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Baiting gill nets—how is fish behaviour affected?

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Abstract

Movements of acoustically tagged cod were tracked in a fjord in northern Norway using a stationary telemetric positioning system. Having observed the basic movement patterns under the prevailing natural conditions, an experimental fleet of gill nets having baited and non-baited nets was introduced. The nets were fished for 12 nights and swimming behaviour of the tagged fish towards the baited and non-baited nets compared. Baiting resulted in increased number of encounters with the gear, but this did not significantly increase catch rates. The majority of fish swam slower in the vicinity of baited as compared to non-baited nets, but did not stay for a longer time at baited than at non-baited nets following an encounter. The mesh size and texture of the bait bags may be crucial for releasing strong responses leading to netting.

Keywords: Cod; Behaviour; Bait; Gill net

1. Introduction

Traditional fishing practices of longlining and trapping use baits for attracting fish towards the gear, taking advantage of the chemically stimulated feeding behaviour in fish (Atema, 1980; Hara, 1982; Løkkeborg, 1990), while the catch success on gill nets depends on the unstimulated natural search activity of fish bringing them into physical contact with the gear (Dickson, 1989; Anderson, 1998). A pilot study with baited gill nets showed that the catch rates of cod (*Gadus morhua*), Greenland halibut (*Reinhardtius hippoglossoides*), ling (*Molva molva*) and saithe (*Pollachius virens*) significantly increased when the nets were baited (Engås et al., 2000). The idea behind this study was to test if bait on gill nets could be used to increase fish density around the nets and thereby give higher catch rates. Higher catch rates would make it possible to reduce soak time and improve quality of the fish caught. It might also lead to a reduction in the number of nets used per vessel without affecting the total catch. Use of fewer gill nets can be expected to decrease the loss of nets, which will have a positive impact on the environment. Lost gill nets are generally difficult to retrieve and nets made of synthetic twines can remain "active" (ghost fishing) for a long time (Erzini et al., 1997; Humborstad et al., 2000).

During the pilot study and when later tested by commercial fishermen, the bait in the bags (50 mm meshed netting) was often foraged by scavengers. To overcome this problem, small-meshed bait bags as used in the Norwegian trap fisheries for cod were used during comparative full-scale fishing experiments with baited nets for cod and ling in Norwegian waters. These

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experiments did, however, not demonstrate any effect of baiting on catch rates (Engås and Jørgensen, unpublished data). Since it is well documented that fish can be attracted to bait by chemically mediated rheotaxis (Løkkeborg, 1998) and the small-meshed bait bags have proven effective in the trap fishery for cod, it is likely that baiting gill nets increases the density of fish around the gill nets. To document that the density increases with baiting and to explore if baiting results in changes in swimming behaviour that may affect capture probability of the gill nets, a small-scale experiment using acoustically tagged cod was initiated.

2. Materials and methods

The study was conducted in the Ramfjord, a small side branch of the larger Balsfjord in northern Norway from 30 August to 24 September 1997. The depth at the experimental site was 60–70 m. Water temperature ranged between 5 °C (1 m above seabed) and 8 °C (1 m below surface) and the salinity between 28‰ (1 m below surface) and 32‰ (1 m from seabed).

Current speed and direction were simultaneously recorded every 10 min using two identical SD6000 current meters (Sensordata a.s., Bergen, Norway). During the initial phase of the study, these meters were placed 2 m above the seabed and about 400 m apart within the study area to gather information on the uniformity of water flow in the fjord. Later upon introduction of baited gill nets, it was important to study the water flow close to the position of baits. The current meters were then placed 10 m apart in the area where the nets were set, one 2 m and the other 5 m above seabed. The current speed ranged between $<0.2\,\mathrm{cm\,s^{-1}}$ (minimum sensitivity of the instrument) and $36\,\mathrm{cm\,s^{-1}}$ (mean $= 4.3\,\mathrm{cm\,s^{-1}}$).

Outdoor light intensity was recorded every 15 min throughout the experimental period with an Li-cor LI-1000 light meter using an LI-210SA photometric sensor (Li-cor Inc., Lincoln, NE, USA). The night time (from the end of civil twilight at dusk to the beginning of civil twilight at dawn) varied from 21:31–03:51 h (1 September 1997) to 19:43–05:26 h (24 September 1997) local time. The low sensitivity of the light meter did not permit a study on swimming activity in relation to light intensity at night.

