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Behaviour of large Atlantic cod at ship wrecks and similar rough bottom structures in the north-eastern part of the central North Sea

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Abstract
There is a substantial difference of opinion between fishermen and the scientific community about the development during the latest decade of the biomass of large Atlantic cod in the North Sea. Knowledge about the distribution of cod on a small geographical scale is important to interpret catch rates of commercial vessels as well as of scientific surveys. Still, the dynamics of small scale spatial distribution of cod is poorly understood. Together with other related research activities, a study was therefore conducted during the summer of 2008 at 10 selected ship wrecks known to hold large cod (>70 cm). The aims were to examine the time budget of cod at these wrecks by use of acoustic telemetry and to investigate the effects of a variety of variables on the observed absence/presence patterns. As foraging was considered a major incentive to locomotion of cod outside the spawning season, stomach samples were collected from wrecks during the study period. A total of 121 cod were tagged with acoustic tags during three different tagging sessions. Two listening buoys were deployed at each wreck. After a field period of more than four months (May-September), 63 cod tagged at 9 wrecks were included in the analyses. Several hundred stomach samples were collected. Preliminary results indicate that the diet of large cod at wreck sites is dominated by prey types from smooth bottom and that absence/presence patterns differ among wrecks. The influences of physical variables will be presented as well.

Keywords: acoustic telemetry; rough bottom structures; behaviour of Atlantic cod; foraging; physical variables

Introduction
It is well known among fishermen that large cod aggregate at rough bottom substrates and especially at underwater structures. Large females are especially important for the spawning stock as they spawn for a longer period of time and provide a higher amount of eggs of better quality compared to younger spawners. Nowadays, where the North Sea cod stock is at a critical low level, they are even more important. Still, these individuals are not included in the stock estimates. One of the reasons is that survey vessels are not able to sample at rough bottom substrates another reason is the poor knowledge of the whereabouts of cod despite decades of research aiming to improve our understanding of this species. Without an understanding of where large cod is located it is

impossible to assess the stock size of large cod and to emply a proper management strategy for this segment of the cod stock.

The marine environment makes it difficult to study cod behaviour directly. The increased availability of electronic equipment makes it possible to collect large amount of continuous data on individual fish over long periods of time. But due to the shortcomings in locating animals that do not surface, an increasing number of studies couple depth and temperature data obtained from data-storage tags (DST) to estimate locations and most probable tracks with different geolocalisation techniques (Gröger et al. 2007, Righton and Mills 2007, Svedäng et al. 2007). At present, these data is used at a large geographical scales due to the low precision of the positioning unless the method is used in an area of very heterogen environment, i.e. large differences in the tidal cycle, salinity regime or temperature. Geolocalisation has been used to study residency and migrations of cod (Neat et al. 2006, Svedäng et al. 2007). Most studies on cod behaviour have been focused on the vertical movements of cod using depth data from DSTs. The resulting depth profiles have been used to compare behaviour in different populations (Righton et al. 2001, Righton and Metcalfe 2002), or to identify distinctive behavioural categories and investigate for daily or seasonal changes. In contrast to DSTs, acoustic tags have been used to study horizontal activity and to determine cod residency in restricted areas (Green and Wroblewski 2000, Righton et al. 2001). Acoustic tags give absent/present data unless the tagged animals are manually tracked. Although it is not possible to directly observe the locomotion tracks of tagged cod using listening buoys, it is a cost efficient way of monitoring several locations or small scale areas for longer time periods. The resulting absence/presence pattern can then be investigated for the effects of different environmental variables..

The main objective of this study was to study cod behaviour on a small geographical scale (hundreds of metres) at ship wrecks during the foraging season with the use of acoustic tags and listening buoys. Further, time budgets of cod at the wrecks as well as their activity patterns related to physical factors and diet composition were investigated over the season and compared across individuals and wrecks.

Materials and Methods

Ship wrecks on Monkey Bank suitable for study locations were selected in collaboration with local gill net fishermen (Fig. 1). Important criteria for the wreck selection were presence of cod in sufficient numbers for tagging throughout the foraging season, no or little fishing activity in the area, wrecks located at different sea bottom types and in different distances from each other so that some wrecks were isolated and others in clusters. The distance between neighbouring ship wrecks ranged from 1- 20 km, and the water depth ranged from 35-55 m. According to the fishermen, wreck 6, 7 and 9 were located on a fine sandy bottom, while wreck 3, 8 and 11 were located on a coarser bottom type. The bottom types for wreck 4, 5, 14, and 15 were unknown. An area of stony bottom nearby some of the wrecks was included in the study area to see whether cod tagged here would also spend time at the ship wrecks. Acoustic receivers were placed 10 m above the sea bottom on the eastern and western side of each ship wreck to record the absence/presence of tagged cod. There were not placed any receivers at the stony bottom. A pilot study from 2007 indicated that the majority of a group of tagged cod may leave a wreck after a few weeks. Cod were therefore tagged with acoustic tags on three separate occasions to ensure that there were tagged individuals at the wrecks throughout the foraging season. **Tagging session 1** lasted from study start and until mid-June and included wrecks 3, 4, 5, and 9. **Tagging session 2** lasted from the start of July and until the end of August and included wrecks 6 and 8. **Tagging session 3** lasted from the end of August and until the study ended in the end of September and included wrecks 3, 7, 9, 11, 14, and 15. During the observation period, some of the buoys were either lost or moved by fishermen. In the latter case, buoys often got stuck into the ship wreck and got lost upon retrieval. These buoys were replaced by new ones during the study.

