almost full circle. The modern Pacific hooks (Fig. 1) look different because of the availability of new materials and manufacturing methods, but they are still designed according to the same hooking principle as the original ones.

In longline fisheries the hooking ability of the hook is only manifested in catch rates. No information on the hooking process is available to form the basis for a progressive improvement. The various longline hooks have therefore mainly been selected and altered to facilitate baiting and gear handling. As the fish has to hook itself in a longlining situation, other properties are required in a longline hook than are needed in most sport fishing situations, yet the forms of the most frequently used types are similar or identical. Overall, this indicates that this is an area where there is room and need for improvement.

General and qualitative descriptions of behaviour of fish to a baited hook are given by Fernö and Huse (1983), Fernö et al. (1986) and Løkkeborg et al. (1989). The objectives of the present behavior studies were to obtain a quantitative description of the hooking-related behaviour of cod (*Gadus* *morhua* L.) and haddock (*Melanogrammus aeglefinus* L.), and to select a behaviour pattern upon which a hook design could be based. Such a behaviour pattern would have to be vigorous and occur frequently.

Based on the behaviour studies the following hypothesis was formulated: a longline hook with its point towards the line of pull will catch more cod and haddock than a hook with its point parallel to the line of pull. This hypothesis was then tested in fishing experiments, where catch rates of hook forms complying with this hypothesis were compared.

MATERIAL AND METHODS

Behaviour studies

Observations on the behaviour of cod towards a baited hook were carried out in an indoor concrete ring tank with an outer diameter of 14 m, a ring width of 2 m and a depth of 2.3 m. A baited hook was suspended 50 cm above the bottom. The hook area was monitored by horizontally and vertically mounted video cameras with video tape recorders. Stereotypic behaviour patterns were identified and described. Longer behaviour sequences were described by combining several behaviour patterns (Slater, 1973). Thirty cod with a mean length of 60 cm were run through a total of 25 trials over 7 days. Each trial lasted for 10 min or until a fish was hooked. Hooked fish were taken out of the experiment. The fish were bought for the experiment at the live fish market in Bergen, and were most likely caught in gill nets or traps as these are the principal gear types for cod in this area. The fish were kept unfed in the experimental tank for 14 days before the experiment started. Mustad Norway No. 6 hooks were used. Pieces of squid mantle 50 mm × 20 mm were used as bait.

Owing to difficulties in obtaining fish for tank experiments, the behaviour of haddock towards baited hooks was studied in the field in inshore waters near Misje, west Norway, at depths between 30 and 40 m. The observation rig consisted of a low-light underwater video camera mounted horizontally on a frame with four Mustad Norway No. 6 hooks baited with 50 mm × 20 mm mackerel strips suspended from a line in front of the camera (see Fernö et al., 1986). A 500-W halogen lamp with a 605-nm filter provided extra illumination when needed in the morning and evening. The filter was a compromise between the visual threshold of haddock of 675 nm (estimated from Girsa, 1959) and the dark red/infrared sensitivity of the video camera, as a 675 nm filter gave insufficient illumination for the camera. The data from the video tapes were treated in the same way as in the tank experiment. A total of 25 trials were carried out. Each trial lasted for 30 min or until there were no free baited hooks left.

Behaviour definitions

A behaviour sequence is a series of behaviour patterns initiated by a bite or incomplete bite, and terminated by hooking or the hook being out of the mouth.

Behaviour patterns recorded for both species

Bite (B). The fish takes in the baited hook and closes its mouth.

Incomplete bite (Bi). The fish takes in only part of the bait or does not close its mouth completely around the baited hook.

Pulling (P). The fish swims slowly with stretched snood with the baited hook in its mouth.

Chewing (C). The fish chews on the baited hook.

Jerk (J). The fish moves its head rapidly sideways with the bait and hook in its mouth.

Jerk series (Js). The fish performs several very fast jerks in succession from side to side with the baited hook in its mouth.

Rush (R). The fish accelerates rapidly with the baited hook in its mouth.

Hook out of mouth (S). The hook with or without bait is spat or pulled out of the mouth.

Hooking (H). Not a behaviour pattern. The fish was considered hooked when the hook was retained in the mouth for 20 s while the fish was struggling.

Similarly described behaviour patterns were used by Fernö and Huse (1983), Fernö et al. (1986) and Løkkeborg et al. (1989).