Cod tagged with hydroacoustic transmitters operating on different frequencies were tracked by means of a stationary positioning system (VRAP, Vemco Ltd., Halifax, Canada) that consisted of three hydrophone buoys anchored in a triangular configuration. The buoys were between 400 and 600 m apart. The receiver system monitored the set of frequencies sequentially, 30 s for each. The signals received from a transmitter during a 30 s time period were aligned and the average position calculated. With 2–9 fish monitored at the same time, the time interval between position fixes varied from 1 to 4.5 min.

Cod were tagged in situ by allowing them to ingest transmitters (16 mm in diameter and 80 mm long) wrapped in mackerel (*Scomber scomber*) bait and enclosed in a fine-meshed bag of thin nylon fabric. The bait-wrapped transmitter was attached by a thin cotton twine to a steel frame that was placed on the seabed. A light sensitive underwater camera was mounted on the frame to identify the fish that ingested the transmitter. The frame had marks 10 cm apart to visually estimate the length of the fish. A more detailed description of the tagging procedure is provided by Engås et al. (1996).

A total of nine cod were tagged (Table 1). Six tagged fish were tracked for 3–6 days before the gill net experiments started on 12 September 1997. Movement of fish out of range of the tracking system could limit the availability of successive position recordings from an individual fish. Two fish moved permanently out of range of the tracking system 5 and 11 days, respectively, after they were tagged. Four fish presumably regurgitated the transmitter 6–14 days after tagging, resulting in a fixed position of the transmitter thereafter. Misleading position fixes due to reflected signals or interference from background noise were manually removed prior to data analysis. Detailed examination of data of a stationary tag suggested reliable position recordings with deviation values below 50. Recordings with deviation values above 50 were therefore excluded from further analyses.

The experimental fleet consisted of two pairs of identical gill nets (Table 2). The nets were separated by a 50 m long × 14 mm diameter nylon rope to provide ample spacing to avoid guiding of fish from one pair of nets to the other (Fig. 1). Gill nets with 120 mm mesh size were used during the first five trials. Despite observations of tagged fish near the nets, the gear

Table 1
Details of the transmitters used and the fish tagged during the study

Tag no.[a]	Frequency (Hz)	Date tagged	Length (cm)	Tracked until	Remarks
4163	57	2 September	45	15 September	Tag regurgitated
4166	63	2 September	–[b]	11 September	Tag regurgitated
4171	72	3 September	50	5 September	Stopped
4173	75	4 September	55	16 September	Caught
4180	60	4 September	40	9 September	Tag regurgitated
4178	54	4 September	50	20 September	Moved out area
4181	67	5 September	–	17 September	Tag regurgitated
4175	78	11 September	63	22 September	Caught
4173	75	16 September	55	21 September	Moved out of area
4185	78	22 September	50	24 September	End of experiment

[a] Tag nos. 4171 and 4178 were ingested by the same fish. Fish with tags 4173 and 4185 had few observations within the experimental area and were not included in the analyses.

[b] No length estimate was made.

Table 2
Specifications for the gill nets used in the experiments

Parameter	120 mm gill net	148 mm gill net
Length of one net (m)	27.5	27.5
Depth (no. of meshes)	40	50
Mesh size (mm)	120	148
Hanging ratio, *E*	0.5	0.5
Netting material	PA twisted monofilament	PA twisted monofilament
Twine thickness (mm)	0.45	0.45
Colour of netting	Green	Blue
No. of PVC floats	11	11

failed to catch any of them during this period. It was suspected that the mesh size was sub-optimal for the tagged fish size and gill nets with larger mesh size (148 mm) were used during the last seven trials.

