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Water Column Monitoring Research and development programme:

Determining the residency of wild fish around offshore installations

Photo: Steven Brooks, NIVA

Norwegian Institute for Water Research

REPORT

Main Office
Økernveien 94
NO-0579 Oslo, Norway
Phone (47) 22 18 51 00

NIVA Region South
Jon Lilletuns vei 3
NO-4879 Grimstad, Norway
Phone (47) 22 18 51 00

NIVA Region East
Sandvikaveien 59
NO-2312 Ottestad, Norway
Phone (47) 22 18 51 00

NIVA Region West
Thormøhlensgate 53 D
NO-5006 Bergen Norway
Phone (47) 22 18 51 00

NIVA Denmark
Njalsgade 76, 4th floor
DK 2300 Copenhagen S, Denmark
Phone (45) 39 17 97 33

Internet: www.niva.no

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Summary

In order to link effects with exposure, recent WCM programmes have discovered the need to determine the residency of fish, caught from within the safety zone of offshore installations. The method of using baited tags to encourage the voluntary ingestion of acoustic tags was thought promising and work was commissioned to develop the baited tag concept for field application. Acoustic telemetry products such as receivers and tag transmitters were obtained from the Norwegian electronics manufacturer Thelma Biotel AS. Developmental work, consisting of a series of cod feeding experiments in large aquaria at the NIVA marine research station in Solbergstrand, discovered some important findings including food preferences, residency time of the tag in the stomach of the fish and excretion pathways. A field trial was conducted in the Trondheimsfjord and although only one tag was eaten the quality of the data was promising for offshore application. The good quality images from the underwater camera with light fixed to the fishing line was also considered suitable for species determination and able to visually document the interactions of the baited tags with the fish. The offshore trial of the baited tag system at Ekofisk proved to be unsuccessful due to the unsuitability of the two fish species present at Ekofisk. It was thought the baited tag system would be more suitable in deeper waters with more voracious fish such as ling, tusk and larger haddock or cod. The baited tag system will be carefully considered for future water column monitoring campaigns.

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Steven Brooks — Project Manager

Adam Lillicrap — Research Manager

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Water Column Monitoring
Research and development programme

Determining the residency of wild fish around offshore installations

Preface

The project was funded by Norwegian Oil and Gas (NOROG) as part of the research and development arm of the Norwegian water column monitoring programme. Initial funding in 2019 was followed by additional support in 2020 that advanced the developmental work into a field application. The development work took place at the NIVA marine research station in Solbergstrand with main support from Joachim Johansen (NIVA) who ensured the testing facilities were fit for purpose, assisted with the experiments and provided suitable care for the test fish.

The design and implementation of the experimental work at Solbergstrand, including the technical aspects of the acoustic transmitters and receivers, data handling and interpretation were performed with the assistance of Bjørnar Beylich (NIVA). Further technical assistance was provided by Erik Høy from Thelma Biotel who manufactured the acoustic transmitters and receivers for the project.

Oslo, September 2021

Steven Brooks

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Summary

Recent water column monitoring programmes have discovered significant biological effects in fish collected around offshore installations on the Norwegian continental shelf (Brooks et al., 2013, Brooks et al., 2014 and Pampanin et al., 2019). Linking the observed biological effects with a chemical source is often challenging, particularly in fish that can migrate large distances, where effects observed in one place may have resulted from exposure from a different location. There is a need therefore to try and determine the residency of fish, caught from within the safety zone of offshore installations, to see if they have permanent residence or are merely passing through. Due to the depth of many offshore installations, over 300 m in Haltenbanken and 150-200 m in the Tampen region, the more traditional method of capture, tag and release was not possible. The method of using baited tags to encourage the voluntary ingestion of acoustic tags was thought promising and work was commissioned to develop the baited tag concept for field application.

Acoustic telemetry products such as receivers and tag transmitters were obtained from the Norwegian electronics manufacturer Thelma Biotel AS. Developmental work, consisting of a series of cod feeding experiments in large (20 000 L) aquaria at the NIVA marine research station in Solbergstrand, discovered some important findings. Squid and King prawns were the preferred food of the cod, with the King prawn being more suitable to encapsulate the acoustic tags. The residency time of the acoustic tags in the stomach of the cod after ingestion ranged from a few hours to 36 days with an average of 16.6 ± 11.6 days when King prawns were used as the bait. Other successful baits included Nephrops and crayfish tails. Acoustic tags, as small as 9 mm in diameter, remained in the gut of the cod after 4 days and did not proceed to the intestine, regurgitation of the tag was considered the only path of excretion.

The field trial in the Trondheimsfjord revealed how difficult it was to find suitably sized fish to take the bait. One acoustic tag was eaten from the sea floor after it had fallen from the fishing line. Data from this tag was obtained from the three receivers placed in the water column. It was possible to determine that the tag remained in the fish for approximately 9 days. Expressing the data as 'minutes since last signal' and the strength of 'signal to noise' it was possible to determine when the tag was out of range of the three receivers, which could be used to determine the approximate position of the tag and fish at a point in time. More precise positioning can be achieved by placing a tag on one of the receivers so that their internal clocks can be kept synchronised, allowing triangulation of the signal. Although only one tag was eaten the quality of the data was promising for offshore application. The good quality images from the underwater camera with light fixed to the fishing line was also considered suitable for species determination and to be able to visually document the interactions of the baited tags with the fish.

The offshore trial of the baited tag system at Ekofisk proved to be unsuccessful due to the unsuitability of the two fish species present at Ekofisk. The dominant fish was dab, which is a flat fish with a small mouth that tends to nibble and bite at food rather than gulp their prey. Juvenile cod were the other fish present and although adult cod may have been ideal, the juvenile fish were not able to gulp the slightly larger baited tags. It was thought the baited tag system would be more suitable in deeper waters with more voracious fish such as ling, tusk and larger haddock or cod. These are typical species of the Tampen and Haltenbanken areas of the Norwegian continental shelf as reported in previous WCM programmes. The baited tag system will be carefully considered for future water column monitoring campaigns.

Sammendrag

Tittel: Vannsøyleovervåkings forsknings og utviklingsprogram: Bestemmelse av villfiskens opphold rundt offshoreanlegg.
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Forfatter(e): Steven Brooks, Bjørnar Beylich
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Nylige overvåkingsprogrammer for vannsøyler har oppdaget betydelige biologiske effekter hos fisk som samles rundt offshoreanlegg på norsk sokkel (Brooks et al., 2013, Brooks et al., 2014 og Pampanin et al., 2019). Å koble de observerte biologiske effektene til en kjemisk kilde er ofte utfordrende, spesielt hos fisk som kan migrere over store avstander, der effekter observert ett sted kan være et resultat av eksponering fra et annet sted. Det er derfor et behov for å prøve å fastslå hvor fisk som er fanget i sikkerhetssonen til offshoreanlegg oppholder seg for å se om de er oppholder seg der permanent eller midlertidig. På grunn av dybden på mange offshoreanlegg; over 300 m i Haltenbanken og 150-200 m i Tampen-regionen, var den mer tradisjonelle metoden for fangst, merking og frigjøring ikke mulig. Metoden med å bruke agn for å oppmuntre til frivillig inntak av akustiske sendere ble ansett som lovende, og det ble satt i gang arbeid med å utvikle konseptet for agnede sendere i felt

Akustiske telemetriprodukter som mottakere og merkesendere ble levert fra den norske elektronikkprodusenten Thelma Biotel AS. Utviklingsarbeid bestående av en serie torskefôringsforsøk i store (20 000 L) akvarier ved NIVAs marine forskningsstasjon på Solbergstrand resulterte i noen viktige funn.Torsken foretrakk agn av blekksprut og kongereke, av de to var kongerekemest egnet til å omslutte de akustiske merkene. Oppholdstiden for de akustiske merkene i magen til torsken etter inntak varierte fra noen få timer til 36 dager med et gjennomsnitt på 16,6 ± 11,6 dager da kongereke ble brukt som agn. Andre vellykkede agn inkluderte haler fra sjøkreps og ferskvannskreps.. En test viste at de akustiske merkene ned til 9 mm i diameter, forble i magesekken i 4 dager, de gikk over i tarmen Å gulpe opp senderen ble ansett som den eneste måten fisken kunne kvittet seg med senderen.

