Tagging Report
PSAT – 2018

Patagonian Toothfish
(*Dissostichus eleginoides*)

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Table of Contents

Summary

Pop-up satellite archival transmitting (PSAT) tags were used in conjunction with a conventional tagging program to examine the movement patterns and habitat use of Patagonian toothfish (*Dissostichus eleginoides*) around the Falkland Islands. Fifteen satellite tags were deployed between June 2017 and February 2018, of which 12 transmitted pop-up locations.

Tags remained on the fish for up to 170 days and popped up between 1.5 and 375 km from the tagging location. Four fish travelled a minimum distance of over 100 km, two of which moved outside the FICZ/FOCZ. Two of the fish tagged during the spawning season seemed to have stayed in the same location after the spawning season, and two other fish tagged at a known spawning location outside of spawning season stayed inside the spawning area through the spawning season. Only one of the three fish tagged during the spawning season moved a long distance after the spawning season.

Tagged fish spent most of their time in waters between 2 and 3°C, and between 1,200 and 1,600 m depth. Temperature readings from tags that did not have depth sensors suggest that some of the fish may have made forays into shallower warmer waters (up to 4°C), especially during the spawning season.

Because of the useful fisheries-independent data collected by these satellite tags, it is recommended that more PSAT tags should be deployed on toothfish in the future, funding permitting. These tags could be deployed in areas where few other tags have been deployed in the past, and scheduled to pop up during the spawning season. Specifically, fish should be tagged north of 53°S with tags scheduled to pop up during the spawning season as this is a gap in our data.

Introduction

Tagging provides a lot of information on the movement, ecology, life history and behaviour of fish species. Although conventional tagging with simple ID tags can be undertaken cheaply and extensively, data gathered in this way rely on the recapture of those tags by research or commercial vessels. This fishery-dependent method is therefore contingent on the location and timing of fishing effort which can bias the detection of movement patterns (Bolle et al. 2005).

PSAT tags offer a fishery-independent alternative to conventional tagging (Arnold and Dewar, 2001). Although the PSAT tags are much more expensive than conventional tags, the "return" rate is much higher (usually around 75% compared to 3% for conventional tags, pers. obs.) and is not dependent on fishing or survey effort. PSAT tags remain on the fish for a pre-determined amount of time, after which they release and pop up at the surface. Once an

uplink connection to the Argos satellite system is established, the tags transmit their location and archived data (usually a record of temperature and/or depth).

Patagonian toothfish (*Dissostichus eleginoides*) around the Falkland Islands have already been tagged with PSAT tags between 2007 and 2010 (Brown et al. 2013). Data from 17 tagged toothfish showed strong site fidelity, with seasonal bathymetric movements. These tags were deployed in the north-eastern area of the Falkland Outer Conservation Zone (FOCZ) and on the south side of Burdwood Bank. In addition, only five of these fish were tagged during the spawning season (June-August), and only two successfully popped off during the spawning season. Therefore, it was necessary to attempt a second PSAT tagging effort in areas that were omitted in the first study, and with tagging and pop-up dates closer to the presumed spawning dates.

Methods

PSAT tags were deployed on toothfish during two research cruises. In June/July 2017 (austral winter), five PSAT tags were deployed on the eastern part of the FOCZ and north of Burdwood Bank (Fig. 1). In February 2018 (austral summer), ten PSAT tags were deployed across the southern area of the FOCZ, along the Falklands Trough, and on the north and eastern edges of Burwood Bank (Fig. 1).