Cod were caught at the wrecks by jigging with hooks from a chartered angler boat. They were anesthetized using the drug MS222 in the concentration 1:15,000 (appropriate for large cod at temperatures of 7-15°C). A small incision was made along the linea alba between the tips of the pelvic fins. The acoustic tag was inserted into the abdominal cavity, and the incision was closed with two stitches using an absorbable suture (Johnson & Johnson Ethicon Vicryl, 3-0, FS-2). After the operation, the cod was placed in a recovery tank with fresh sea water. The cod was held upside-down in its lower jaw and was pulled around in the tank to let water flow across the gills. When it started ventilating, it was released into the tank where it stayed until release less than half an hour after surgery. A special cage was used to release the cod at the sea bottom. This was done to prevent cod from staying at the surface due to excess air in the swim bladder. The cage opened itself when it touched the sea bottom.

Data from the acoustic receivers were downloaded every month during the study and after retrieval at the end of the study. The percentage of days present at the wreck out of the total observation days were used as measures for residency during the foraging period. Absence/presence patterns were analysed based on scatterplots of detections. Only the periods between first and last detection were included. Several behavioural categories could be defined: **total absence** periods in which the individual where not detected for more than 24 hrs; **presence** periods where the individual were continuously detected and had only few short absence periods; **day absence** with distinct periods where the individual was not detected, or was only detected a few times, during the day in consecutive days, the start and end of the absence period were similar on different days; **night absence** with distinct periods where the individual was not detected, or was only detected a few times, during the day in consecutive nights, the start and end of the absence period were similar on different days; **erratic absesnce** where there is no apparent pattern in the distribution of absence-periods. There may be mostly periods with absence or mostly periods with presence. The behaviour of the individual cod was assigned to the defined categories and individuals tagged at different ship wrecks were compared. Model data for water current and sea level was obtained from the Danish Meteorological Institute. Histograms of detection count data were used to explore the effect of 24 hr cycle and the tidal cycle on the presence of tagged individuals at each wreck, and data from the different wrecks were compared.

Stomach samples were collected from cod caught at ship wrecks during May, June, July-August and September, i.e. at the study start and at the end of each tagging session. Stomach samples were collected using commercial gill netters with experience in ship wreck fishery. At the wreck, gill nets of 85 mm half mesh size were set in three lines, each with 2-3 nets. All the lines were set parallel to the water current. One line was set over the wreck, the two others on each side of it. The fish were chased into the gill nets by knocking at the wreck with a heavy chain. In this way the standing time of the gill nets were reduced and the quality of the samples increased. The total length of each cod in the catch was measured and its stomach sampled and frozen onboard the vessel. The stomach samples were kept frozen until analysis in the laboratory.

In the laboratory, the samples were thawed in cold water. The individual stomach was then opened and its contents put into a sieve (200 μm mesh size). The partly digested prey were carefully separated using water. The prey were identified to the lowest possible taxa and weighed and length measured individually. Based on information about prey habitat found in the literature, the bottom type at which cod have been feeding was determined.

Results

The observation period started 12 May and terminated 24 September 2008. A total of 121 cod were tagged at 10 different ship wrecks and a stony bottom area (Table 1). There was not caught any fish suitable for tagging at ship wrecks 1 and 2. The downloaded data contained detections from 2723 fih-days. None of the receivers placed at wreck 3 were retrieved. Thus, data could not be obtained from this wreck. One receiver that was stuck in wreck 14 was later caught by a fisherman so that data was recorded on this receiver until 20 October.

Approximately half of the tagged individuals (n = 63) representing 9 of the wrecks were used in the analyses (Table 2). Two individuals were detected at one other wreck than their tagging location. None of these individuals were detected at their tagging location. Cod 313 was tagged at wreck 3 and were observed during 4 consecutive days at wreck 9 *ca.* 40 km away. Cod 376 was tagged at wreck 7 and observed in 68 consecutive days at wreck 14. None or a few detections considered to be false were obtained for 46 individuals. All 12 cod tagged at the stony bottom were included in this group in addition to the 17 tagged at wreck 3, and another 17 cod not detected by the nearby VR2-receivers. For the remaining 12 individuals, detections were considered to be valid, but too few (< 60) to be included in the analyses.