Feltforsøket i Trondheimsfjorden viste hvor vanskelig det var å finne fisk i passende størrelse for å ta agnet. Én akustisk sender ble spist fra havbunnen etter at den hadde løsnet fra fiskesnøret. Data fra denne senderen ble hentet fra de tre mottakerne plassert i vannsøylen. Det var mulig å fastslå at merket ble værende i fisken i omtrent 9 dager. Ved å uttrykke dataene som "minutter siden siste signal" og å se på styrkeforholdet mellom signal og akustisk støyvar det mulig å bestemme når taggen var utenfor eller i utkanten av rekkevidden til de tre mottakerne, som kan brukes til å bestemme den omtrentlige posisjonen til taggen og fisken på et tidspunkt. Mer presis posisjonering av fisken kan oppnås ved å benytte en sender på en av lyttebøyene, da kan man kan holde klokkene synkronisert og dermed kan man triangulere signalets posisjon. Bare en sender ble spist, men kvaliteten på dataene var lovende for bruk av metoden offshore. Bilder av god kvalitet fra undervannskameraet med lys festet til fiskelinjen ble også ansett som egnet for artsbestemmelse og i stand til visuelt å dokumentere interaksjonen mellom agnene med fisken.

Offshoreforsøket med agnede sendere utenfor Ekofisk viste seg å være mislykket ettersom de to fiskeartene som var tilstede på Ekofisk ikke klarte å spise agnet. Området var dominert av sandflyndre, disse har liten munn og de biter og river i agnet fremfor å sluke det i sin helhet. Den andre arten som tilstede var torsk, og selv om voksen torsk kunne ha vært ideell for dette forsøket, så klarte ikke ungfisken å sluke våre agn. Det ble antatt metoden med agnede sendereville være mer egnet i dypere farvann med mer glupsk fisk som lange, brosme eller større hyse og torsk. Tidligere WCM-

undersøkelser har vist at disse artene er vanlige i områdene rundt Tampen og Haltenbanken. Metoden med agnede sender vil bli vurdert for framtidige vannsøyleovervåkingsprogram

1 Introduction

The Norwegian Offshore Water Column Monitoring (WCM) programme is a biological effects monitoring programme that investigates the potential effects of offshore oil and gas activities on marine life. The programme includes a field investigation every three years with research and development work performed in the interim years between the field investigations. This report concerns one of the research and development programmes that was funded in 2019 and was designed to determine if suitable methods can be developed to determine the residency of fish populations around offshore installations.

1.1 Rationale

Within the WCM, significant genotoxic and neurotoxic responses have been measured in wild fish collected around offshore platforms, including Njord A (Brooks et al., 2014) and Statfjord A (Pampanin et al., 2019). The fish species have tended to be demersal fish such as tusk and ling, although effects have also been reported in more pelagic species such as saithe and cod. Linking the cause of the effect in wild fish is difficult since recent history of the individual fish movement is unknown. If the fish caught are merely passing though they are not representative of the area with respect to contaminant exposure.

A tagging system has been designed in order to try and provide more information on the residency of fish populations around offshore platforms. Typically, offshore platforms on the Norwegian continental shelf are in deep waters and the typical method of catch, tag and release is not possible due to the pressures and resulting damage to the fish as they are brought to the surface. Previous studies have attempted to bait acoustic tags in order to encourage their voluntary ingestion (Winger et al. 2002; Winger and Walsh, 2001). Atlantic cod were found to voluntarily ingest acoustic tags baited with mackerel (*Scomber scombrus*), which were subsequently tracked for up to 18 days before the fish went out of range of the receivers (Winger et al. 2002). Such an approach of baiting acoustic tags together with video surveillance, which could provide information on the species and size of the fish taking the bait, has great potential in the offshore deep-water environment.

This project was designed to develop a suitable approach to monitor fish movement and make it suitable for use around offshore installations. The approach involved the voluntary ingestion of baited acoustic tags together with video surveillance. Laboratory studies were first performed in order to optimise the approach. Following the laboratory studies, a field trial in a coastal fjord was performed in order to test the suitability of the approach and trial out two different delivery systems.

1.2 Objective

The main objective was to determine if wild fish that are collected from around offshore oil and gas installation are permanent residents or temporary visitors.

This will be achieved by developing a suitable method to monitor fish movement that can be applied to the offshore scenario.

2 Development work

2.1 Choice of acoustic tags and receivers

Following discussions with several international telemetry companies a local Norwegian group, Thelma Biotel (www.thelmabiotel.com) was selected to provide the acoustic tags and receivers.

Acoustic tags of three different sizes were selected, which were set-up to measure activity and tilt. The details of the tags are provided in Table 1 and visually in Figure 1. Three receivers were also obtained to collect information from the tags.

Table 1. Specifications for the three types of acoustic tags provided by Thelma Biotel including size, the time interval when information is sent to the receivers, the total expected lifetime of the tags, the signal frequency and the type of information that is collected (activity and tilt). Specific details can be found in the appendix.

Label	Ø (mm)	Length (mm)	Weight in air (g)	interval (sec)	Lifetime (months)	Frequency (KHz)	Information
A-MP9L	9	30	6.6	30-90	6-7	67, 69, 71	Activity and tilt
A-MP13	13	32	6.9	30-90	6-7	67, 69, 71	Activity and tilt
A-LP16	16	44	18.4	30-90	6-7	67, 69, 71	Activity and tilt

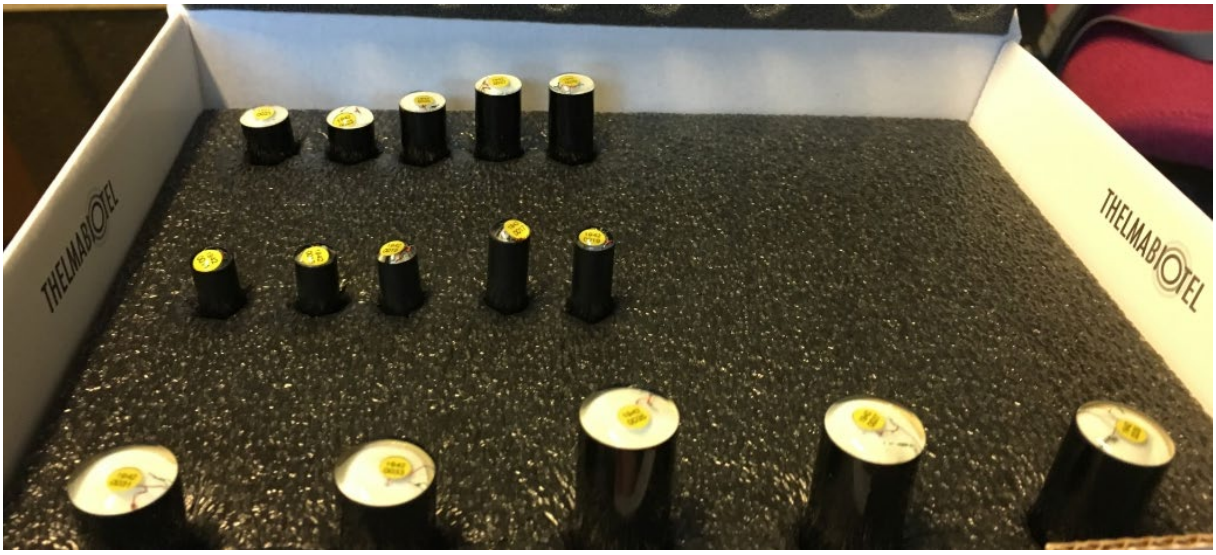


Figure 1. The three sizes of acoustic tags that were provided by Thelma Biotel. 13 mm ø top row, 9 mm ø middle row, 16 mm ø bottom row.

2.2 Controlled aquarium studies: approach

2.2.1 Test species

The Atlantic cod (*Gadus morhua,* 1-4 kg) were selected as the test species due to their availability, familiarity as a test species, commercial importance, and being a relevant fish species for the WCM. Since the laboratory tests that were to be performed involved feeding studies, it was important to obtain wild caught fish for the experiments as opposed to farm fish that were reared on feed pellets.

Wild caught cod were collected by fishing line from the west coast of Norway. The fish were kept in seawater pens by a local fisherman until sufficient numbers were obtained. The fish were delivered to the NIVA marine research station in Solbergstrand, near Oslo, where they were placed in large seawater tanks (approximate 20,000 L, Figure 2) with flow-through seawater at 10-12°C. During the holding period, fish were fed either pieces of fish fillet and/ or prawns daily.