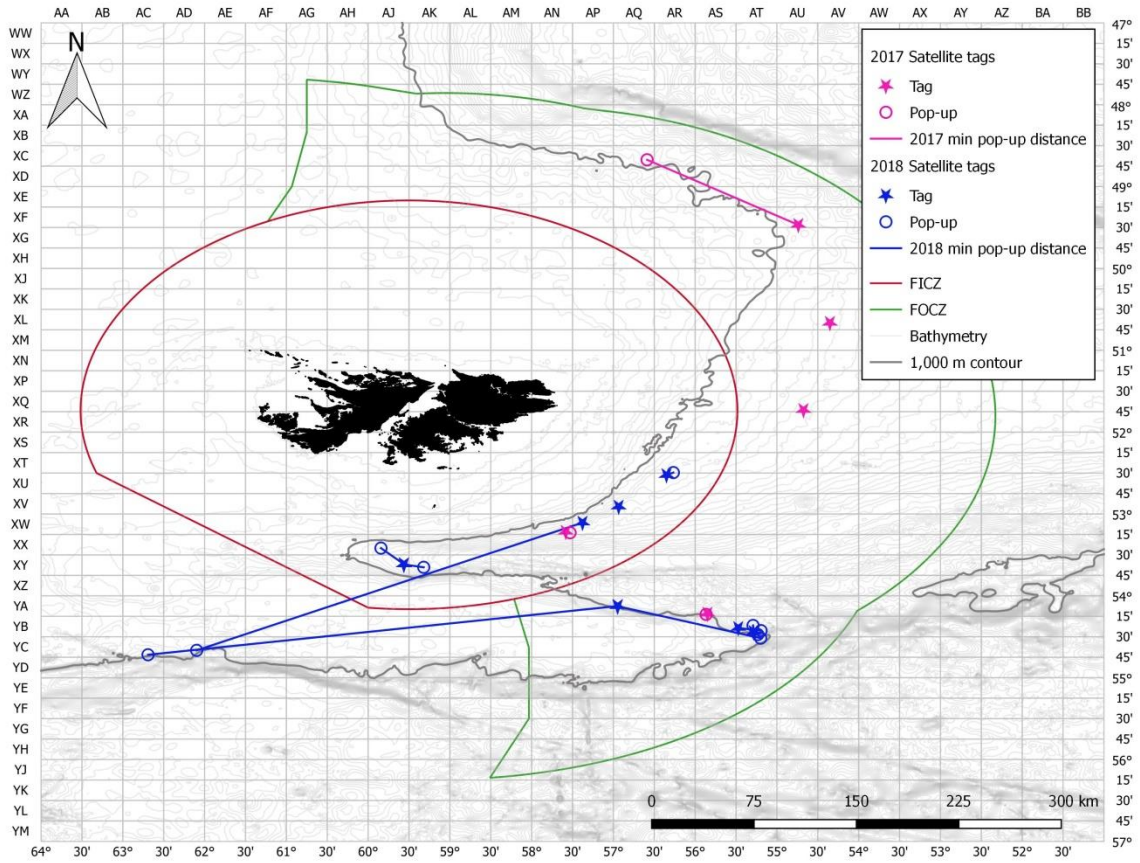

Figure 1. Map of the Falkland Islands and the Falklands Inner Conservation Zone (FICZ) and Falklands Outer Conservation Zone (FOCZ) boundaries. PSAT locations are shown for the 2017 (pink) and 2018 (blue) deployments. Filled triangles are the tagging locations and open triangles are the pop-up locations (when available). Straight lines represent the minimum distance between tagging and pop-up locations. Numbers refer to the tag numbers of each fish.

All PSAT tags used for this study were manufactured by Wildlife Computers (Redmond, WA, USA). Tags deployed in 2017 were MK-10 PAT tags (Fig 2A) that record and archive daily temperature and depth readings throughout their deployment period. These tags were set to pop-up 100 days after tagging. Toothfish in 2018 were tagged with MR-PAT tags (Fig. 2B) that only recorded temperature data for the last 100 days of their deployment. These tags were programmed to pop up during the spawning season in late July/early August, approximately 160 days after deployment.

Once the PSAT tags popped up, they transmitted their location and archived data to the satellites. After retrieval of the data, the tagging and pop-up locations of all tags were plotted and the archived data analysed for depth and temperature occupancy by the tagged toothfish.