Around 76% (n = 48) of the analysed cod spent more than half their time at the same ship wreck as they were tagged (Fig. 2, Table 2). Of these, 73% (n= 35) spent 95 % or more of their time at the wreck. Three individuals spent more than 100 days at the wreck. On the other hand, 24 % (n = 15) of the cod spent less than half their time at the wreck where they were tagged, and 8 individuals spent less than 20 % of their time at the observed wrecks. Examples of the five behavioural categories observed in the different individuals can be seen in Fig. 3. Most of the individuals displayed behaviour from several of the categories, and almost all cod displayed the “presence” behaviour (Table 3). Individuals within the same category were tagged at different wrecks. Some individuals shifted category after weeks with the same behaviour (Fig.3).

The increase and decrease in the number of detections with the time of day observed in all the wrecks suggested that the cod behaviour were affected by the 24-hr cycle (Fig.4). However, the peaks and drops occurred at different time at the different wrecks. Most locations had a peak around midnight and then again in the morning or mid-day. The drops were observed in the morning, afternoon, or evening. Wreck 7 was out of phase with the other wrecks except for the increase in detections around midnight. Wreck 9 and 15 had a decrease in detections around midnight and during the day, and increase in the morning and evening. The tidal cycle also affected the number of detections. The detections over the two tidal cycles were added across 12 hrs showing one peak instead of two. All the wrecks had an increase of detections around 6 hrs since last high tide except for wreck 6 in which the phase was opposite (Fig.5).

During four months of the foraging season, 391 stomach samples were collected from the ship wrecks (Table 4). Main prey types were masked crab (*Corystes cassivelaunus*), swimming crab (*Portunus depurator*), dab (*Limanda limanda*), sand eel (*Ammodytes tobianus*) and sea mouse

(*Aphrodite aculeata)*. Except for swimming crab, these are all species characteristic for smooth bottom types meaning that cod do not forage at the wreck substrate, but have to leave it. Although there were large variations between wrecks during the different months, masked crab dominated the diet at most wrecks in June, while in August the cod switched to swimming crab, and in September dab dominated together with swimming crab (Fig. 6).

Stomach samples and acoustic data were collected simultaneously for eight of the wrecks. None of the tagged individuals were caught during stomach sampling so a direct comparison of the two datasets was not possible. However, there were large differences in the prey species taken for different individuals at the same wreck. For example, in august individuals from wreck 6 preferred sea mouse or swimming crab, while in September they ate swimming crab and/or dab while only a few still ate sea mouse (Fig. 7).

Discussion

This study demonstrates that cod believed to belong to a migrating population spend most of their time in very restricted offshore geographical areas (in the scale of hundreds of metres) for long time periods (months) outside the spawning season. Fishermen have for long known that rough bottom structures give higher catches of large cod compared to smooth bottom types. Until now it was not known whether the individuals aggregating here were stationary or whether there was a continuous flow of individuals passing by during their continuous search for food. Resident populations confined to small areas have been documented the year round in a coastal area of the Shetland Islands and just after spawning off the south-western coast of Sweden (Neat et al. 2006, Svedäng et al. 2007). Righton et al. (2001) suggested that cod were resident during the foraging period in the southern North Sea.

Preliminary analyses of the different behavioural categories observed in cod staying at wrecks indicate that **presence** were the dominating type of behaviour, but a quantification of the time spent on each category are yet to be conducted. A predominant inactive behaviour during the summer has previously been found in the southern North Sea with the aid from depth data obtained from data-storage tags and acoustic tagging of a few individuals (Righton et al. 2001, Righton and Metcalfe 2002). Spending most of their time in such a small area implies that their biological requirements must be found within that area or in an area close by as the individuals return to the same wreck after being absent. Food consumption and energy saving are two means of contributing to the energy budget, and thus survival, of an individual. They result in opposite modes of behaviour: locomotion and inactivity, respectively. The results from the stomach samples show that even though cod were caught on rough substrate habitats, they were only eating prey items from smooth bottom. The detection radius of the receivers may be one kilometre during good weather conditions. It is therefore unknown if some of the resident cod forage on the sea bottom outside the wreck area, but still within the detection area. Cod leaving the detection area are likely to be on foraging trips as foraging is considered to be a major incentive of locomotion outside the spawning season. However, a maximum search area will be calculated for each individual from an anticipated swimming speed and the duration of the period absent from the wreck during further analyses.

The absence of detections from cod tagged at the stony bottom type may indicate low exchange rate of individuals between different types of hard bottom substrates. The low exchange rate recorded between wrecks, even at wrecks located within few kilometres of each other, suggests that other factors than just the habitat type were influencing the observed behaviour. In fact, the two individuals with a documented wreck shift were detected at a wreck tens of kilometres away from the tagging site. There was an effect of both time of day and tidal cycle on the detection rates at all the wrecks. The daily patterns in absence patterns can be related to the diurnal activity of the major prey, which may explain the decreased presence of cod in many wrecks during the day and night, respectively. The higher number of detections between high and low tide correspond to cod staying at the wreck during the periods of strongest water current. The wrecks provide shelters from the water current. In this way cod can save energy compared to being exposed to the current at the smooth bottom type. Fish have often been observed in higher densities on one side of an underwater structure compared to another (Stanley and Wilson 1997 and references herein). This is thought to be an effect of water current.