Fishing experiments

Three fishing experiments to test the catch rates of three hook types were carried out: Experiment 1 in the Lofoten area in winter during the Arcto-Norwegian cod spawning season; Experiment 2 off Vardø, north Norway, during the spring cod fishery; Experiment 3 off Vardø during the summer cod and haddock fishery. All lines were set either 10–20 m off the bottom at 60–150 m depth, or pelagically at 60 m depth when fishing for haddock. The lines were made of 1.8–2.0 mm diameter monofilament nylon, with 1-m long 0.8-mm monofilament nylon snoods fastened to the line with swivels at 2-m intervals. Comparisons were made between neighbouring hook blocks. In the cod part of Experiment 3, each hook block consisted of experimental and standard hooks alternating along the line. The catches of 50 hooks of one type were then compared with the catches of the 50 correspondig hooks of the other type. This was done to avoid effects of patchy fish distribution as experienced in Experiment 2. A total of 19 500 hooks were fished. Details of the fishing experiments are given in Table 1. Mustad Norway No. 6 was used as standard hook in all fishing experiments. This hook has been the standard

TABLE 1

Fishing experiments

Exp. No.	Location	Time	Hook types	Species	Block size	Numbers of comparisons
1	Vardø	Spring	WG/N	Cod	50	24
2	Lofoten	Winter	WG/N	Cod	50	50
3	Vardø	Summer	WG/N	Cod	50	26
3	Vardø	Summer	"R"/N	Cod	50	35
3	Vardø	Summer	WG/N	Haddock	100	8
3	Vardø	Summer	"R"/N	Haddock	100	9

WG, Mustad Wide-Gap No. 5/0; N, Mustad Norway No. 6; "R", "Rush" hook.

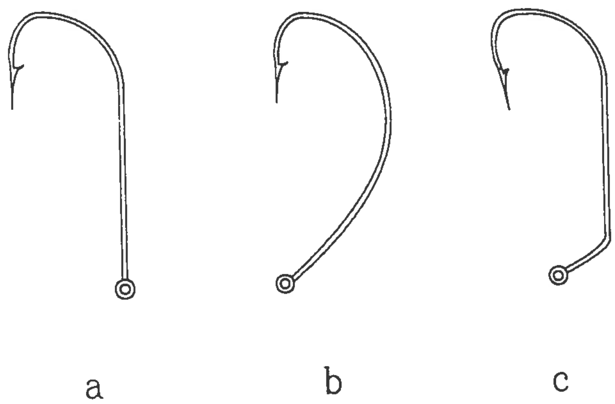

Fig. 2. Hooks used in the fishing experiments. (a) Mustad Norway No. 6 (standard hook). (b) Mustad Wide-Gap No. 5/0. (c) "Rush". Note point aiming at eye in the latter two hooks.

hook in north Norway cod and haddock fisheries for many years. The experimental hooks were a Mustad Wide Gap No. 5/0 produced for sport fishing in America, and a hook named "Rush" which was designed for the experiment and produced by O. Mustad & Søn A/S. Both hooks were selected to comply with the experimental hypothesis, i.e. with the point aiming at the eye. The forms were, however, otherwise dissimilar in order to achieve two independent tests of the hypothesis. Sizes were selected to compare well with the standard hook. The different hook types are outlined in Fig.2

The Wilcoxon paired sample test was applied in all catch comparisons.

RESULTS

Behaviour studies

Figure 3 shows a matrix of transitions from one behaviour pattern to another within the behaviour sequences of the cod study. The upper numbers in

First behaviour pattern (columns); Second behaviour pattern (rows)

	B	Bi	R	J	Js	P	H	S
B								
Bi								
R	38 22.8	5 22.4	10 12.4	14 17.6	0 1.3	12 4.2		
J	41 32.3	55 31.8	4 17.6	8 24.9	1 1.8	3 8.0		
Js	3 2.3	0 2.3	1 1.3	3 1.8	1 0.1	0 0.4		
P	17 7.8	7 7.7	0 4.2	3 6.0	0 0.4	0 1.5		
H			13 2.7	2 3.8	2 0.3	0 0.9		
S	40 74.9	71 73.8	51 40.8	82 57.6	4 4.1	12 14.0		
SUM	139	138	79	112	8	27	17	280

Fig. 3. Transition matrix showing observed and expected values for transitions from one behaviour pattern to another within behaviour sequences. Upper numbers in squares are observed values, lower numbers are expected values. First behaviour pattern of a transition is given above the square, second at left side.

