Feasibility of tagging Monkfish (*Lophius piscatorius*) with Pop-up Satellite Tags in Icelandic waters

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Abstract

Vertical movements of *Lophius piscatorius* were tracked with Pop-up Satellite Tags, for the first time in subarctic waters. Five out of eight tags sent recorded information via satellite after they reached the ocean surface. The days at liberty ranged from 7 days to 58 days. Two tags shed loose after a few days at the bottom but the three other reporting tags were released from their subjects with the Constant Depth Release mechanism (CDR), after staying within a 20 m depth range for 7 days. First GPS position was received within 3 days for one tag (tag A) but the other tags drifted for 30 to 78 days in the surface layers of the Irminger ocean before establishing a connection with a satellite. One tag was also physically retrieved and analyzed in the lab after it washed ashore on a beach in SW Iceland. A horizontal path was estimated for that tag with geolocation based on a tidal location model.

Keywords: Pop-up Satellite Tag; *Lophius Piscatorius*; Tidal Location Model

1 Introduction

1.1 *Lophius piscatorius*

Monkfish, *Lophius piscatorius* (Linnaeus, 1758), are demersal fish that reside mainly in the benthic environment and are generally found on a soft clay or gravel bottom at depths from 20 to 1000 meters in the NE-Atlantic and Mediterranian Sea (Caruso, 1986). Their morphology suggests a benthic lifestyle, they are negatively buoyant, have a dorsoventral flattened body and almost leg like pelvic fins that they can use for digging in and maneuvering on the seafloor. They are a lie-and-wait predator that use their transformed fin rays, the illicium, a lure on the top of its head that mimics small fish, as a kind of fishing rod to attract prey (Wilson, 1937; Laurenson et al., 2004; Field, 1966). Monkfish are opportunists, their diet is diverse and it reflects the habitat and the food supply in a particular region (Laurenson and Priede, 2005; López et al., 2016) and seasonal prey availability (Crozier, 1985) which mainly consists of fish and crustaceans (López et al., 2016).

Seasonal migration of Monkfish to deeper waters in winter were detected around the Faroese Islands (Ofstad et al., 2013) and of *L. americanus* in NW-Atlantic (Jean, 1965). Crozier 1985 and Laurenson 2005 noted a seasonal difference in diet composition and stomach fullness of Monkfish in the N-Atlantic and the Mediterranian respectively. That may be associated with geographic and temporal setting (Laurenson and Priede, 2005) but given its body morphology which is adapted to a benthic environment, increased activity of Monkfish in winter (Ofstad et al., 2013) lowers its chances of successful feeding. Lesser stomach fullness in winter (Laurenson and Priede, 2005) indicates spawning migration to deeper waters over winter and feeding in shallow waters over summer (Ofstad et al., 2013).

1.2 *L. piscatorius* in Icelandic waters

In the latter part of the 20th century Icelandic fishermen mostly caught Monkfish as by-catch in lobster gear off the south coast of Iceland. Catch-limits were not set by the Icelandic Directorate of Fisheries until at the turn of the century (Anon., 2002) when Monkfish spatial distribution increased significantly and extended to the coast in the west and north-west of the country. (og svo norður að Langanesi) There have been reports of Monkfish caught on pelagic longlines south of Iceland (Solmundsson et al., 2010) and in a pelagic trawl in the Norwegian Sea at latitudes above 70°N (Hislop et al., 2000). Pelagic Monkfish juveniles have been found off the coast of the north western tip of Iceland (Thangstad, 2006) and ripe female monkfish have been caught along the south coast of Iceland (Solmundsson et al., 2010). The main conclusions of Sólmundsson et al. (2010) is that rising ocean temperature and salinity with favorable currents opened larger feeding and nursery grounds and aided larval dispersion to the west and north of Iceland resulting in an expansion of the stock.