The main prey species obtained in this study are common prey items of large cod in the area (Hislop, 1997). Even though prey types varied across individuals and months, cod could be grouped into feeding time categories that match the categories found in the acoustic data. Some individuals had a preference for one prey species, while others exhibited a more compound diet consisting of several prey species. In the acoustic data some individuals showed a preference for one type of behaviour while others shifted often. Also, the switch in main prey species over the season was comparable to the switch in behaviour types that occurred after many weeks with the same behaviour. As predator strategy changes when the prey preference shifts, foraging behaviour is expected to have large influence on locomotion behaviour. However, a simultaneous recording of food intake and locomotion is necessary to provide direct evidence for the link between behavioural pattern and prey preference and for the effect of foraging on presence of cod at wrecks as compared to the influence physical parameters.

Acknowledgements

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Figures

Fig. 1. Map of the study area. Individual wrecks are depicted with numbers. ICES square numbers are shown in red. The coloured areas indicate different bottom types.

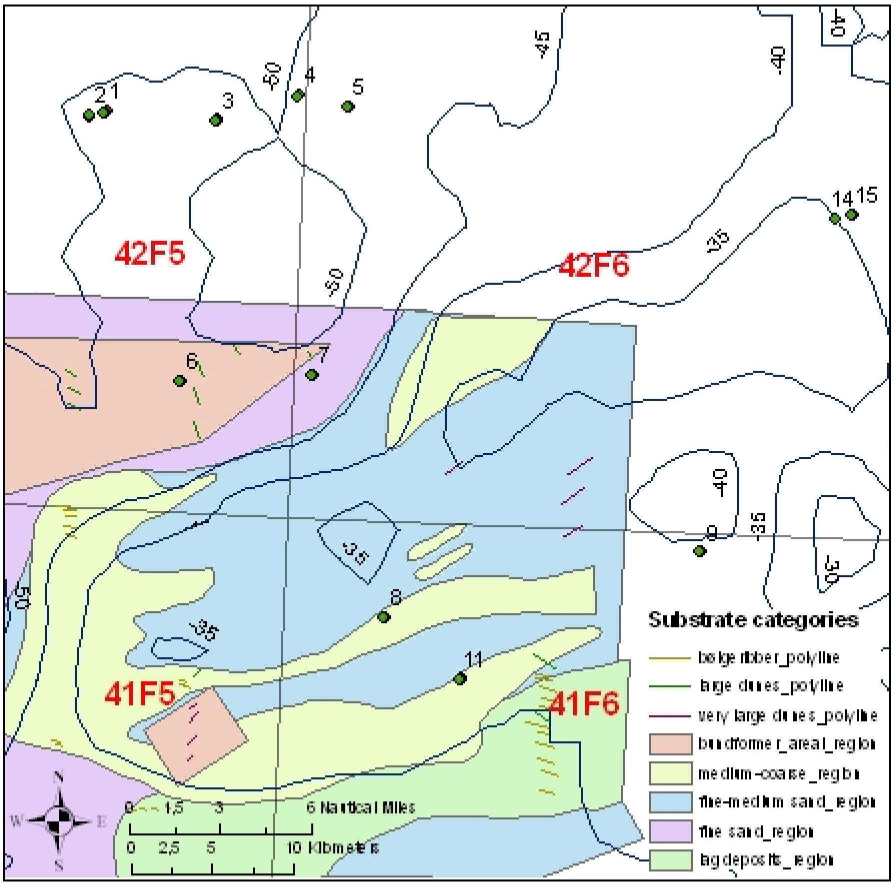
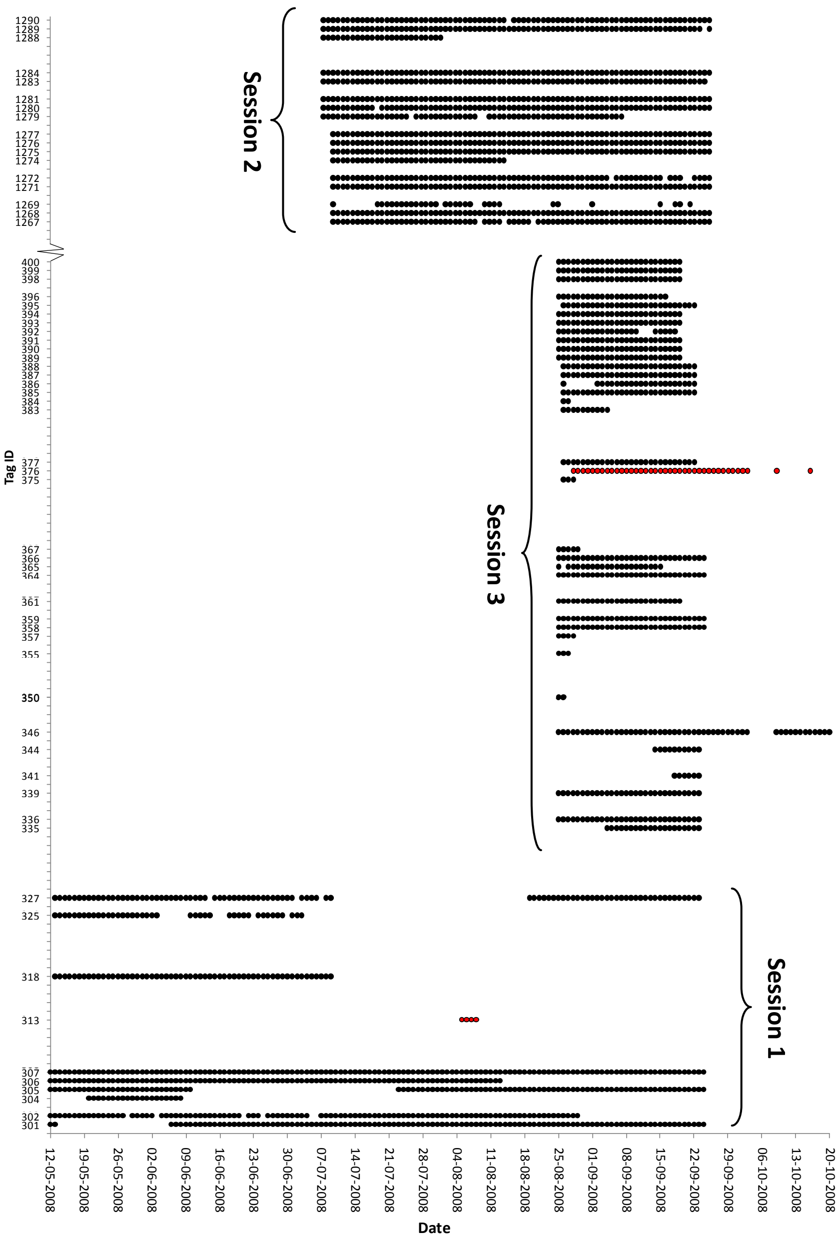