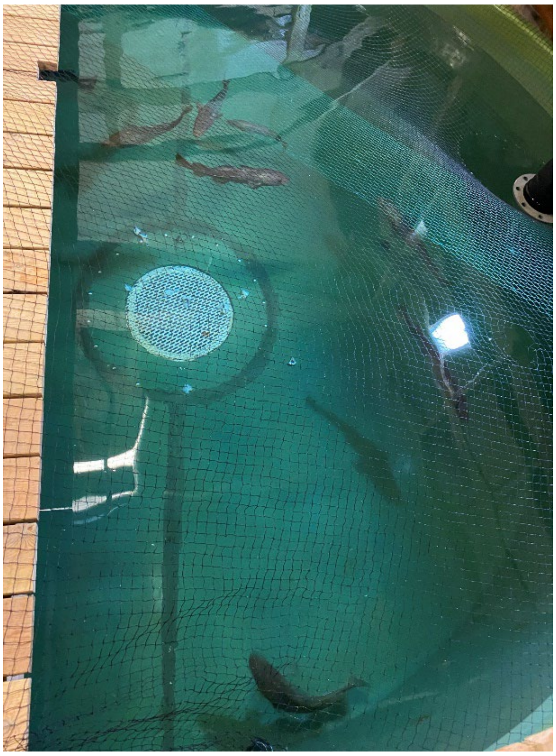


Figure 2. Cod held within one of several 20 000 L round tanks at the NIVA marine research station in Solbergstrand. Flow-through system with an approximate water flow of 50-100 L/ min.

2.2.2 Suitability of bait to cod

Initial experiments were performed to determine the food preference of the wild cod. Pieces of bait including fish fillet of cod and herring (*Clupea harengus*) as well as king prawn (*Penaeus monodon*) tails and squid (*Loligo vulgaris*) were suspended in the water column on a cotton line to determine fish preference to the different baits. Whole prawns were used, whilst the fish and squid were prepared into bite sized pieces approximately the same size as the prawns.

Although no quantitative measure of food preference was made, it was clear from observations that squid pieces were the preferred food group to the cod closely followed by whole prawns, whilst the fish pieces (cod and herring) were often left to the very end but were eventually eaten after the squid and prawns were consumed.

2.2.3 Tag ingestion and residency time in cod

A series of experiments were performed in the large fish tanks at the NIVA marine station, where the acoustic tags were sewn into different bait and fed to the fish using a tripod system that was equipped with an underwater camera (WaterWolf®) to identify the fish taking the bait. One or more receivers were placed in the experimental tanks to collect information from the tags during the tests.

2.2.3.1 Test 1: Squid and herring bait (3 tags and 5 fish)

Acoustic tags were wrapped in squid tissue or herring fillet enclosed in cotton mesh and sewn into place with cotton thread (Figure 3). The baited tags were attached to a tripod with a thin cotton thread and placed into the large seawater tank with five randomly selected cod.

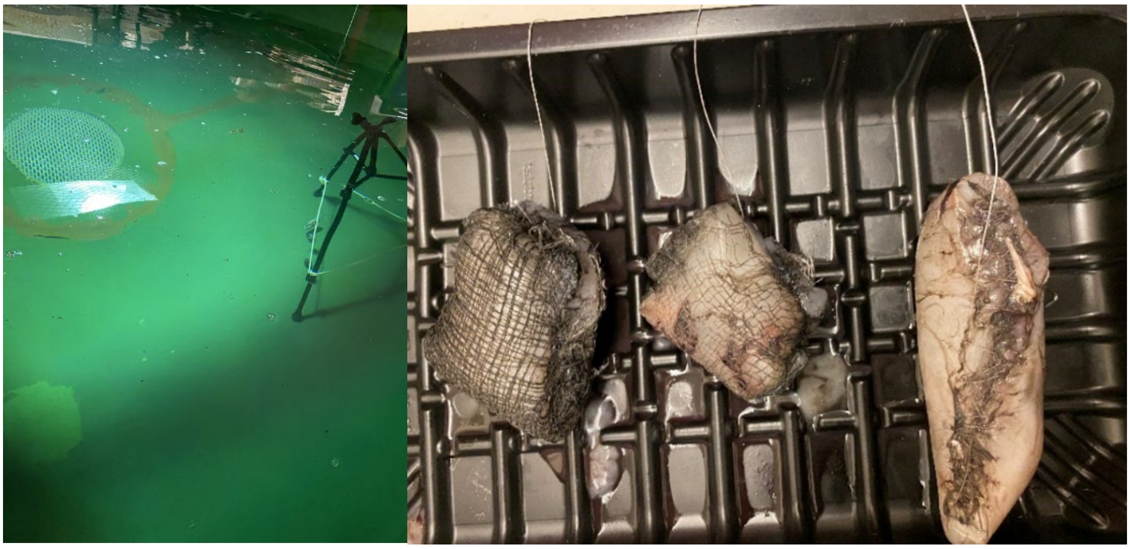


Figure 3. Acoustic tags baited in squid (left and centre) and fish (herring)

2.2.3.2 Test 2: Cod fillets and King prawn bait (3 tags 5 fish)

Acoustic tags were wrapped in cod fillet and sewn together with cotton thread, a small tag was wrapped and sewn into a single king prawn tail (Figure 4). The tags were attached to the tripod and placed in the large seawater tank with five randomly selected new cod. An underwater video camera (WaterWolf®) was installed on the tripod to record activity for up to 4 hours or until the bait was eaten.

Figure 4. Acoustic tags wrapped in fish fillet and king prawn (left) and attached to the tripod for exposure to the cod. Image from the underwater video camera (right) shows the moment when the king prawn was eaten by an approaching cod.

2.2.3.3 Test 3: King prawn bait (5 tags, 10 fish)

Acoustic tags were sewn into one or two king prawns with the smaller tags only needing one prawn, whilst 2 prawns were helpful to fully encapsulate the medium and large tags. As before, the baited tags were attached to the tripod and placed in the large test tank with 10 new randomly selected cod. The video camera mounted to the tripod and an iPhone camera (v11 pro) held above the water were used to record the behaviour of the fish during the test (Figure 5).

Figure 5. Acoustic tags baited with king prawns and sewn together with cotton (top image). Small tags (ø 9mm) were able to fit into one prawn, while 2 prawns were used to better encapsulate the medium and large tags (ø 13 and 16 mm). Baited acoustic tags hanging from the tripod in the large seawater tank, receiver positioned on the wall of the tank.

2.2.3.4 Test 4: Location of the tag inside the cod

It has been assumed that the acoustic tags were excreted from the fish by regurgitation. However, in order to confirm the location of tags inside the fish five acoustic tags (at 69 KHz) were baited with King prawn and exposed to 15 fish in one of the large fish tanks. In addition, a further 5 tags (at 67Khz) were exposed to another 15 fish in a separate tank. After four days the fish were removed from both tanks, dissected and the location of the tags inside the fish recorded.

2.3 Controlled aquarium studies: results

2.3.1 Test 1: Squid and herring bait

Although some interactions were recorded during the 4 hours of observations including the fish approaching the bait, touching the bait with its mouth and even holding the bait for a short time in their mouth, none of the bait were eaten by the cod. This was surprising since squid appeared to be the most popular food choice when fed to the fish. However, in order to ensure that the tags remained inside the squid, the bait were wrapped in a cotton mesh. The presence of the mesh on the outside of the squid may have deterred the fish from eating the squid bait. The cotton mesh was used on the outside of the herring fillet and may have been responsible for the observed result. Video observations were made for 4 hours, however the bait was left overnight and the following day and remained uneaten until retrieved after approximately 48 h.

2.3.2 Test 2: Cod fillet and King Prawn bait

When acoustic tags were baited with 2 cod fillets and 1 king prawn, the cotton mesh was not used but the tags were held in the bait by securing with cotton thread. A few minutes after the tripod containing the baited tags were placed in the seawater tank, the king prawn was consumed by a cod (shown in Figure 4). The tags baited with fish fillet were left in the tank overnight, but were not eaten by the fish.

2.3.3 Test 3: King prawn bait

Due to the success of the king prawn in encouraging the cod to voluntarily ingest the acoustic tags, 5 tags were baited solely with King prawn and exposed to 10 cod. All tags were eaten by the cod within 10 minutes from the time the tripod was placed into the seawater tank.

2.3.3.1 Further tests with King prawn as bait

Since King prawns were clearly the best delivery system of the tags into the cod, further experiments were performed using the King prawn as bait. On all occasions when the King prawn was used the cod had taken the bait within 10 minutes of introduction. In addition to the King prawn, Nephrops tails (*Nephrops norvegicus*) and head (or thoracic region) were also used as bait on eight occasions as well the tail of a freshwater crustacean (*Astacus astacus*). Tails from Nephrops and freshwater crayfish were superior in holding the tag inside the bait and it was assumed they provided better protection from nibbling by smaller fish. These baits were also willingly consumed by the fish. The results of these experiments are shown in the table below including the residency time of the tag inside the fish (Table 2).