Migration and larval dispersion from Norway and the British isles can be the basis for the Icelandic population of Monkfish (Thangstad, 2006; Hislop et al., 2001). With a pelagic juvenile stage up to 3-4 months (Hislop et al., 2001) a portion of the Icelandic stock may be from dispersal of larvae from the Faroe Islands to Iceland or active migration of adult fish (Solmundsson et al., 2010).

High recruitment of juveniles in 2000-2010 point to this being a local population for the most parts but the absence of juvenile Monkfish before the stocks expansion points to migrating adults being the main foundation of the Monkfish catch in the late 1980 and early 1990 (Solmundsson et al., 2010). The stock's recruitment has been low since 2008 and the catch has been declining in recent years (Anon., 2015) which might be related to the temperature and salinity decline in Faxaflói (west coast Iceland) from 2010 to 2014 (Valdimarsson and Ólafsdóttir, 2014) and could be the cause of the northern boundary of the species retracting further south, as it were between 1985 and 1998 (Solmundsson et al., 2010).

1.3 Pop-off Satellite Archival Tags

To shed light on horizontal and vertical movements of Monkfish, Pop-off Satellite Archival Tags (PSAT) were put on Monkfish in south west and west Iceland. PSATs are relatively big compared to other tags in underwater biotelemetry but they deliver data regardless of fish mortality or the PSATs recovery. They are externally attached and slightly positively boyant so they float up to the surface when the tagging mission ends. The monkfish should not be affected by the physiological cost from drag forces or buoyancy of the PSATs (Lynch et al., 2017) but the tags effects on the monkfish hunting strategy or predator avoidance are unknown. The use of PSAT's on Monkfish around Iceland in winter is challenging for a number of reasons, firstly because this is a bottom dwelling animal so the tagging mission depends solely on data transmission after pop-off, no intermediate positions will transmit. Secondly the low irradiance in high latitudes and bad weather conditions (Serreze et al., 1997) make satellite connection after pop-off difficult so first location after pop-off may not be revealed with much precision. After an extensive tagging effect study on the deep-water sable fish *Anoplopoma fimbria* in the North Pacific (Echave, 2016), Goetz et al. (2018) bypassed the issue of incomplete data recovery by fetching the PSAT's by boat with radio direction-finding equipment, although combined with GPS locations through the Argos system.

1.4 Tidal location model

Together with bathymetry data and the data from the PSAT the location of Monkfish is proposed with a tidal location model. The model, as described in (Thorsteinsson et al., 2012) and supplements: "..has been calibrated and verified extensively with data from harbors and mooring stations around Iceland and elsewhere. Its accuracy on the Icelandic shelf is within a few centimeters in amplitude and a few minutes in phase." At best the model can propose a location up to 10-20 km but because of its accuracy and sensitivity in tidal amplitude and phase it is difficult to assess the proposed area with much certainty ef gögnin eru ekki mjög stöðug.

2 Methods

2.1 Pop-up satellite archival tag (PSAT)

Monkfish were tagged with the SeaTag-MOD PSAT from Desert Star Systems, LLC dimensions (175mm L x 25mm D (tube) x 54mm D (max. width float)) in November 2013 at two locations (tagging locations 1: Grundarfjörður and 2: Grindavík) off South-West and West Iceland (see figure 2). The fish were caught in gill nets that had been soaked for up to 48 hours at depths of around 50 meters. They were placed in a fish container with sea water prior to tagging for a visual assessment of viability. Length measurements, to the nearest cm on a measurement board, were taken aboard and only large fish, over 80 cm fork length, were tagged. To avoid early recapture, the release was outside the main fishing area.

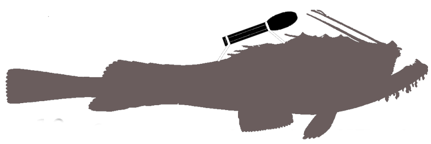

Figure 1: A figure based on a sketch by Bean 1895 (Pietsch, 2009) of *L. piscatorius* carrying a PSAT.