Fig. 2 The distribution of detections during the three tagging session for all tagged cod included in the analyses.



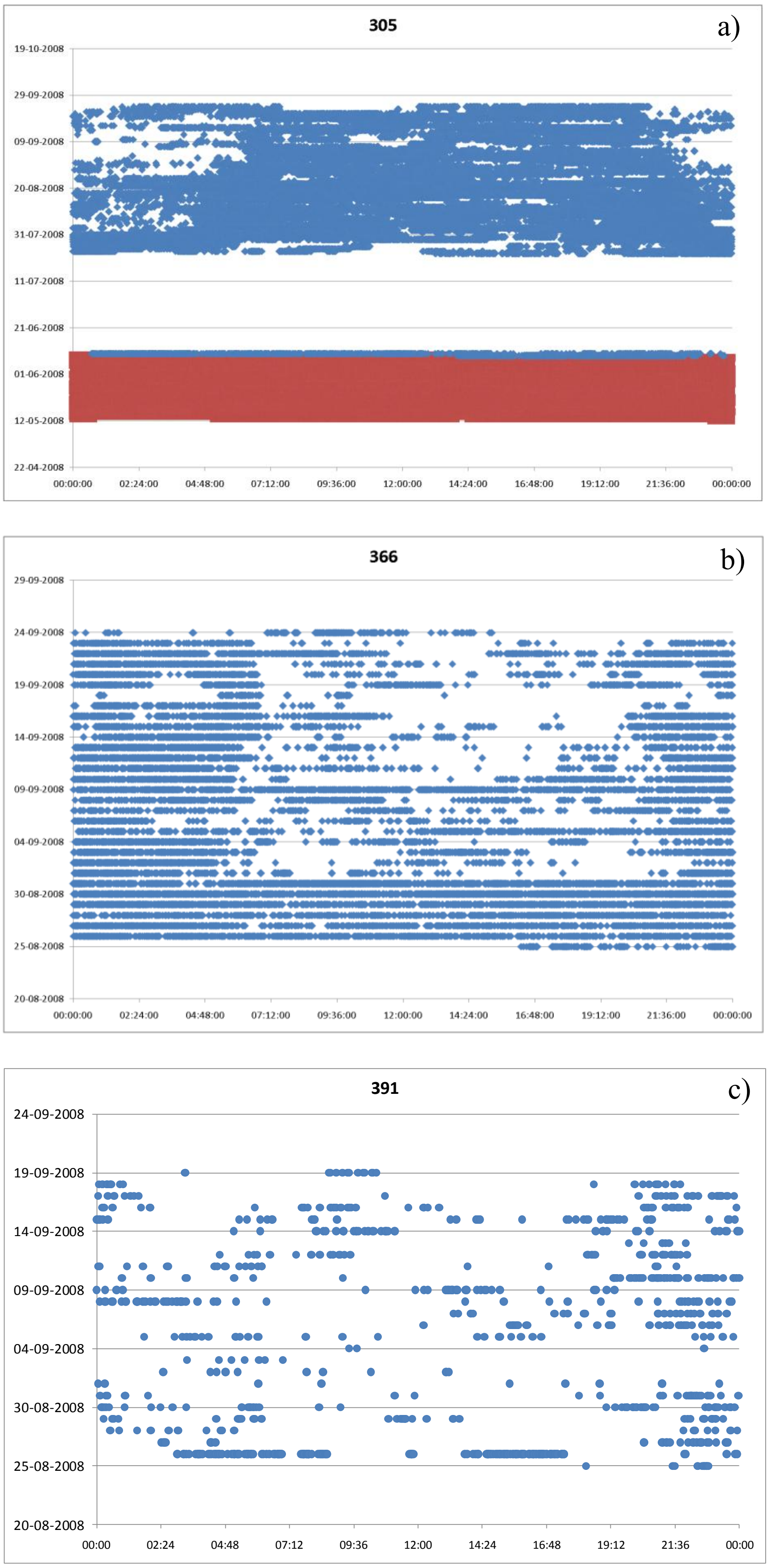


Fig. 3. Examples of the different behavioural categories: a) Presence (red), total absence (white) and night absence (blue); b) Day absence; c) Erratic absence.

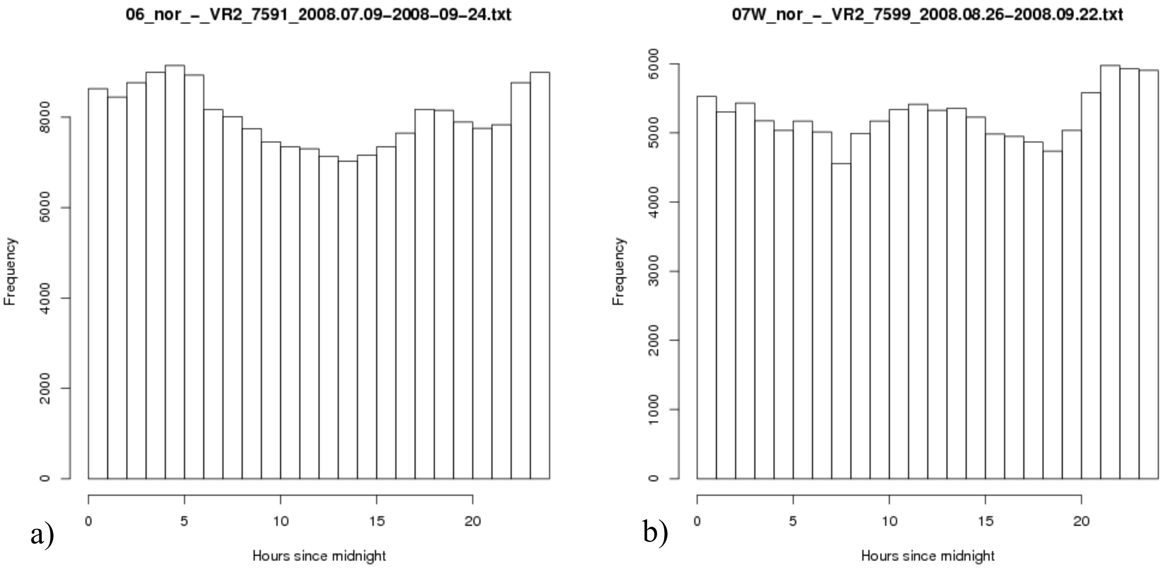


Fig. 4. Examples of the effect of time of day on detection level for a) wreck 6 and b) wreck 7.