The residency of the King prawn in the fish following ingestion varied between the tests. The earlier tests initiated on the 9th and 13th January had residency times for 8 tags between 23 and 36 days, However, those performed later on the 29th January had a residency time for 4 tags between 5 and 20 days, with 2 additional tags only lasting for 4 h and 20 min inside the fish before being excreted. Nephrops were also found to be easily consumed by the cod, residency times in the fish ranged from 4 to 11 days when Nephrops were used as bait.

Table 2. Results of the experiments where the acoustic tags were baited with King prawns (n=20), Nephrops (n=8) and a freshwater crustacean. Data includes tag information and time the tag remained inside the fish (residency time in days (d)), head (h) and tail (t).

Tad ID	Size (ø mm)	Bait	Eaten		Excreted		Residency (d)
			Date	Time	Date	Time	
11	9	King prawn	09.01.20	11:20	09.02.20	21:20	31
17	9	King prawn	09.01.20	14:30	14.02.20	19:30	36
23	13	King prawn	09.01.20	14:50	13.02.20	21:20	35
13	9	King prawn	13.01.20	16:30-40	05.02.20	-	23
19	9	King prawn	13.01.20	16:30-40	10.02.20	03:45	28
25	13	King prawn	13.01.20	16:30-40	05.02.20	-	23
31	16	King prawn	13.01.20	16:30-40	05.02.20	-	23
37	16	King prawn	13.01.20	16:30-40	10.02.20	08:00	28
15	9	King prawn	29.01.20	10:45-11:50	05.02.20	-	7
21	13	King prawn	29.01.20	10:45-11:50	03.02.20	10:00	5
33	16	King prawn	29.01.20	10:45-11:50	29.01.20	-	4 h
39	16	King prawn	29.01.20	10:45-11:50	18.02.20	-	20
35	16	King prawn	29.01.20	10:45-12:05	09.02.20	10:25	11
27	13	King prawn	29.01.20	14:15	29.01.20	-	20 min
21	13	Nephrops (h)	05.02.20	-	09.02.20	01:15	4
33	16	Nephrops (t)	05.02.20	-	09.02.20	01:15	4
13	9	FW crustacea (t)	06.02.20	11:30-12:30	17:02.20	17:20	11
25	13	Nephrops (t)	06.02.20	12:15-12:55	10:02.20	03:00	4
31	16	Nephrops (t)	06.02.20	11:45	17:02.20	17:00	11
11	9	King prawn	28:02.20	13:20	07.03.20	17:50	8
17	9	King prawn	28.02.20	13:40	07.03.20	17:10	8
23	13	King prawn	28.02.20	13:30	09.03.20	02:10	10
29	13	King prawn	28.02.20	13:30	09.03.20	02:10	10
35	16	King prawn	28.02.20	13:15	09.03.20	02:35	10
15	9	Nephrops (t)	28.02.20	10:00-11:00	08.03.20	07:45	9
21	13	Nephrops (t)	28.02.20	11:30	08.03.20	07:40	9
27	13	Nephrops (t)	28.02.20	11:00-12:00	08.03.20	-	9
39	16	Nephrops (t)	28.02.20	10:30-11:00	08.03.20	07:35	9

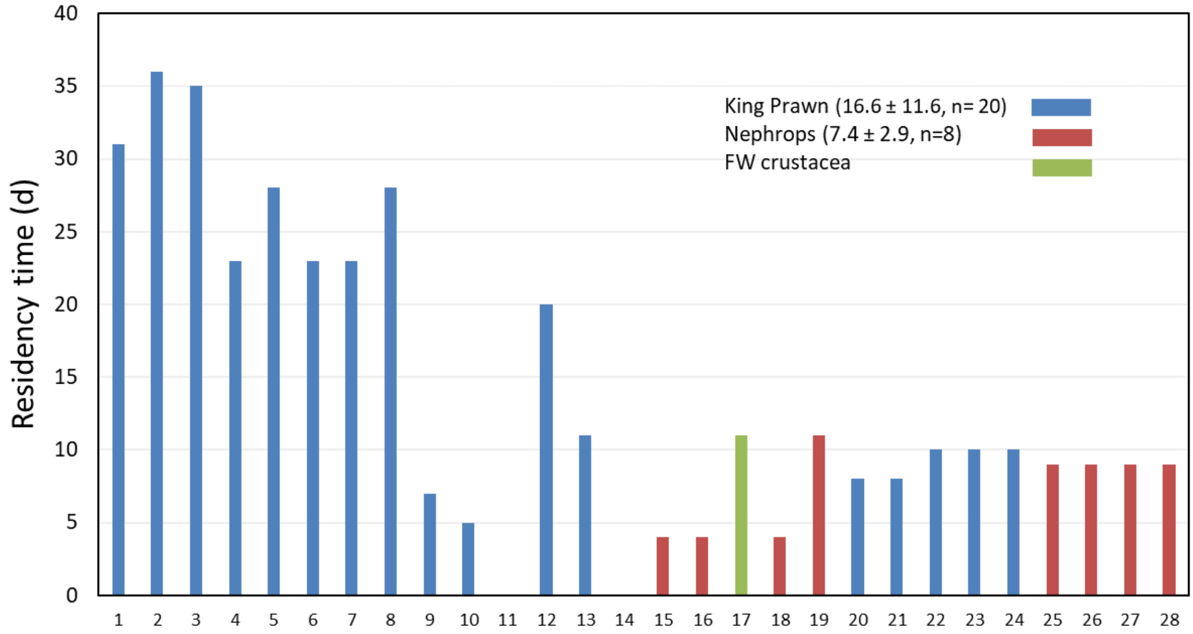


Figure 6. Residency time of the acoustic tags in the fish following ingestion. Tags baited with King prawn (n=20), Nephrops (n=8) and a FW crustacea (n=1).

2.3.4 Output data from the tags

In addition to presence and absence, the data received from the tags can provide useful information on when the tags are eaten and when they are excreted based on their activity (Figure 7). The dotted red line shows the approximate time when the tag was eaten by the fish, after this point activity is present and highly variable.

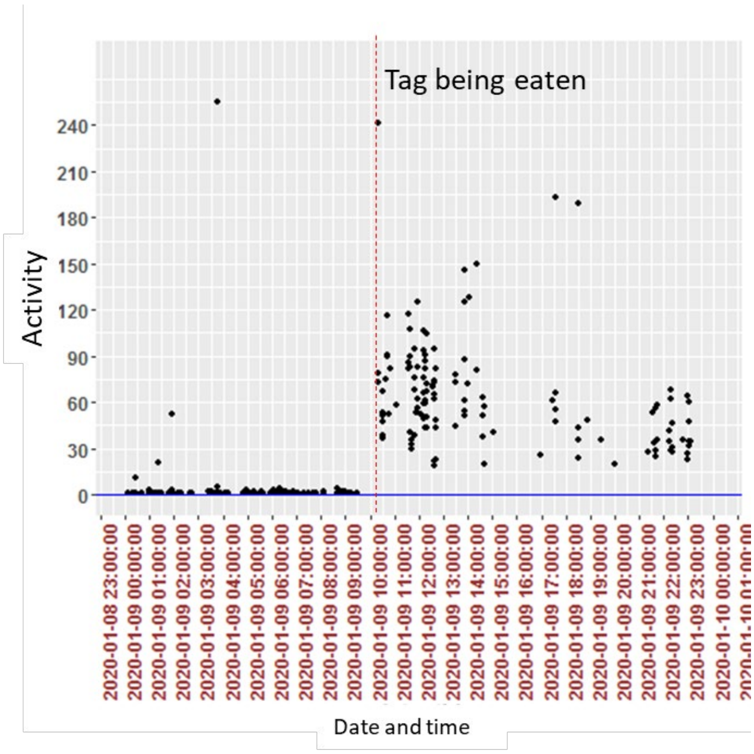


Figure 7. Activity data showing the moment the tag is consumed by the fish.

The data for orientation of the tags (tilt) inside the fish were investigated to see if it could provide any information on the transport of the tag inside the fish, for example, as it passes along the gastro-intestinal tract (Figure 8). The results were somewhat inconclusive and may just represent the general orientation of the tag inside the gut of the fish. The question of whether it is possible for the tag to exit the stomach through the intestine and eventually be excreted through the anus needs to be known, later tests were designed to determine this.