A two-point attachment aligned the tags along a longitudinal axis on the fish with two barbed plastic umbrella anchors in the dorsal muscle behind the third dorsal spine. The tether material is a plastic coated stainless steel wire.

The tags were programmed to pop off after 365 days at liberty and had a constant depth release mechanism (CDR) to pop-off from their anchors if they remain within a depth range of 20 m for 7 consecutive days to account for mortality.

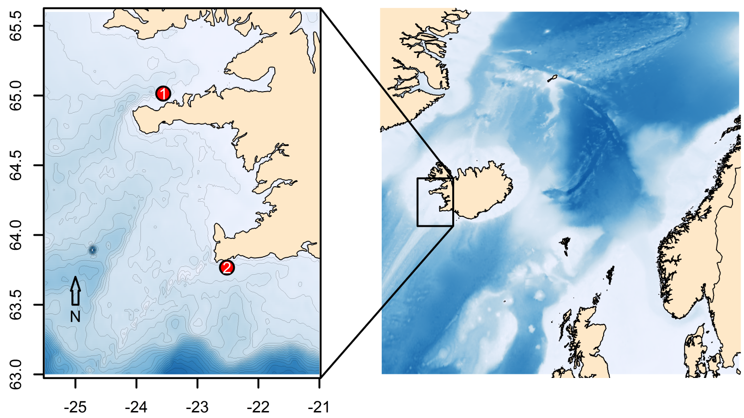

Figure 2: Tagging locations 1, Grundarfjörður and 2 Grindavík in West Iceland. Axis display decimal degrees and depth contours are 50 m.

The tags were set to record a point-in-time measurement at a 4 minute time interval and send data via satellite trough the Argos telemetry system (`www.argos-system.org`) when at the ocean surface. The data was processed and analyzed with the manufacturer's software (Desert Star Systems) and R (R Core Team, 2017).

Sunrise, civil dawn, civil dusk and sunset time were estimated for release points 1 and 2 (setja inn GPS) using the R package maptools (Bivand and Lewin-Koh, 2017)

2.2 Tidal location model

Depth and time data was compared to a tidal location model developed by Tómasson and Káradóttir 2005. The procedure followed is described in (Thorsteinsson et al., 2012) in all aspects except the data was passed through a low pass filter to remove noises of high frequency; flickering depth measurements made it difficult to identify tidal waves with the model so the depth data was evened out with a cut-off frequency of $\frac{1}{64}$ min^{-1}.

3 Results and Discussion

3.1 Tag A

Tag A had the most retention time and the shortest time period between pop-up and first given GPS position (see table 1). Three days after CDR the first GPS signal was detected (63.29806, -24.57637) 114 km SW of the tagging location 2 in Grindavík (see figure 2).

Large vertical migrations (VM) were the most frequent with this fish (fish A), the maximum being 228.92 m in 3 hours 12 minutes. Less vertical activity was during daylight hours (Tukey HSD, p>0.4.99e-10) and data points with VM>5 m/h were 72,6 % of data points (re-check).