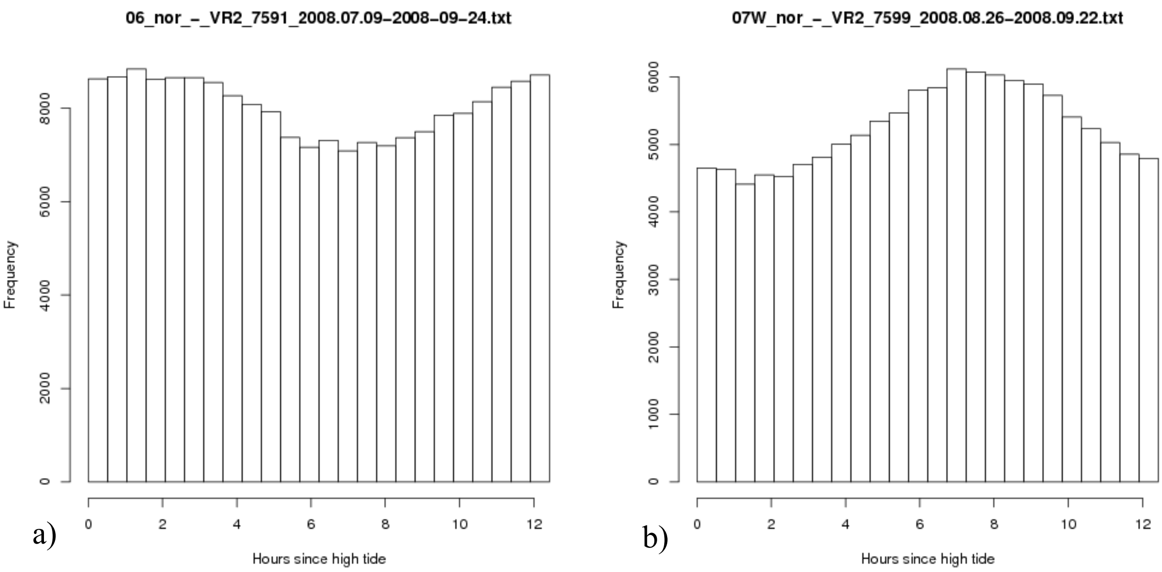


Fig. 5 Examples of the effect of tidal cycle on detection level for a) wreck 6 and b) wreck 7.

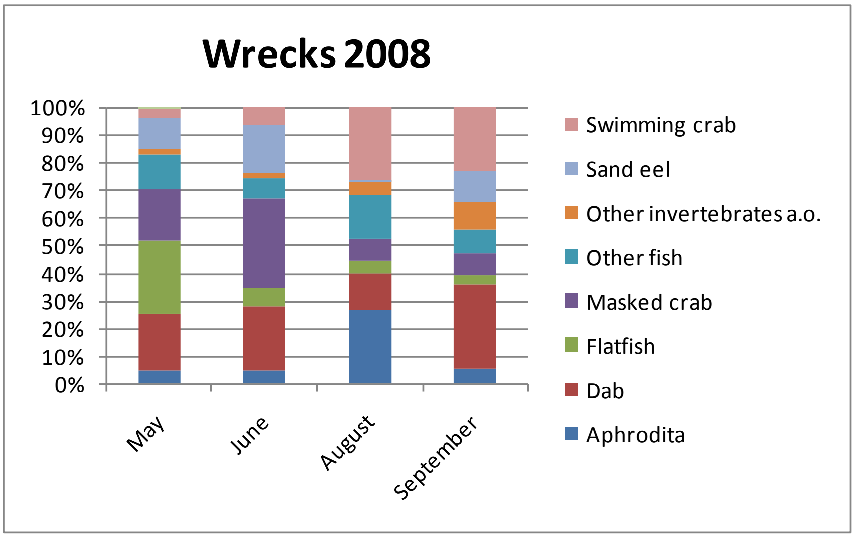


Fig. 6. The diet of cod in four months during the foraging season.