Bait of thawed frozen mackerel was attached to one of the two pairs of nets. Two whole mackerels, each cut into three pieces, were put into a fine-meshed woven polyethylene bag (34 cm × 22 cm, black colour, 70% light reduction property). Four bags were attached to each net of the pair to be baited (a total of eight bait bags) at positions beneath the floats, excluding the floats on the extreme ends of the nets. Six trials were

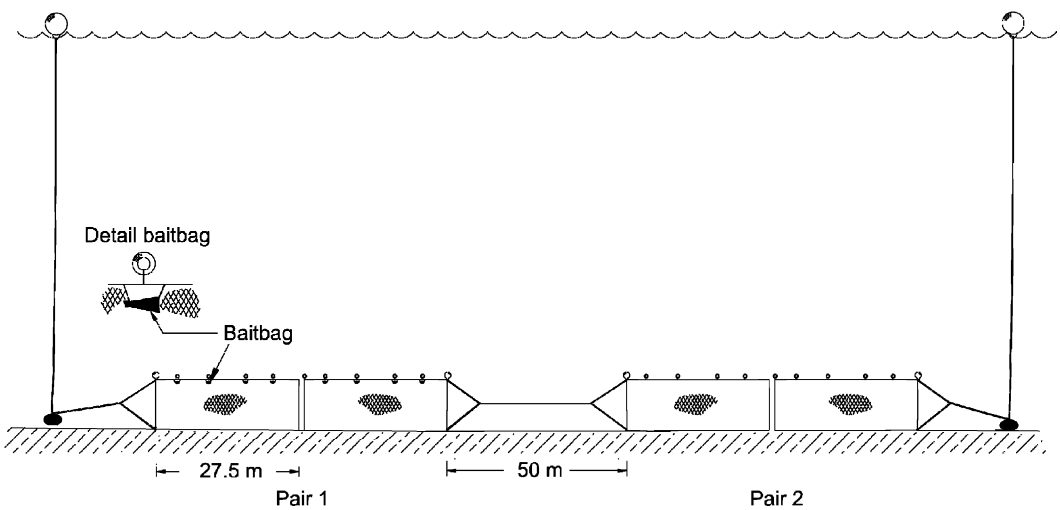

Fig. 1. Schematic diagram of the experimental gear used in the study (not to scale). Baits were attached to one of the two pairs of nets, while the other pair was not baited. Trials were conducted with baits attached either to the float line or at corresponding positions on the lead line.

conducted with bait attached to the float line and five with bait mounted to the lead line of the nets at corresponding horizontal positions. Acoustic transmitters were attached on either ends of the fleet to monitor its position and the fleet was set across the length of the fjord (perpendicular to the general current direction) to enable spread of feeding attractants over a large area. The pair of nets to be baited and the position of the nets in the fjord (within the triangle defined by the three buoys) were chosen at random before each setting. The fleet was set out around 09:00 h and hauled after 12:00 h. For every fish caught, species, total length and mode of capture (gilled, wedged or tangled) were recorded. The stomach contents of fish were visually examined to record the feeding state.

Mean hourly swimming speed was calculated to study diurnal activity patterns previous to and following the introduction of baited nets for fish that provided sufficient continuous position data. The spatial variation in the current speed and direction within the study area restricted the analysis of fish movements relative to tidal influence.

The shortest distance between the position of a fish and the pair of nets was calculated separately for baited and non-baited nets for every valid position recorded during the periods when nets were set. Allowing for minor variations in the precision of the averaged position fix and considering possible fish movements between consecutive position recordings, an area within a horizontal distance of 25 m from the pair of baited nets was defined as its 'near field'. A similar near field was defined for the non-baited nets. This horizontal distance formed half the distance between the baited and non-baited nets and therefore avoided overlapping of the near fields. A far field was arbitrarily defined as the area outside a distance of 150 m from the nets.

A fish that entered the near field of nets and stayed there for at least 4 min (the estimated time a fish entering the near field needed to reach to the net and exit the field again, based on an average swimming speed of 0.23 m s^{-1}—the calculated 75 percentile swimming speed for the pooled data) was defined as an encounter.

Swimming speed of individual fish was calculated using the time interval and the distance between successive position recordings. This approach implicitly assumed fish to follow the straight-line track between the position fixes and could therefore underestimate the actual value (Løkkeborg et al., 2002). The error is likely to increase with the time interval between position recordings and therefore calculations of swimming speed were not performed when the time interval exceeded 10 min.

For all multiple-comparisons tests the Dunn–Ŝidák method was used to limit the experimentwise error rate to $\alpha = 0.05$ (Sokal and Rohlf, 1995). To increase the power of the tests, the procedure of Holm (1979) was followed.