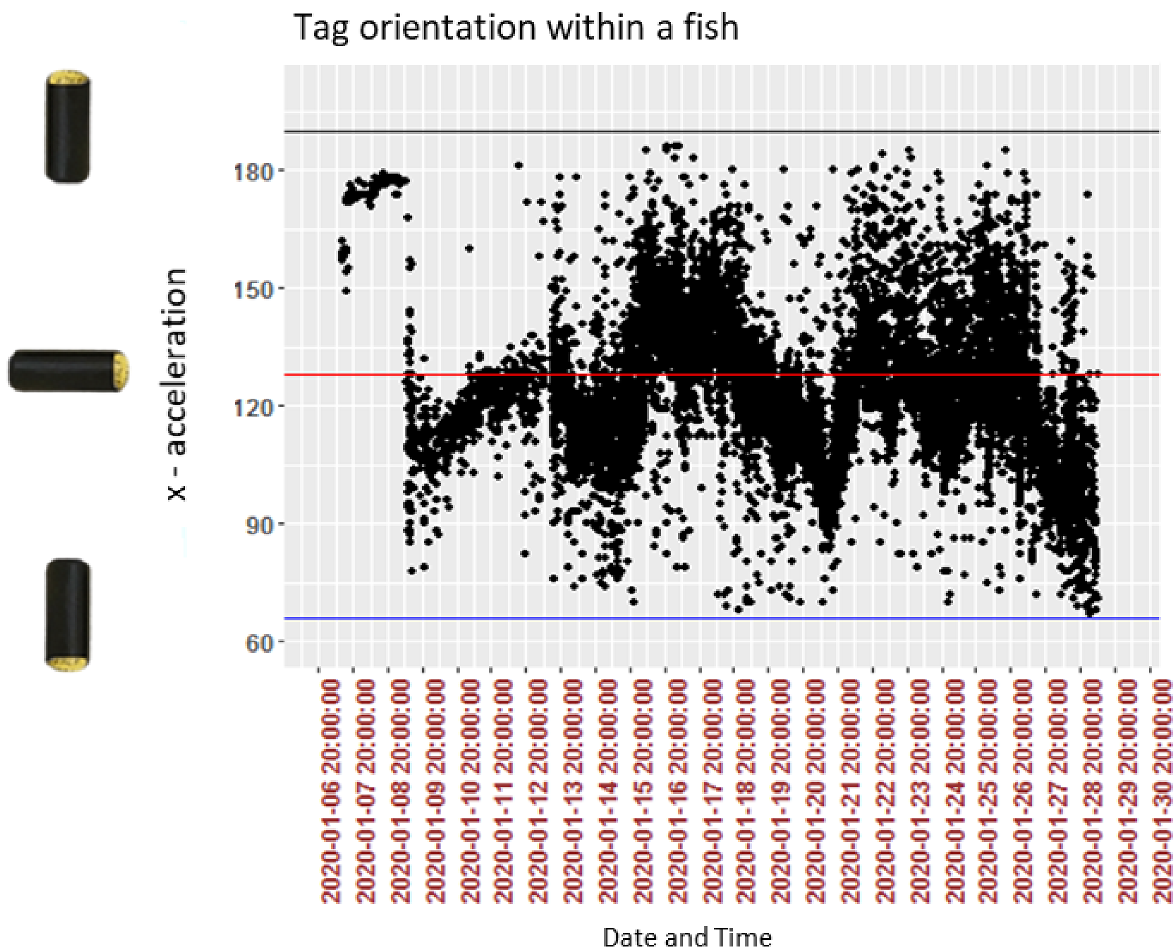


Figure 8. Acceleration of the tag inside the fish over approximately 20 days. An averaged line in the plot represents the tilt of the tag corresponding to the tag images on the left. Deviations from the averaged line represents acceleration (changes in speed or direction) of the fish

2.3.5 Test 4: Location of the tags in the cod.

Of the 10 tags baited with King prawn and exposed to the 30 cod, only one tag was not ingested. It was thought that this tag had fallen out of the King prawn bait when being eaten. As a result, only nine tags were to be retrieved from the fish. The results of the exposure are shown in Table 3.

From tank 1, since all five tags were retrieved in the first 8 fish, the remaining fish were not dissected. In all cases, the tags were retrieved from the hind gut of the cod and had not entered the intestine. Five tags were found in three fish, two tags were found in the largest (by weight) as well as the smallest (by weight) fish sampled. The smallest fish had taken the two smallest tags (9 mm), which were each enclosed in one king prawn. While one tag was found in the stomach of the longest fish.

For tank 2, a different approach was taken, the receiver was used to identify if a fish had eaten a tag removing the need to dissect fish unnecessarily. Only two fish were identified, and three tags were retrieved, with two tags found in the stomach of one fish.

From this simple experiment it appears that the tags were unable to access the intestine of the fish for eventual excretion through the anus. The only way for the tag to be excreted from the stomach was by regurgitation. This finding removes the potential hazard of the tag being lodged with the intestine of the fish, which would likely cause pain and discomfort to the fish and lead to its ultimate death.

Table 3. The retrieval of the tags from the stomach of the fish

Tank	Fish	Weight (g)	Length (cm)	Tag size (ø mm)	Notes
1	1	2334	62	-	
1	2	2395	56	-	
1	3	3782	73	16	Tag still wrapped in prawn, located in the stomach
1	4	2541	58	-	
1	5	4304	71	16, 13	Tags still wrapped in prawn, located in the stomach
1	6	3135	62	-	
1	7	701	41	9, 9	Tags still wrapped in prawn, located in the stomach
1	8	968	40	-	
2	1	3209	70	9, 16	Tags still wrapped in prawn, located in the stomach
2	2	1823	57	16	Tag still wrapped in prawn, located in the stomach

Figure 9. Cod dissection showing the distended stomach containing prawn bait. Cod fish number 5, tank 1 as in Table 3, two tags were present in the hind gut. The cod were fed with additional prawns on the morning of the dissection, which is the reason for the full stomach of the fish.

3 Field trials

3.1 Trondheimsfjord

A field trial of the baited tag system was trialled at a specific location in the Trondheimsfjord on the 10th and 11th November 2020. Local knowledge from a Trondheim fishing club was obtained, which led to the participation of a fisherman (Erik Dahl) for a two-day field trial. A boat (Harry Borthen) and captain were hired for two days for deployment of the moorings containing the acoustic receivers, the fixed feeding frame and fishing with baited tags (Figure 10). The acoustic receivers used to collect the data from the tags were placed in three corners of a triangle approximately 500 m from each other (Figure 11).

Figure 10. Harry Borthen in the Trondheimsford harbour (left), the deployment of the fixed feeding frame containing 3 baited tags, camera and lights (centre left), the design of the baited fishing line with light, video camera (WaterWolf®), bait and lead weight (centre right) and fishing with baited rod and line from the vessel.

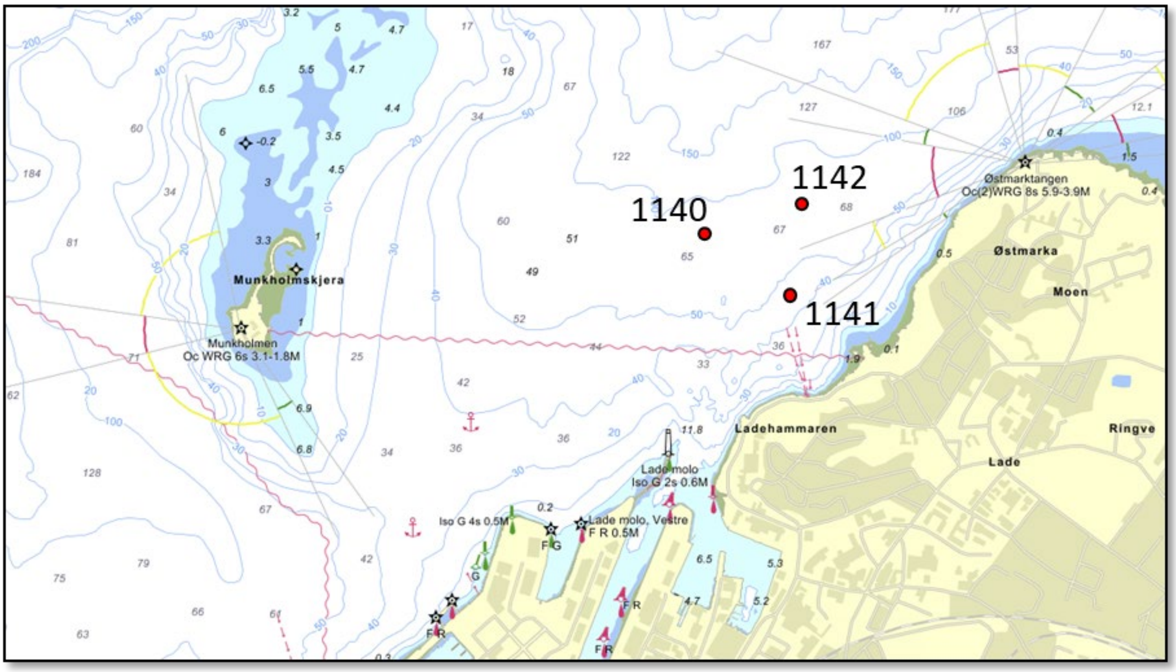


Figure 11. Location of the fishing area in the Trondheimsfjord including the triangulation of the three acoustic receivers (1140, 1141 and 1142) on weighted moorings (red circles).