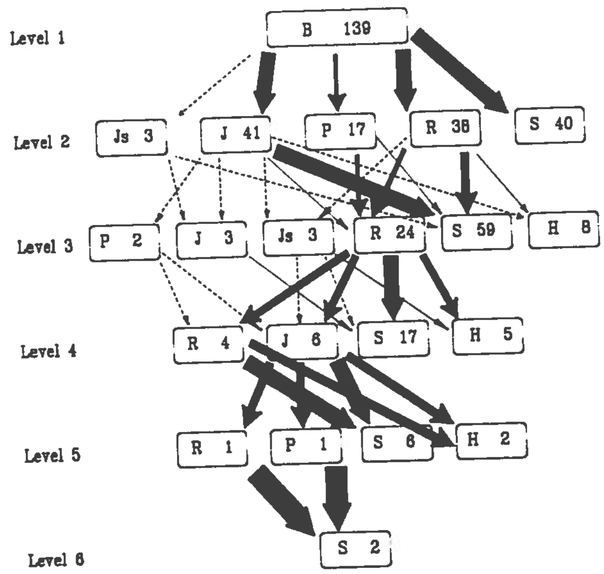

Fig. 4. Behaviour flow chart for cod taking a baited hook. All observed sequences are summed. Each sequence starts with a bite (B), and ends either with hook out of mouth (S) or hooking (H). The thickness of arrows indicates the relative importance of the transition between the two behaviour patterns at the levels in question. Infrequent transitions (less than 4% of total at level) are represented by dotted lines.

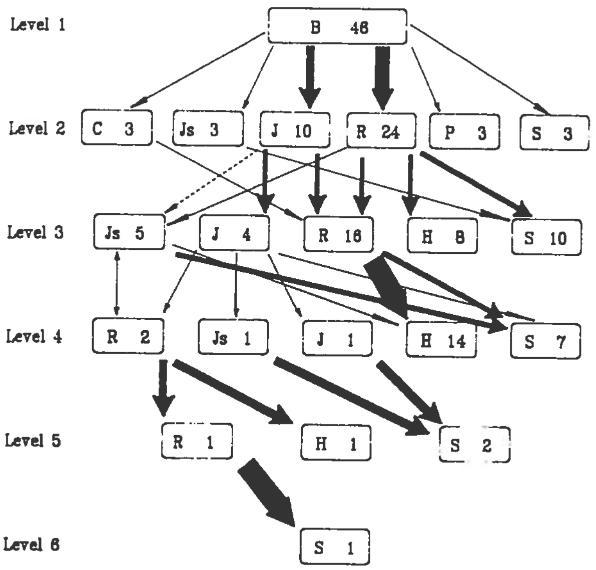

Fig. 5. Behaviour flow chart for haddock taking a baited hook. For explanation, see Fig. 4.

the squares are observed values, the lower are expected values (Lemon and Chatfield, 1971; Fernald, 1977; Huse, 1979). The main function of the matrix is to show possible combinations of behaviour patterns which occur more or less frequently than expected if all possible combinations of behaviour patterns had the same probability of occurring. A statistical analysis of the matrix is complicated by the fact that not all transitions are possible (B/Bi and H/S can only be first and last behaviour patterns, respectively, in a transition). The matrix was therefore visually inspected for large differences as recommended by Slater (1973).

Figure 4 presents a flow chart summing all sequences in the cod experiment starting with a "bite". Each level contains the corresponding behaviour pattern in each of the summed sequences. The sequence B–P–J–Js–R–S thus has the B in Level 1, the P in Level 2, the J in Level 3 etc. The sum of "rushes" in these sequences was 67, and the sum of "jerks" 50.

Figure 5 presents a behaviour flow chart for the 46 sequences in the haddock experiment starting with a "bite". The sum of "rushes" was 43 and the sum of "jerks" 15.

Fishing experiments

The results of the fishing experiments are given in Table 2. The experimental hooks caught more fish than the standard hook in all experiments, and the difference was statistically significant in all but one comparison.