3. Results

The number of encounters (fish entering the near field) of the tagged fish with the baited nets was significantly higher than the number of encounters with the non-baited nets for three out of four fish for which an adequate number of observations were available (Table 3). An illustration is given for fish 4181 (Fig. 2). The movements prior to the introduction of gill nets did not show clustered observations at the locations where the baited nets were later set (Fig. 2).

Swimming speed was lower in the near field of baited than of non-baited nets (Table 4). There was also evidence that the swimming speed in the near field of baited nets was lower than in the far field of the nets (Table 5), but no support for a difference in swimming speed between the near field of the non-baited nets and the far field. Only one of the studied fishes presented evidence that a fish entering the near-field of baited nets stays there for a longer period of time than it does after an encounter with the non-baited nets (Table 6).

Table 3
Number of recorded encounters of the near field of the baited and non-baited nets for each fish

Fish no.	Encounters with baited nets	Encounters with non-baited nets	*P*-value[a]
4163	11	1	0.0063*
4173	2	4	0.6875
4175	44	35	0.3682
4178	12	0	0.0005*
4181	20	6	0.0094*

[a] The binomial probability of the observed encounters under the null hypothesis of equal encounter probability for the baited and non-baited nets.

* Values significant at the adjusted levels.

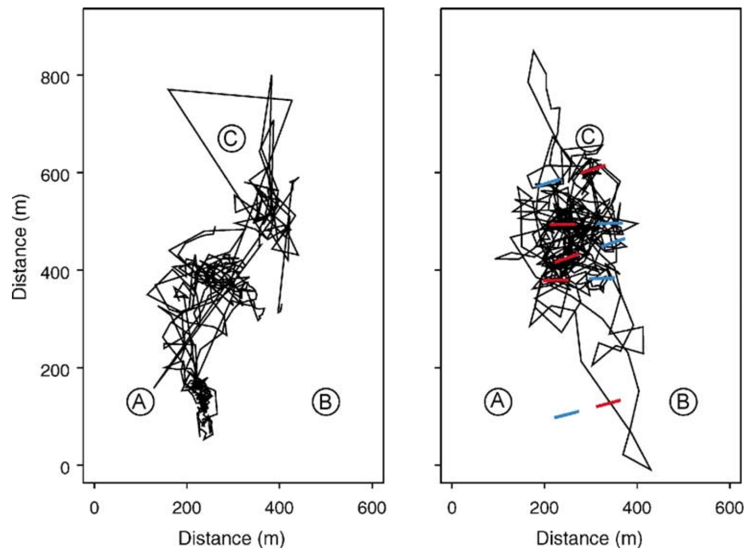

Fig. 2. Left: movements of a fish (tag 4181) observed for a period of 3 days before introduction of the gill net fleet. The fish did not show any tendency to remain in the area where baited nets were later set. Right: movements of the same fish during five nights when the experimental gear were set in the area. Red and blue bands represent locations of baited and non-baited nets, respectively. Note clustered observations close to baited nets. A, B and C mark the locations of hydrophone buoys.

Table 4
Observed median swimming speed ($m\,s^{-1}$) in the near-fields of baited and non-baited nets

Fish no.	Baited net		Non-baited net		*P*-value[a]
	n	Median	*n*	Median	
4163	51	0.101	6	0.226	0.0439
4173	37	0.034	10	0.197	0.0002*
4175	206	0.118	100	0.170	0.0004*
4178	36	0.202	3	0.345	0.1258
4181	165	0.069	37	0.123	0.0108*

[a] The value is significant for a Wilcoxon two-sample test of the null hypothesis of no difference in swimming speed between the two near-fields.

* Values significant at the adjusted levels.

Observations of hourly swimming speed of tagged fish prior to the introduction of baited nets indicated diel variation in activity (Fig. 3). A tendency of crepuscular rhythm was observed, cod being more active