3.1.1 Results from the field trial

Based on the underwater video footage one tag (tag17) appeared to be eaten by a haddock (*Melanogrammus aeglefinus*). However, the data later revealed that although some initial activity occurred during fishing, after this initial period the tag showed no activity. It appeared therefore that either the tag was immediately regurgitated by the haddock or that the tag had become dislodged from the bait during feeding (Figure 12).

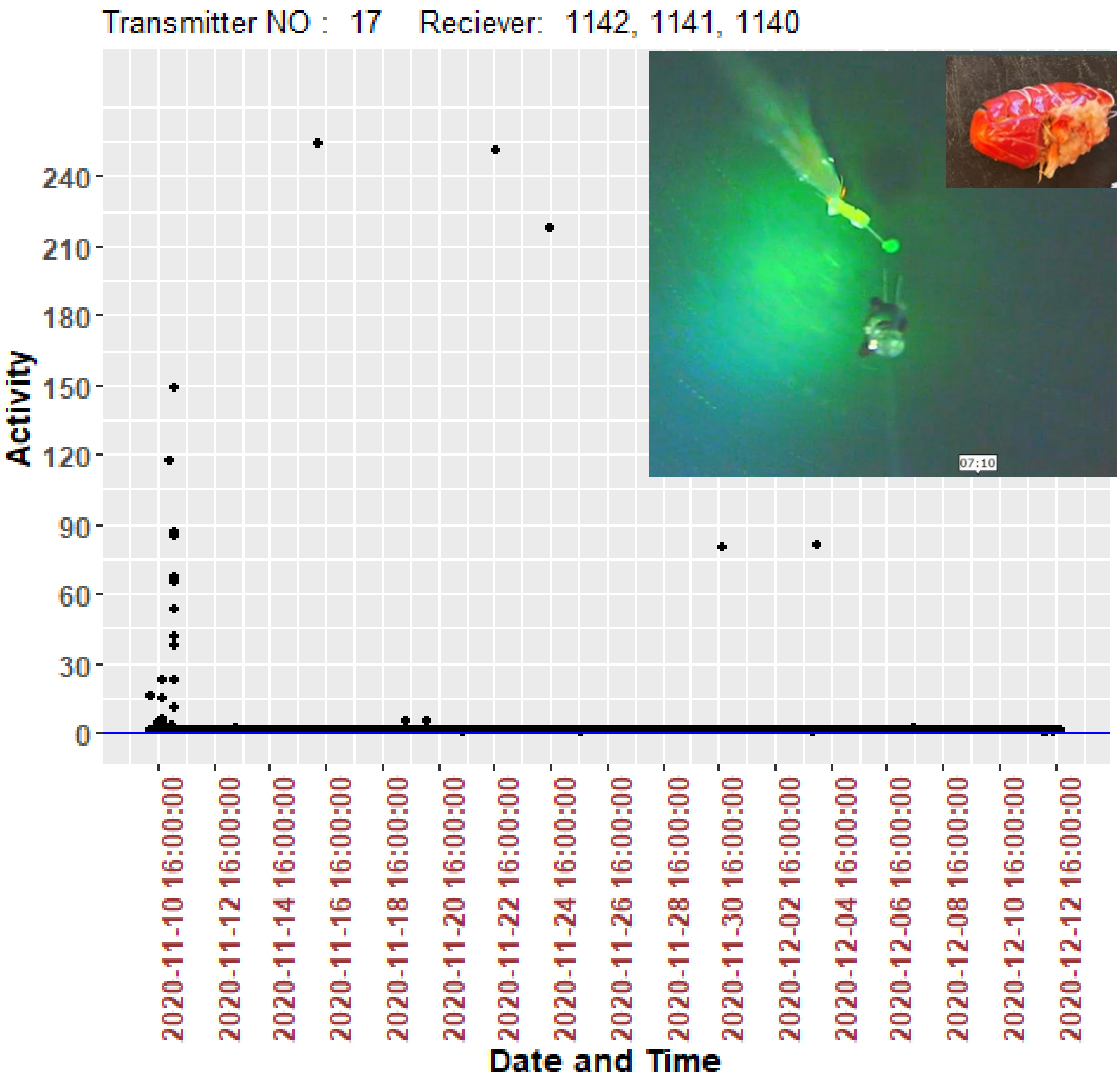


Figure 12. Activity data from tag 17 obtained from the 3 receivers 1142, 1141 and 1140. Inserted photo taken from the video footage at the time the tag was presumably eaten. Tag 17 was baited with the tail of shrimp (inserted photo).

The baited tags were connected to the fishing rig with a single line of cotton making it easier for the fish to remove the bait. However, this weak link in many cases broke causing the bait and tag to be lost to the sea floor. It seemed that most of the line breaks were caused by us reeling in at normal fishing speeds. It is deemed important to reel in slowly in order to avoid this in future.

Starting the trial, the bait was sewn into the fish with cotton thread. Further into the trial we discovered that bait elastic (Norwegian: agnstrikk) was far better for encapsulation of the tag in the bait. The tag was better secured in the bait and we were able to make baits that were long and thin rather than a lump. This is far more appealing to the fish both because the baits diameter and size goes down and the bait is allowed to move. This was also the way the fisherman preferred to have his baits. However, using the bait elastic for attaching the bait to the fishing line seemed to create more wobbling and swirling and it seemed more likely to break when reeling in.

One of these tags (tag 25), which was wrapped in 2 king prawns was eaten by a fish from the seafloor and activity data was recovered. Since video camera footage was not available the fish species that consumed the tag was not known but due to the activity and knowledge of the main fish in the area was likely to be a cod or haddock. The data showed the initial activity during fishing then 2-3 h of inactivity with the baited tag on the seafloor, followed by the tag being eaten and a period of activity. The activity was high for the next 9 days (11^{th} to 20^{th} Nov) before the tag was most likely regurgitated by the fish.

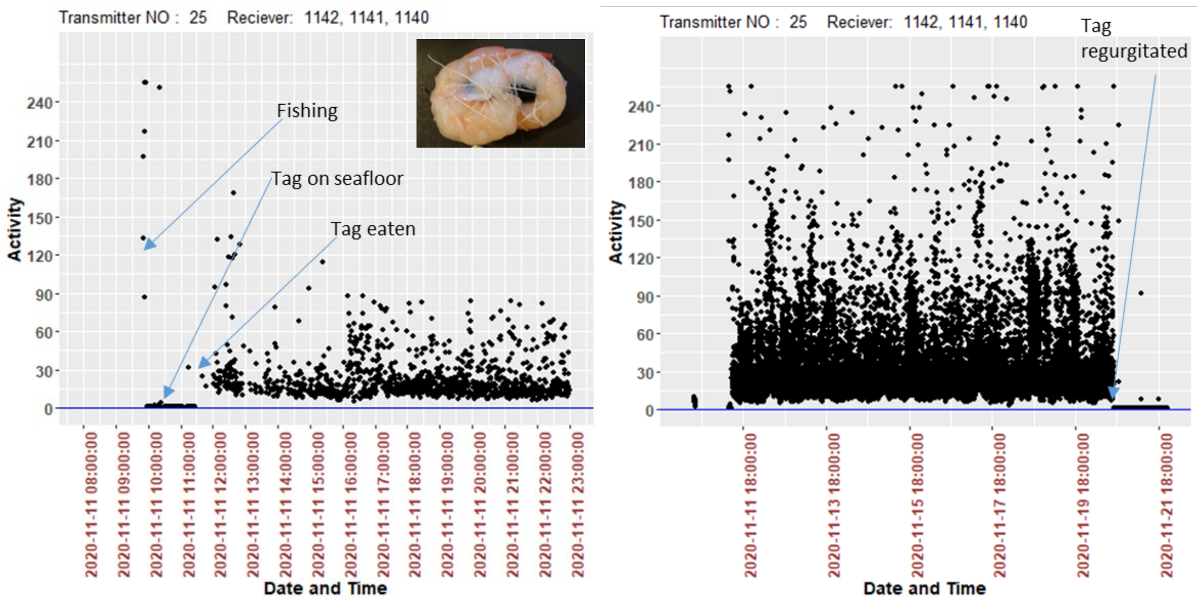


Figure 13. Activity data collected from tag 25, showing some activity during fishing, then inactivity with the tag lying on the seafloor for 2-3 h until high activity after the tag was eaten from the seafloor. High activity continued for approximately 9 h before the tag was excreted by regurgitation.