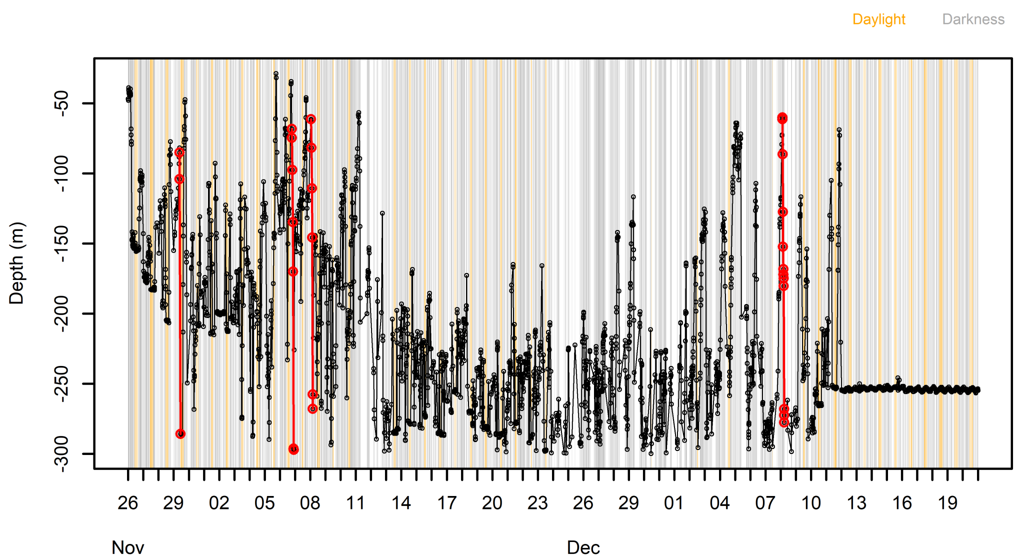

Figure 3: Depth profile of tag A. Red lines represent the largest unbroken vertical migrations spanning over 200 m.

The pattern of the tags longitudinal axis (Z) varied over the course of the mission but had an increasing upward anterior tilt towards the end of the deployment. That upward tilt coincides with a sudden change in behavior of the fish and settling on the sea-bottom. Changes in the free rotating plain of the x and y axis can be seen on DAL: 9, 17, 20, 48 and 54. A change in the x- and y-axis can indicate stress for an outside force is necessary to rotate the tag. On the 54th DAL (the day after a quick spurt up from the bottom) the XYZ axis show an irregular pattern but no changes in depth until CDR.

Table 1: PSAT performance summary. Tag number and location of deployment, number of recording days under water, number of days after pop-off until the tags first GPS position, percentage of data points with the programmed time step of 4 minutes, average time between data points in minutes. Tag C (**bold**) was physically retrieved.

PSAT				Data Density	
Tag No.	Tagging location	Retention Time (d)	First GPS (d)	4 min. time step. %	Mean point diff. (span) (m)
A	1	56	3	33.07	32 (4-632)
B	2	32	30	43.53	14 (1-578)
C	2	26	78	43.15	13 (2-124)
-	-	-	-	**99.89**	**4 (3-4)**
D	2	12	66	32.93	27 (4-152)
E	1	7	64	34.26	19 (4-234)

3.2 Tag C - (Tidal Location Model)

Tag C was captured and analyzed in the lab. It had an uninterrupted, four minute time step of data recordings. Therefore it was possible to make use of a tidal location model to estimate the horizontal movements of the fish (Tómasson and Káradóttir, 2005). High frequency irregularities in the PSAT's depth measurements made comparison to the tidal wave model impossible without a low-pass filter. (The retrieved tag was activated in a stationary water container and the recorded 15 depth measurements in 5 minutes with variance = 0.82 m.)

The fish was released in Breiðafjörður (see figure 4) on the 14 of November 2013. The depth at the point of release was around 150 m. After release, the fish traveled for about 72 hours, 50 km north to Rauðasandur where it kept within -60 to -80 m depth range for 5 days. Then the fish traveled south, for 4 days, to an underwater valley named Kolluáll at -210 m depth with warmer water. Finally the fish traveled to a slightly increasing depth until the tag's CDR at -270 m on the 10 of December after 26 DAL.