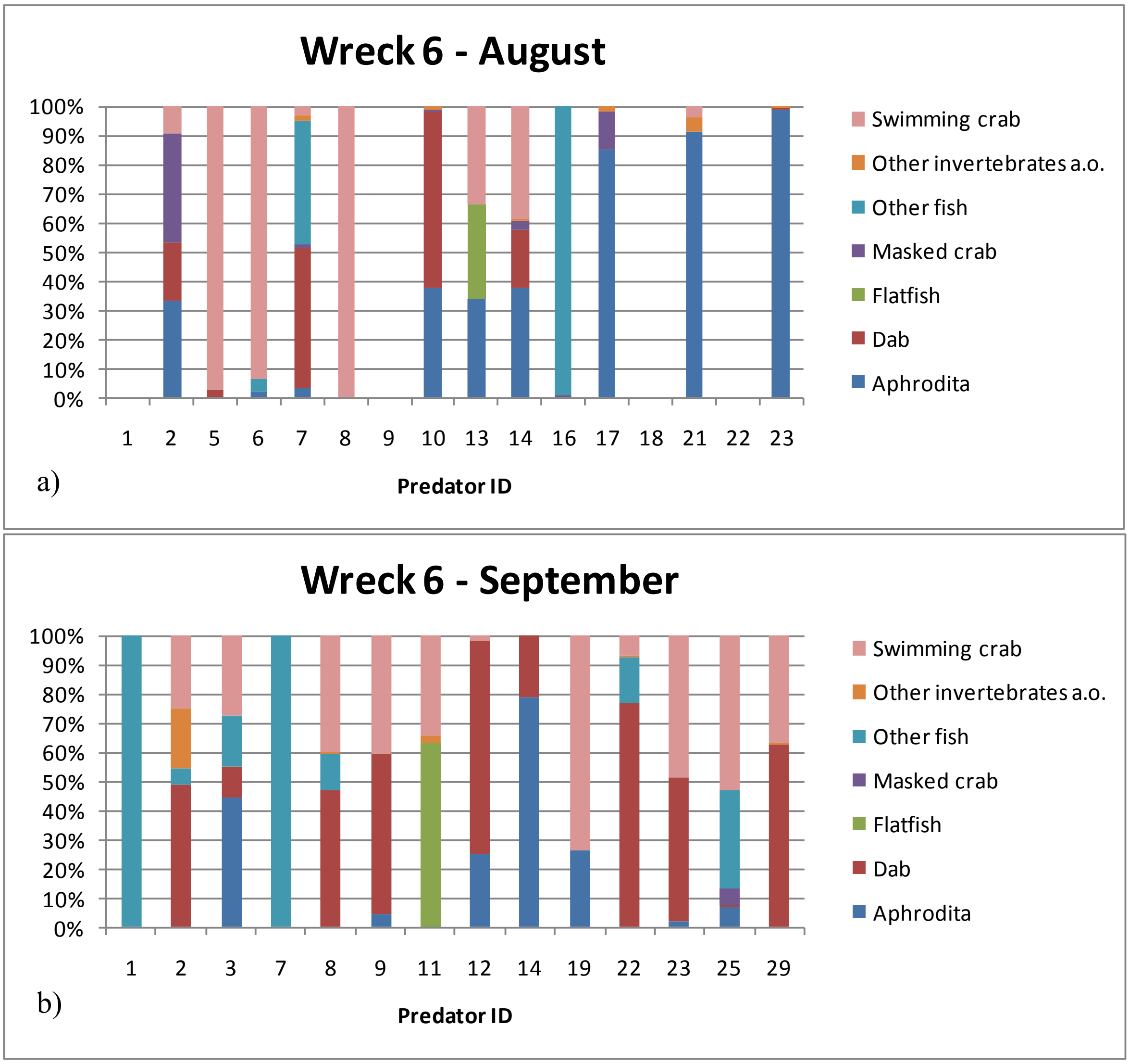


Fig. 7. Example of variation in diet among individuals at the same wreck and a shift in diet in a) august and b) september.

Tables

Table 1. All the cod tagged during the three tagging sessions.

Tagging session	Wreck ID	Tagging date	n	Body length (cm)		
				Min	Max	Mean ± SD
	1	-	0	NA	NA	NA
	2	-	0	NA	NA	NA
1	3	12-05-2008	7	50	96	72 ± 15
	4	13-05-2008	3	64	85	76 ± 11
	5	13-05-2008	2	87	88	88 ± 1
	9	12-05-2008	7	51	101	75 ± 17
	Stones	13-05-2008	12	52	71	60 ± 8
2	6	08-07-2008	11	62	87	74 ± 7
	8	07-07-2008	11	50	88	69 ± 11
3	3	26-08-2008	11	63	88	76 ± 8
	7	26-08-2008	11	61	79	70 ± 5
	9	25-08-2008	11	60	83	68 ± 7
	11	25-08-2008	12	60	98	68 ± 10
	14	25-08-2008	11	61	88	72 ± 11
	15	25-08-2008	12	62	93	72 ± 10

Table 2. An overview of the individuals which were included in the analyses at each tagging session and ship wreck.

Tagging session	Wreck ID	n	Mean length (cm) ± SD	Mean presence (days) ± SD	Mean % of tot. days ± SD
1	4	1	64	91	97
	5	2	88 ± 1	50 ± 12	53 ± 13
	9	7	76 ± 17	81 ± 49	59 ± 36
2	6	9	74 ± 6	67 ± 19	86 ± 25