Information on the general location of the tag within the fjord, whilst in the fish stomach, can be obtained by comparing the data from the three receivers. For example, a signal is sent from the eaten tag to the receiver every 30-40 seconds, by plotting the minutes between received signals it is possible to determine when a fish is out of range from one or more receivers. The data from receiver 1141 shows that a signal from the tag transmitter was received frequently, only on one occasion was the time between signals at 30 min. The tags and receivers had no specific range, but rather the tags had a specific signal strength. The range was greatly affected by water conditions such as salinity, layering, temperature etc. as well as potential noise sources such as engine noise from vessels. The trial area is near the mouth of a river and it was also expected that water currents and potentially higher suspended particulate matter will affect the range. The location was however also close to the offices of Thelma Biotel and thus well known to them. They made a general estimate of 500 m range for tag 25 (type: A-MP13).

The fish appeared to stay within the approximate 500 m range of receiver 1141, also it appears that the tag was regurgitated within the range of this receiver. For receivers 1140 and particularly for 1142, there were many occasions when the time between signals was greater than 30 min and above 50 min. Showing that the fish was out of range of these receivers for longer periods of time.

Additionally, the signal to noise ratio can provide a rough indication of the distance the tag is from the receiver (Figure 15). The data clearly shows a stronger signal to noise ratio for receiver 1141 between 30 and 40 compared to 1140 and 1142 who had a similar signal to noise ratio of 10 to 20. This supports the minutes per last signal data and indicates that the fish was almost continuously within the range of receiver 1140 during the nine days inside the fish and appearing in and out of range of 1141 and 1142. The proposed position the fish occupied during the nine days is shown in Figure 16.

A more precise method of positioning of the fish can be achieved by attaching a tag to one of the receivers, the difference in time for the transmitted signal from this tag to reach the different receivers can be used to resynchronise the clocks on the receivers. Tagged fish can then be precisely located by using the time difference of signal reception in the different receivers to triangulate the fish.

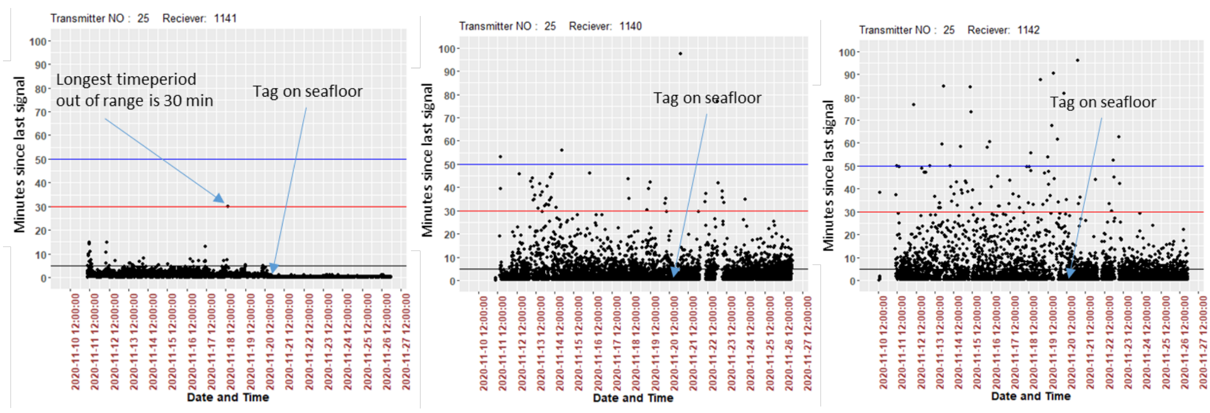


Figure 14. Minutes since last signal for the three receivers (1141 (left), 1140 (centre) and 1142 (right)) over time, to indicate the frequency and length of time the tag 25 was out of range of the receivers.

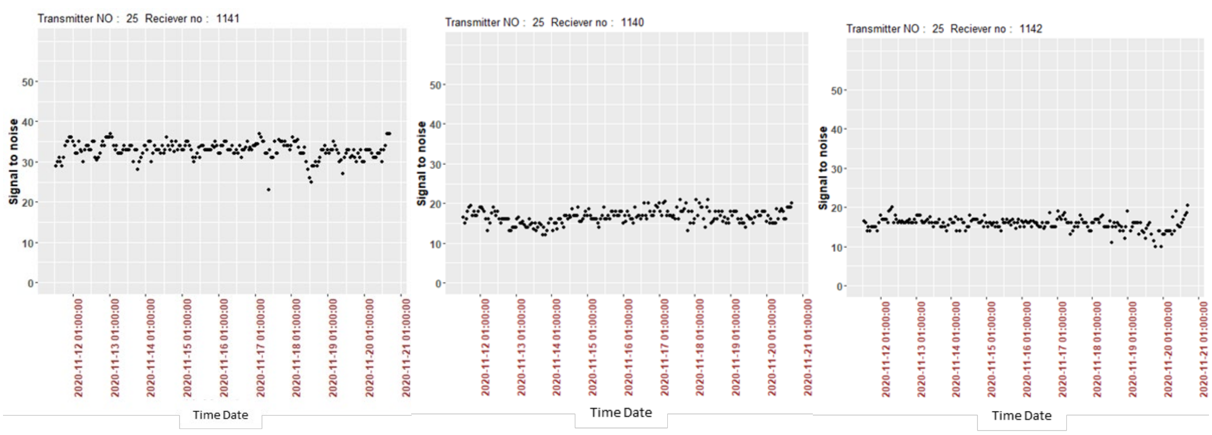


Figure 15. Signal to noise ratio for tag transmitter 25 from the three receivers 1141 (left), 1140 (centre) and 1142 (right).

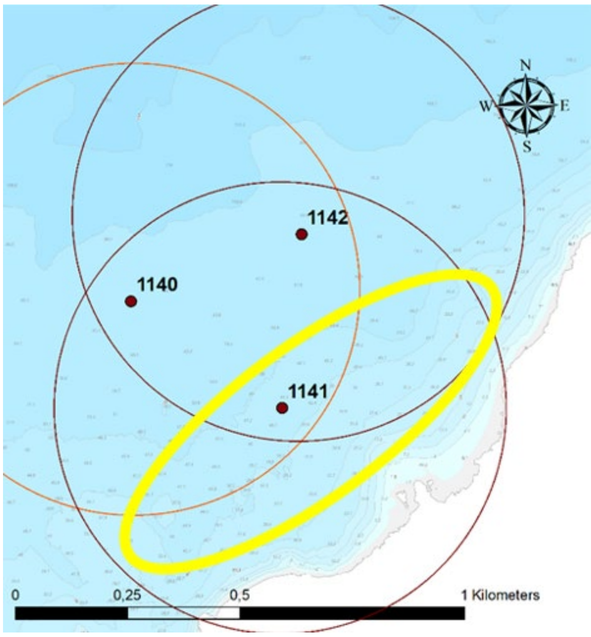
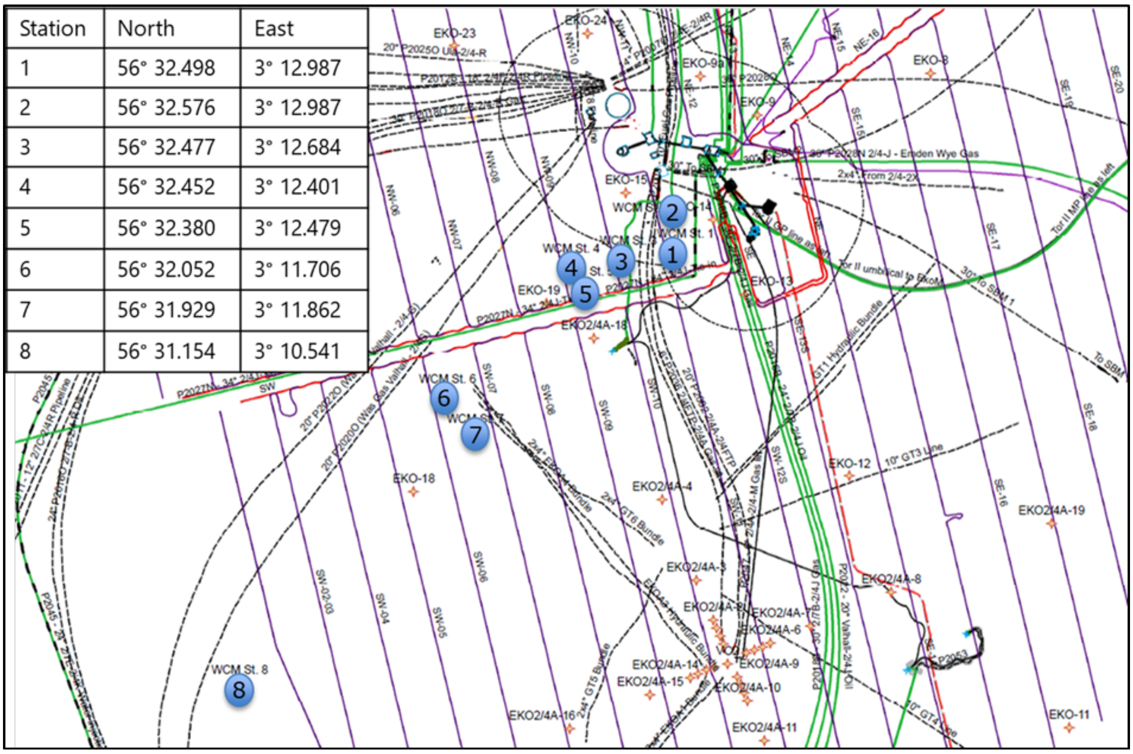