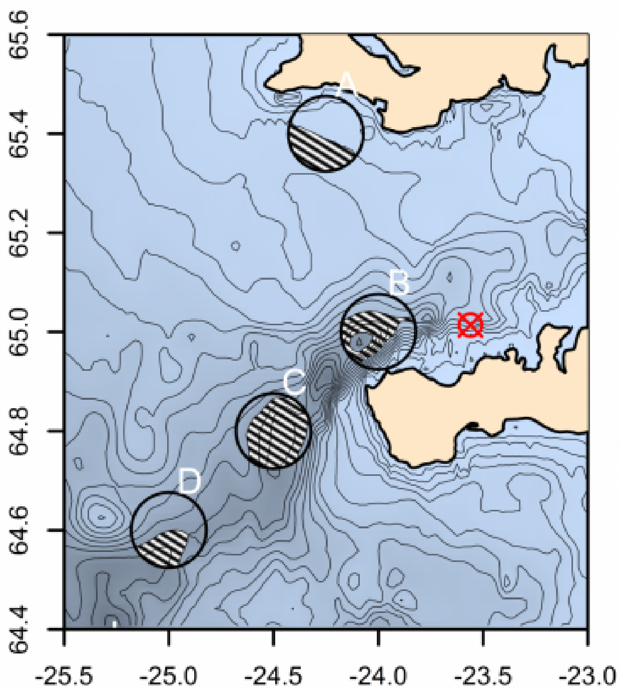

Figure 4: Estimated location of Monkfish C based on the Tidal Location Model and timed depth measurements. The release area was just outside Grundarfjörður (⊗) on 14 November 2013.

The fish migrated aprox. 50 km two times in three to four days. The pressure data and accelerometer data together can give us certain hints about the swimming behaviour of the fish. In the former swimming phase from the tagging location to point A on figure x the fish swam for approx. 38 hours with the longest continuous event up to 14 hours and 54 min. In the second largest swimming phase the swimming time was approx. 52 hours and 48 minutes with the longest continuous event up to 16 hours and 24 min (see fig.5).

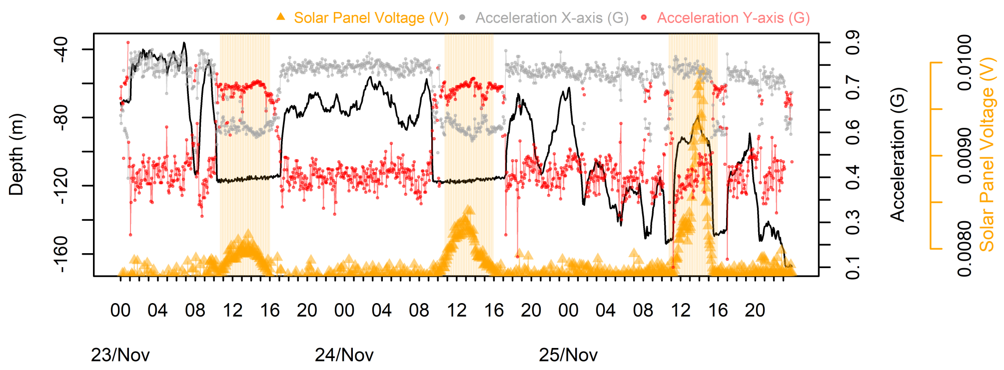

Figure 5: Diel activity. Depth measurements, light intensity and vertical tilt of Fish C. A change in behavior is seen with changes in light intensity; either the fish lay on the bottom or swam when light intensity rose. Shaded areas depict daylight hours near the release point at GPS: 64.896113, -23.706438.

3.3 Tag D (133452)

Tag D shed from its subject after 13 DAL. The fish dove to approx. -160 meters after release but had no significant changes in acceleration on X, Y or Z axis for the rest of the deployment. On the sixth day the vertical movements reduced and subsequently the accelerometer data show abrupt changes in the free rotating plain of the X and Y axis while the Z axis (longitudinal axis) moved to a near horizontal position. Two days before the tag shed, the Z axis rose to a vertical position over a time period of a couple of hours. It remained vertical for two days until it floated to the surface. The fish likely died and scavengers loosened the tag's anterior anchor, with the floater pointing upwards or in the direction of underwater currents (see fig.6).