TABLE 2

Results of the fishing experiments

Exp. No.	Hook types	Species	*P*	Catch numbers	% increase	Fish size (kg)
1	WG/N	Cod	0.01	303/226	34	2–10
2	WG/N	Cod	0.13	443/388	12	4–15
3	WG/N	Cod	0.001	517/415	33	2–10
3	"R"/N	Cod	0.001	943/765	23	2–10
3	WG/N	Haddock	0.01	441/386	14	1–6
3	"R"/N	Haddock	0.01	544/493	10	1–6

See Table 1 for hook type abbreviations. Fish sizes are estimated round weights.

DISCUSSION

Behaviour studies

The sums in Fig. 3 show that, apart from "bite"/"incomplete bite", "jerks" occurred most frequently, followed by "rushes". "Jerks" were, however, more connected to "incomplete bites" than "rushes". The high frequency of "incomplete bites" is probably a result of hook-avoidance learning related to the laboratory situation (see Fernö and Huse, 1983), as both cod and haddock in the field most often make "complete bites" (Løkkeborg et al., 1989; Huse, 1979). Numbers of "rushes" and "jerks" following "bites" were close to equal (38 to 41), but B–R was 67% over-represented compared with only 27% for B–J. Transitions occurring more than twice as frequently as expected were B–P, P–R and R–H. This corresponds to a sequence where the fish bites, tries to pull the baited hook away, is stopped by the stretched line, "rushes", and finally is hooked. Of behaviour patterns leading to hooking, "rushes" dominated with 13 out of 17. As the fish always "rushed" after hooking, and as the precise moment of hooking sometimes was difficult to decide, this transition may, however, have been somewhat over-recorded. The transition Js–H was also strongly over-represented, but had a low frequency of occurrence (2 out of 17 hookings). Altogether the transition matrix strongly indicates that the "rush" is the behaviour pattern leading to hooking in most cases.

In Fig. 4, seven of the eight hooked fish at third level, with only one behaviour pattern between "bite" and hooking, were hooked after a "rush". This is an additional strong indication that the "rush" is a prominent behaviour pattern in the hooking process for cod.

Of the 23 haddock hooked in Fig. 5, 21 were hooked following a "rush". Also seven of the eight fish hooked at the third level, with only one behaviour pattern between "bite" and hooking, were hooked after a "rush". This agrees well with the cod experiment. The overall conclusion is that the "rush" should form the behavioural basis for a cod and haddock longline hook design.

Hook form

Figures 4 and 5 show that hooking frequencies are rather low considering that the force applied by the fish in a "rush" should be sufficient to hook the fish, provided that the hook form and the fish movement allow the hook point and barb to penetrate the mouth. Figure 6a and b indicates that this only occurs with the traditional Atlantic hook form when the shank and snood form an angle larger than approximately 45°C with the fish side in the rush. If this assumption is correct, a hook with the point in the line of pull, i.e. a line through the point also runs through the hook eye (Fig. 6c) should have a higher hooking probability than a traditional longline hook because it will penetrate for any angle between fish and snood in the rush. Two experimental hooks (Fig. 2) with this characteristic, but otherwise dissimilar, were selected for the fishing experimets, and were compared with a standard hook. The two experimental hooks clearly do not fall into either the Pacific or the Atlantic hook-form category, but can be said to be hybrids between the two. They form almost a complete circle like the Pacific hook, but it is still the point and barb which penetrate when force is applied to the snood, as in the Atlantic hook.

Fishing experiments

Fishing Experiment 1 gave a statistically significant increased catch of 34% for the wide-gap hook compared with the standard hook. In Experiment 2, however, the cumulative catches were still largest for the wide-gap hook, but the result was not statistically significant. Very patchy fish distribution and a higher proportion of swallowed hooks (41% in Experiment 2 compared with

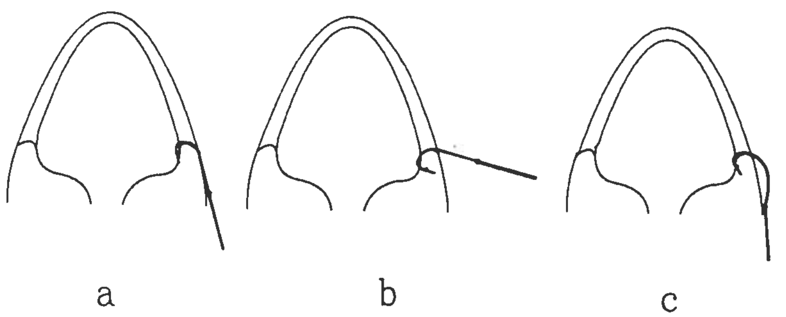

Fig. 6. Schematic lateral section through a fish head during the hooking process. (a) Standard hook with small angle between hook and fish body (no hook penetration). (b) Standard hook with large angle between hook and fish body (hook penetration). (c) Wide-gap hook with small angle between hook and fish body (hook penetration).