	8	8	70 ± 20	88 ± 25	88 ± 25
3	7	9	70 ± 6	20 ± 11	70 ± 41
	9	7	69 ± 5	22 ± 13	71 ± 40
	11	11	68 ± 11	25 ± 1	98 ± 6
	14	4	71 ± 12	24 ± 25	42 ± 44
	15	5	68 ± 6	19 ± 11	64 ± 37

Table 3. The number of tagged cod displaying the different behavioural categories. The same individual can display behaviour from several categories. The Wreck ID is the wreck the behavoiur was observed.

Total absence	Presence	Day absence	Night absence	Scattered	Wreck ID
	15				7, 7, 7, 9, 9, 9, 9, 11, 11, 11, 11, 14, 14, 15, 15
				3	6, 11, 11
	8	8			6, 7, 7, 8, 9, 9, 9, 14
	4			4	6, 8, 11, 11
	3		3		9, 15, 15
1		1			8
	1		1		6
		1		1	6
	7	7	7		6, 6, 7, 7, 7, 8, 11
	4		4	4	9, 9, 9, 11
3	3	3			8, 8, 14
3	3		3		9, 9, 9
	3	3		3	6, 6, 15
2	2	2	2		8, 8
	1	1	1	1	11
9	54	26	21	16	

Table 4. An overview of the collected stomach samples.

Wreck ID	May	June	August	September	Sum
1	0	8	0	9	17
2	0	3	0	0	3
3	0	13	16	1	30
4	0	5	2	0	7
5	0	4	3	5	12
6	0	0	16	14	30
7	0	0	0	3	3
8	0	0	20	6	26
9	0	18	0	22	40
10	0	10	0	0	10
11	0	15	0	19	34
12	0	13	0	16	29
13	0	0	0	0	0
14	0	0	0	22	22
15	0	0	0	0	0
Other	58	11	2	57	128
Sum	58	100	59	174	391