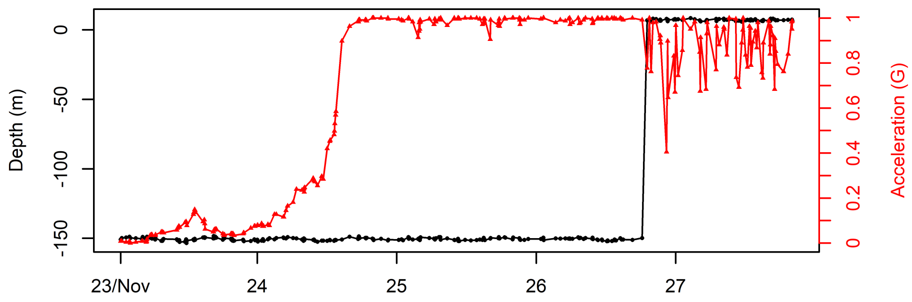

Figure 6: Tag D shedding off the fish and floating at the surface.

3.4 Conclusion

Three of the five retrieved tags popped off their subjects with the CDR mechanism but two of them shed off. One of the shed tags, tag D (133452), displayed considerable disorientation on its vertical and longitudinal axis shortly before shedding loose; it was in vertical position at the end of its mission which indicates either that the tag lost its anterior anchor or that the time of pop-up was postmortem. Tag A 133449 also showed signs of disorientation in the last days after settling on the bottom. In other cases there were no indications of mortality when CDR occurred. If the species under research has a preferred habitat that overlaps with the CDR's conditions it is wise to better adjust these conditions or turn the CDR off altogether or set a specific date and make sure the first GPS after CDR is a priority transmission before transmitting the recorded sensor data. Incomplete data recordings were an issue in this study as may have been expected (Musyl et al., 2011) Færa úr PSAT inngangi hingað

Since radio waves do not travel far trough sea water the tags need to surface in order to send a signal to a satellite. They require a time frame of about 8-12 minutes to give their first position after surfacing. Depending on the weather, wind waves might keep the tags underwater hindering the device

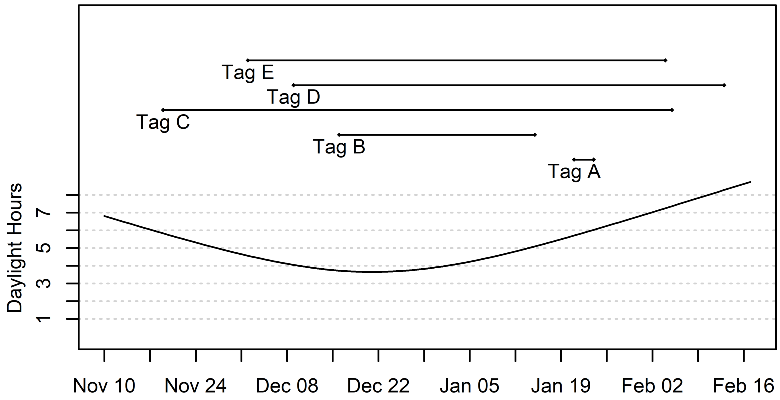

Figure 7: The surface time of the PSAT and sunlight hours from early November 2013 to mid February 2014 at the Snæfellsnes Peninsula in Iceland.

from establishing a connection. There is a permanent low pressure area in winter between Iceland and Greenland at latitudes 60°–65°N (Serreze et al., 1997) and given the sunlight conditions at these high latitudes (see fig. 7) the chances of optimum conditions for the PSAT are greatly reduced in winter. Tags with a larger float for more stabilization at the ocean surface should be considered in future experiments and a pop'off event in the summer months. Another failure is the PSAT's programming, they are programmed to use their battery to report a GPS location if the CDR has not happened, that feature suits well for animals close to the surface. But if the CDR has happened they prioritize energy for sending data packages before sending GPS.

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