16% in Experiment 1) may explain this difference. Swallowed hooks will obviously even out the differences in hooking rate as both hook types should secure the fish equally well when swallowed. Patchy fish distribution will make it hard to obtain a statistically significant result with a hook block-type experimental design.

With the neighbouring hook comparison design of Experiment 3 the wide-gap hook again showed nearly the same improvement in catch rate over the standard hook as in Experiment 1. The "Rush" hook also had a significantly higher catch rate than the standard hook in this experiment, although somewhat lower than the Wide-Gap hook.

Both the Wide-Gap hook and the "Rush" hook had significantly higher catch rates of haddock than the standard hook, the Wide-Gap hook also producing somewhat better results than the "Rush" hook. This shows that the hypothesis also holds for haddock, which was expected, as the behaviour of cod and haddock relevant to this hooking principle seems to be quite similar. There are, however, other marked differences between the species in the behaviour towards baited hooks (Løkkeborg et al., 1989). An even greater increase for haddock than for cod would not be unlikely since only 6% of the haddock had swallowed the hook compared to 16–41% of the cod, but with the highly patchy fish distribution experienced in the haddock experiment, local gear saturation could mask the real difference in hooking probability. The tendency of haddock, in contrast to cod, to make repeated responses towards baited hooks (see Løkkeborg et al., 1989) could also have caused this effect.

Our conclusion is that the Wide-Gap and "Rush" hooks give a substantially higher catch rate for cod and haddock than the Norway hook which for a long time has been the standard longline hook in the cod and haddock fisheries in northern Norway. We attribute this property to the common factor of these two hooks, that a line through the point of the hooks also runs through the eye.

ACKNOWLEDGEMENT

The valuable assistance of skippers and crews of the longliners "Fjellsegga" and "Singsholmen" is gratefully acknowledged.

REFERENCES

Fernald, R.D., 1977. Quantitative behavioural observations of *Haplochromis burtoni* under semi-natural conditions. Anim. Behav., 25: 643–653.

Fernö, A. and Huse, I., 1983. The effect of experience on the behaviour of cod (*Gadus morhua* L.) towards a baited hook. Fish. Res., 2: 19–28.

Fernö, A., Tilseth, S. and Solemdal, P., 1986. Field studies on the behaviour of whiting (*Gadus merlangus* L.) towards baited hooks. Fiskeridir. Skr. Ser. Havunders., 18: 83–95.

Forster, G. R., 1973. Line fishing on the continental slope. The selective effect of different hook patterns. J. Mar. Biol. Assoc. UK, 53: 749–751.

Girsa, I. I., 1959. Effect of differences in illumination on the availability of food organisms to certain fishes. Tr. Inst. Morfol. Zhivotn. Akad. Nauk SSR, 13: 118–128. (Fish. Res. Board Can. Transl. Ser. No. 492).

Hurum, H.J., 1977. A History of the Fish Hook and the Story of Mustad, the Hook Maker. A&C Black, London.

Huse, I., 1979. The importance of hook form and gear materials in long line fisheries for cod (*Gadus morhua* L.) and haddock (*Melanogrammus aeglefinus* L.) examined in behaviour studies and fishing experiments. M.Sc. Thesis, Univ. Bergen (in Norwegian).

Lemon, R. E. and Chatfield, C., 1971. Organization of song in cardinals. Anim. Behav., 19: 1–17.

Løkkeborg, S., Bjordal, A. and Fernö, A., 1989. Responses of cod (*Gadus morhua* L.) and haddock (*Milanogrammus aeglefinus* L.) to baited hooks in the natural environment. Can. J. Fish. Aquat. Sci., 46: 1478–1483.

Slater, P.J.B., 1973. Describing sequences of behaviour. In: P.P.G. Bateson and P.H. Klopfer (Editors), Perspectives in Ethology. Plenum Press, New York., pp. 131–153.