Figure 16. The yellow ellipse shows the approximate location of tag 25 when within the fish for nine days in relation to the positions of the receivers. Based on the data from the time between last signal and the signal to noise ratio from the three receivers.

3.2 Ekofisk

The water column monitoring programme of 2020 was postponed until 2021 due to the restrictions caused by the COVID-19 pandemic. The WCM2021 involved monitoring the potential effect of the produced water discharge at the Ekofisk complex. Mussel monitoring stations were placed in the expected area of the produced water plume for a period of 6 weeks. In addition to mussels, scallops and various oceanographic instrumentation on the monitoring stations, the acoustic receivers (1140, 1141 and 1142) were placed at three of the closest monitoring stations (1, 2 and 3) at an approximate depth of 40-45 m (Figure 17). The rigs were deployed on 23rd March and retrieved 6th-7th May.



Station	North	East
1	56° 32.498	3° 12.987
2	56° 32.576	3° 12.987
3	56° 32.477	3° 12.684
4	56° 32.452	3° 12.401
5	56° 32.380	3° 12.479
6	56° 32.052	3° 11.706
7	56° 31.929	3° 11.862
8	56° 31.154	3° 10.541

Figure 17. Approximate positions of the monitoring stations at Ekofisk for the water column monitoring programme of 2021. Acoustic receivers 1140, 1141 and 1142 placed at monitoring stations 1, 2 and 3 respectively, at a depth of approximately 40-45 m.

New tags were purchased for the Ekofisk study and included five 7 mm and five 9 mm diameter tags, detailed information on the tags is provided (Table 4). Two 16 mm tags were also obtained, which were attached directly to two of the receivers, in order to enable triangulation.

Table 4. Specific information on the Thelma Biotel acoustic transmitters (tags) used at Ekofisk.

Transmitter type	*Weight in air/ water (g)*	*Transmit interval (sec)*	*Life time (d)*	*Diameter (mm)*	*Length (mm)*	*Data collected*	*Power*
ADI-HP9	5.9/ 3.9	35	100	9	32	ID, Depth, activity, tilt	High-power 149 dB
ADI-HP7	3/ 1.8	27	42	7	28	ID, Depth, activity, tilt	High-power 143 dB
R-HP16	29/14.9	300-300	>2000	16	70	NA	High-power 158 dB

As part of the WCM2021, fishing within the 500 m safety zone using rod and line is a method that is effectively used to catch fish for chemical and biological effects assessment. From the two-day fishing effort on the 7th and 8th May 2021, it was clearly established that only dab (*Limanda limanda*) and small cod were present, with 30 of each species caught with no sign of any other fish species.

Fishing with baited tags within and around the safety zone of the Ekofisk platform took place on the deployment cruise of the WCM2021 on the 25th-26th March 2021. Underwater video surveillance with the WaterWolf® on the fishing line confirmed that only small cod and dab were present. The underwater video also identified a lot of interaction with the baited tags, particularly from the dab, which were seen to bite and wrestle with the bait for extended periods of time (Figure 18). However, despite this interaction none of the baited tags were ingested by the fish. These difficulties were expected and was the reason why the smallest transmitters available from Thelma Biotel were purchased. We also used mackerel and squid as our main baits because we could make those baits smaller than king prawns. Mackerel was introduced as bait on this cruise because it is well known as a good bait for most fish and the trial in the Trondheimsfjord showed that bait elastics were suitable for keeping tags securely wrapped in fish filet.

The young cod present at Ekofisk were too small to fully ingest the baited tags, this was despite the use of smaller tags (7 mm Ø) and minimum sized bait to encourage ingestion. For dab, which are generally a smaller flatfish with small mouths that tend to nibble rather than gulp their food, they were considered an unsuitable species for ingesting baited tags.

Figure 18. Images taken from the underwater video camera (WaterWolf®) positioned on the fishing line showing the acoustic tag wrapped in mackerel bait with interest from a small cod and dab (left image) as well as a dab trying to eat the bait (right image).

Although the underwater video cameras showed that none of the baited tags were ingested by the fish, during fishing some of the baited tags were lost to the seafloor. As we experienced at Trondheimsfjord, it is possible for the baited tags to be eaten from the seafloor by fish and there was a possibility for movement to be detected on the receivers when they were retrieved, and data analysed. However, the data collected by the three receivers confirmed that none of the baited tags were consumed by fish either during fishing or eaten from the seafloor.

Overall, Ekofisk was not the most suitable location to trial the method of tagging fish through the ingestion of baited tags. Ekofisk is located in the most southern section of the Norwegian sector of the North Sea in relatively shallow waters (70-80 m). It is recommended that this method of baited tagging be performed at an installation in deeper waters where larger demersal fish species such as ling (*Molva molva*), tusk (*Brosme brosme*), haddock and larger cod species would be present and more likely to fully ingest the tags. The experiences gained from this activity at Ekofisk will be utilised in future WCM programmes.

4 Conclusion

Development work

- Food tests revealed squid, king prawns, herring and cod were the order of preference for the cod in the tank experiments.
- King prawns were effective in holding and concealing the acoustic tags and ensured that the cod ingested both tag and bait.
- The residency time of the tags inside the stomach of the cod before regurgitation was on average 16.6 ± 11.6 (n=20) days when king prawns were used, 7.4 ± 2.9 (n=8) for Nephrops tails and 11 days (n=1) for freshwater crustacean tail. The maximum residency time was 36 days.
- Activity data from the tags clearly showed when a tag was dormant prior to being eaten and increased activity levels after being ingested.
- Tag orientation data was successfully interpreted but it was not clear how this could provide any significant meaning to the fish tagging experiments.
- Location of the tags inside the cod two days after ingestion revealed in all cases (n=9) that the tags remained in the stomach and did not entire the intestine. Therefore, the only way the tag could leave the cod was through regurgitation. Smallest tag diameter tested was 9mm.
- The more voracious cod where found on several occasions to have more than one tag inside their stomach. This may suggest that the fishing method with one bait may be more suitable than the fixed frame holding several tags.

Field trial

- The Trondheimsfjord field trial showed how the light, video camera and bait assembly on the end of the fishing line was able to obtain excellent visuals of the bait and the species of fish interacting with the bait.
- Triangulation of the receivers and the data obtained from the one tag that was eaten in the Trondheimsfjord was able to determine the approximate location of the fish in the fjord and showed the potential for application to the offshore scenario.
- At Ekofisk, the video footage clearly showed numerous interactions of the fish species (Dab and juvenile cod) with the baited tags.
- The lack of ingestion of the tags by the fish was interpreted as the unsuitability of the species present and size of cod present at Ekofisk.
- It was believed that using the same baited tag design at a site with larger demersal fish species such as ling, tusk, haddock and larger cod, as well as saithe and whiting as caught in other WCM programmes would be more successful in ingesting the tags and determining residency.
- The use of bait elastic to keep the tag in place was far superior to cotton, and it allowed the use of fish filet as bait. It seemed that cotton is better than bait elastic to secure the final bait to the fishing line.
- Applying this baited tag concept to future WCM programmes where offshore installations are located in deeper waters such as those in Tampen and Haltenbanken should be considered.

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Økernveien 94 • NO-0579 Oslo, Norway
Telephone: +47 22 18 51 00
www.niva.no • post@niva.no