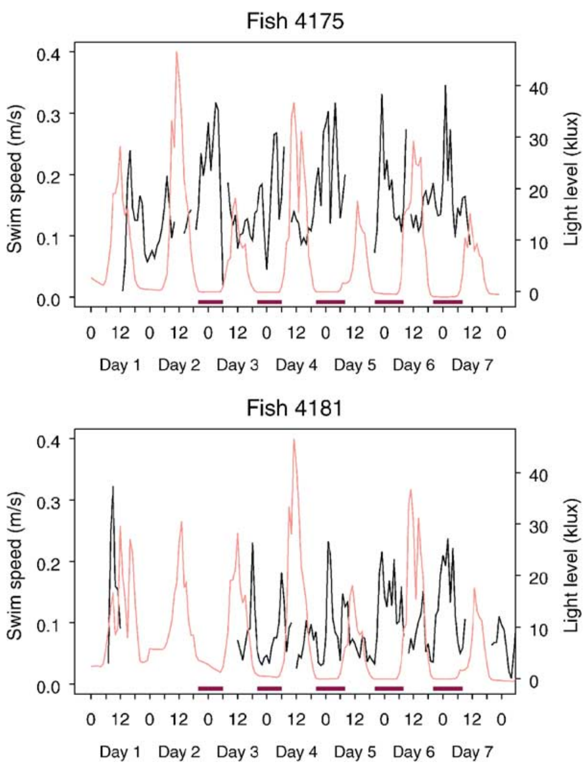

Fig. 3. Hourly swimming speed of fish 4175 and 4181 before and after introduction of baited gill nets (solid lines). Dotted red line indicates out door light intensity during 24:00 h cycles. Horizontal bands along the *x*-axis indicate the time period when baited.

Table 5
Observed median swimming speed (m s^{-1}) in the near field of baited nets and in the far field of the experimental nets

Fish no.	Near-field baited net		Far field		P-value[a]
	n	Median	*n*	Median	
4163	51	0.101	85	0.142	0.0067*
4173	37	0.034	179	0.080	0.0013*
4175	206	0.118	318	0.165	<0.0001*
4178	36	0.202	308	0.184	0.7844
4181	165	0.069	114	0.054	0.9440

[a] The value is significant for a Wilcoxon two-sample test of the null hypothesis of no difference in swimming speed between the two areas.
* Values significant at the adjusted levels.

during dawn and dusk, with least activity around midnight. The activity pattern changed upon the introduction of baited gill nets during night time, with periods of high activity now coinciding with the presence of baited nets.

Fish movements directed towards baited nets, with the fish changing its apparently random movement directions and heading towards the gear, were observed several times from distances up to 400 m (Fig. 4) and in one case from 800 m. It was not possible to relate these movements to the presence of the odour plume from the baits due to marked variations in the speed and direction of water flow (Fig. 4).

A distinct pattern of fish movement relative to baited nets was repeatedly observed, whereby the tagged fish, after moving close to the baited net for a period of time, swam away up to 400 m, made a sudden turn and directly returned to the same baited net (Fig. 5). The track followed by the fish thus had the shape of loops, with distances up to 150 m between the track the fish followed when it swam away and when it returned.

Table 6
Median values of observed residence times (s) in the near-fields of baited and non-baited nets

Fish no.	Baited net		Non-baited net		P-value[a]
	n	Median	*n*	Median	
4163	11	614.0	1	337.5	NA
4173	2	486.4	4	564.1	0.5333
4175	44	605.4	35	376.6	0.0016*
4178	12	425.2	0	–	NA
4181	20	569.7	6	670.8	0.5727

[a] The value is significant for a Wilcoxon two-sample test of the null hypothesis of no difference between the two groups of nets.
* Values significant at the adjusted levels.

Table 7
Number of fish caught by species and mode of capture

Species	Number caught	Mode of capture		
		Gilled	Wedged	Tangled
Baited nets				
Cod	9	2	1	6
Haddock	3	1	2	0
Saithe	9	2	2	5
Total	21	5	5	11
Non-baited nets				
Cod	8	2	4	2
Haddock	1	1	0	0
Saithe	1	1	0	0
Total	10	4	4	2

The number of fish caught on the baited and non-baited gill nets was not significantly different either by individual species or with all species pooled (Wilcoxon paired sample test) (Table 7). The catch on the gill nets comprised of cod, saithe and haddock and included two tagged fish on the 12th and 13th day of their tagging. Fifty-two percent of the fish caught on baited nets (11/21) were caught by tangling, the rest were either gilled or wedged, whereas 80% of the catch on the non-baited nets belonged to the latter category and only 20% (2/10) were caught by tangling. The corresponding figures of tangling for cod were 67% (6/9) on baited nets against 25% (2/8) on non-baited nets. The differences were, however, not statistically different ($P = 0.195$ and 0.156; chi-square test). Thirty-two percent of all fish caught had their stomachs partly filled with smaller fish and/or other invertebrates at different stages of digestion, while the rest had empty stomachs.

4. Discussion

The small-meshed bait bags mounted on gill nets increased the number of net encounters of cod and thus seemed to release chemically stimulated feeding behaviour. The number of fish caught was, however, not influenced by the presence of bait. This was also

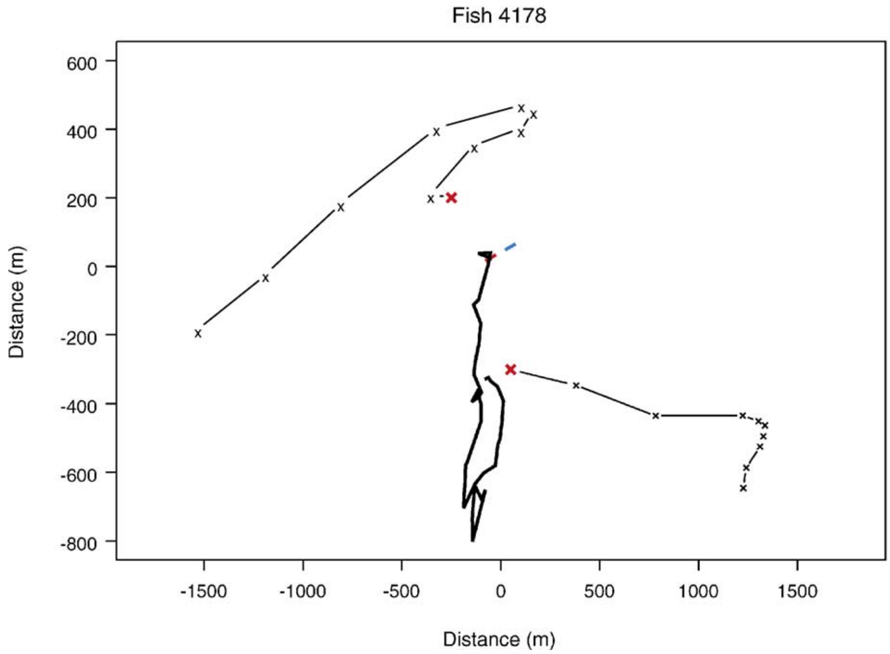

Fig. 4. Example of fish movement (bold line) directed at the baited nets from a distance of 600 m. The fish movement covers the time period from 02:48 to 05:27 h on 15 September. Red and blue bands represent the baited and non-baited nets. Also shown are the progressive vector diagrams for the current measured by two current meters. The measurements cover the time interval from 21:00 h on 14 September (shooting of nets) to 06:00 h on 15 September. The positions of the meters are indicated by red *x*'s and the distance between consecutive plotting symbols on the current trajectory corresponds to a 01:00 h time period.

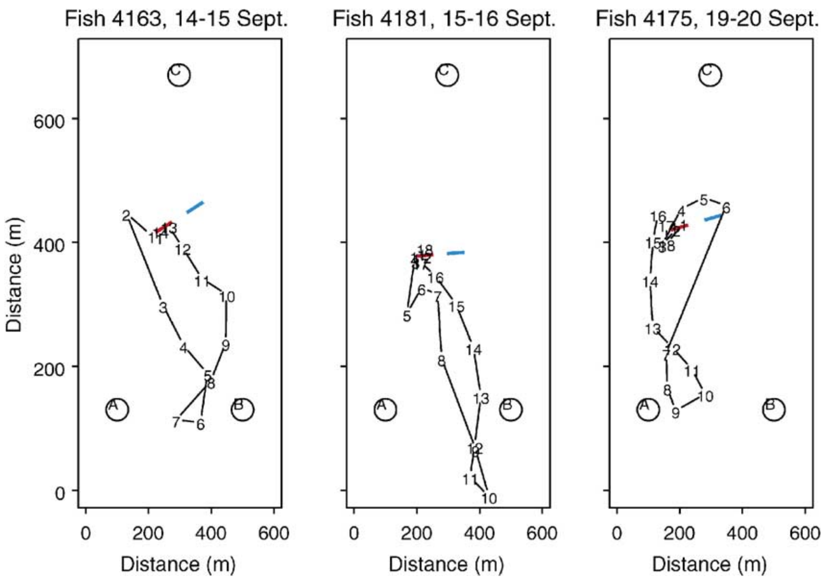

Fig. 5. Fish moving in loops relative to the baited nets. Red and blue bands indicate baited and non-baited nets, respectively. A, B and C mark the locations of hydrophone buoys. Direction of fish movements is indicated by progressing serial numbers.

found in full-scale fishing experiments with baited gill nets for cod and ling (Engås and Jørgensen, unpublished data), whereas Engås et al. (2000) using a different type of bait bag observed higher catch rates of cod, saithe, ling and Greenland halibut on baited than on non-baited gill nets.

The number of fish monitored in the present study is small, but represents the maximum number that could be simultaneously tracked with the VRAP system without compromising on the spatial and temporal resolution of the data. To compensate the low number, the nets were fished for several nights (12) and the location of the nets randomly varied between nights. As there are no indications that the behaviour of the tagged fish is in any way different from that of the remaining cod population in the fjord, the findings should therefore have a more general validity.

The low swimming speed observed close to the baited nets could explain why frequent encounters did not increase the catch. Fish swam slower in the near field of baited nets than in the near field of non-baited nets or in the far field of the nets. Slowly swimming fish may detect and avoid a gill net before contact, reducing the probability of getting enmeshed. About 50% of the fish caught on the baited gill nets were tangled compared to only 20% on non-baited nets, supporting that the low swimming speed close to baited nets reduce the probability of becoming gilled.

Fish did not stay for a longer time at baited than at non-baited nets following an encounter. A fish approaching a bait bag is presumably in a conflict situation (Fernö and Huse, 1983) with minor changes in the approach and withdrawal tendencies determining the outcome. The bait bags used, with stiff texture and fine-meshed netting through which no part of the bait protruded, might not have been optimal to release strong responses. In the study with a positive effect of bait bags, Engås et al. (2000) used bait bags of white nylon netting with softer texture and larger meshes allowing fish physical contact with the bait.

Observations on the swimming activity of the tagged cod before the baited gill nets were introduced indicated a diurnal rhythm with least activity at night and indications of peaks of activity at dawn and dusk. Løkkeborg and Fernö (1999) documented a similar activity pattern of cod at the same locality and in the same season as the present study was done. Feeding behaviour should largely mould the activity of cod of the size used in these studies, as they should experience low risk of predation (Palsson, 1994). Cod makes use of both the visual and chemical senses to search for and localise food (Brawn, 1969). A reduced swimming speed of cod at night as compared to daytime could be related to a lower probability of encountering prey without visual cues (Løkkeborg and Fernö, 1999). Introduction of a baited net at night changed the activity rhythm of cod. Highest activity was now observed at night, indicating that cod initiate active search when chemically stimulated by a food source even under non-visual conditions. Løkkeborg and Fernö (1999) observed no difference in the threshold to olfactory stimulation in cod between day and night. Continuous release of feeding attractants from a bait with fixed location could provide accurate cues of its location and the ability of cod to localise a food source after chemical stimulation may be relatively independent of light (Løkkeborg and Fernö, 1999). Reactions from long distances at night observed in the present study support that cod are able to forage and locate prey under non-visual conditions.

Cod were repeatedly observed to return to a baited net, increasing the encounter rate with the nets. The swimming pattern often formed the course of a loop that differed from the “random” loops when no bait was present. The fish first located the bait and stayed there for some time. It then left the location of the bait, swam away for some distance and then returned to the very location of the bait. Although the current system in the fjord is complex, the approaches did not seem to depend on the odour plume from the baits, as the fish did not always swim upstream. The fish might have learned the location of the food source. Spatial maps based on underwater landmark memory have been suggested to permit orientation of aquatic animals (Braithwaite et al., 1996; Cannici et al., 1999) and ling has been observed to repeatedly return to a small core area within its home range (Løkkeborg et al., 2000).

The variable catch rate on baited gill nets in different fishing experiments emphasises the need for improved understanding of the behaviour of fish in relation to bait bags. Although baits presumably increased the number of encounters with baited nets in all experiments, bags seem to influence the behaviour of fish close to the net. Telemetry studies cannot resolve the near-field interaction between the fish and the bait bags and behavioural studies using UTV-cameras in addition to further fishing experiments with different types and positions of bait bags are warranted.

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