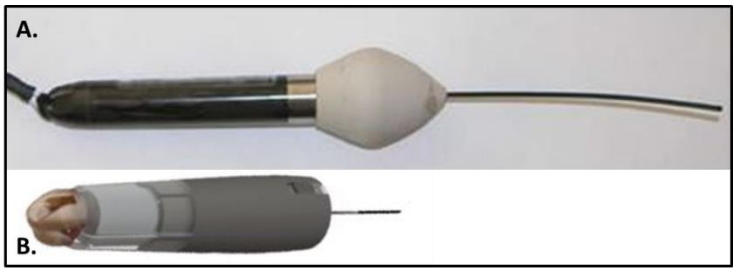

Figure 2. The two Wildlife Computers PSAT tags used for this study. A. Mk10-PAT satellite tag. B. MR-PAT satellite tag.

Results

Of the fifteen total PSAT tags deployed, twelve successfully reported their location and data to satellites, and three were not heard from (Table 1). These three lost tags may have gotten damaged, run out of batteries, or flooded, and therefore failed to establish a satellite uplink. Unfortunately, the lack of data makes it impossible to determine what exactly happened.

Table 1. Tagging and pop-up information for all toothfish tagged with PSAT tags in 2017 and 2018 in the Falkland Islands. Light grey rows are tags that prematurely popped up and floated on the surface before reporting, dark grey rows are tags that never reported.

Tag #	Length (cm)	Tag Date	Tag Lat	Tag Long	Fate	Pop-up Date	Pop-up Lat	Pop-up Long	Total Dist (km)	Days	Bearing
153744	125	30/6/17	-51.73	-54.68	Lost						
153745	134	14/6/17	-53.22	-57.58	Early	9/7/17	-53.23	-57.53	3.82	25	111°
153746	136	11/6/17	-54.22	-55.85	On time	22/9/17	-54.23	-55.87	1.55	103	222°
153747	136	5/7/17	-50.67	-54.35	Lost						
153748	119	8/7/17	-49.47	-54.74	Early	3/9/17	-48.67	-56.59	161.83	57	303°
53656	112	13/2/18	-53.61	-59.56	On time	24/7/18	-53.42	-59.84	28.78	161	319°
53657	146	13/2/18	-53.62	-59.56	On time	26/7/18	-53.65	-59.32	16.54	163	103°
53658	127	15/2/18	-54.12	-56.95	On time	28/7/18	-54.72	-62.69	374.29	163	258°
53659	137	15/2/18	-54.13	-56.95	On time	30/7/18	-54.52	-55.20	120.86	165	112°
53661	112	16/2/18	-54.44	-55.28	On time	1/8/18	-54.36	-55.29	9.08	166	355°
53672	114	16/2/18	-54.44	-55.29	On time	3/8/18	-54.47	-55.23	4.71	168	134°
53673	129	17/2/18	-54.39	-55.47	Floater	22/2/18	-54.43	-55.19	18.37	5	101°
53678	110	18/2/18	-53.11	-57.38	On time	7/8/18	-54.67	-62.10	348.96	170	239°
53679	119	19/2/18	-52.91	-56.94	Lost						
53684	106	20/2/18	-52.53	-56.35	Floater	20/2/18	-52.49	-56.27	6.64	1	58°

The other twelve satellite tags reached the surface and transmitted to the satellites, providing location and archived data. Two of these twelve tags prematurely popped up within 5 days, and floated on the surface until the satellite transmission automatically initiated. These floaters may have gotten dislodged from the toothfish, or the toothfish may have died and/or been eaten. The ten PSAT tags that worked properly recorded toothfish movement distances between 1.5 and 375 km during periods ranging from 25 to 170 days (Table 1).

Eight of the tags popped up within 30 km of the tagging location, including the two that prematurely popped up (Fig. 3). All of these popped up within the FICZ/FOCZ, and showed high site fidelity. Two fish that were tagged on known spawning grounds outside of the spawning season (tags #53661 and #53672) seemed to stay in the spawning area for over 160 days through to the spawning season (Fig. 3). Two fish tagged during the spawning season (tags #153745 and #153746) also showed high site fidelity after the spawning season (Fig. 3), including one that remained in a known spawning location (tag #153746). Two fish tagged outside the spawning season and outside known spawning areas (tags #53656 and #53657) showed only short movements over 160 days into the spawning season.

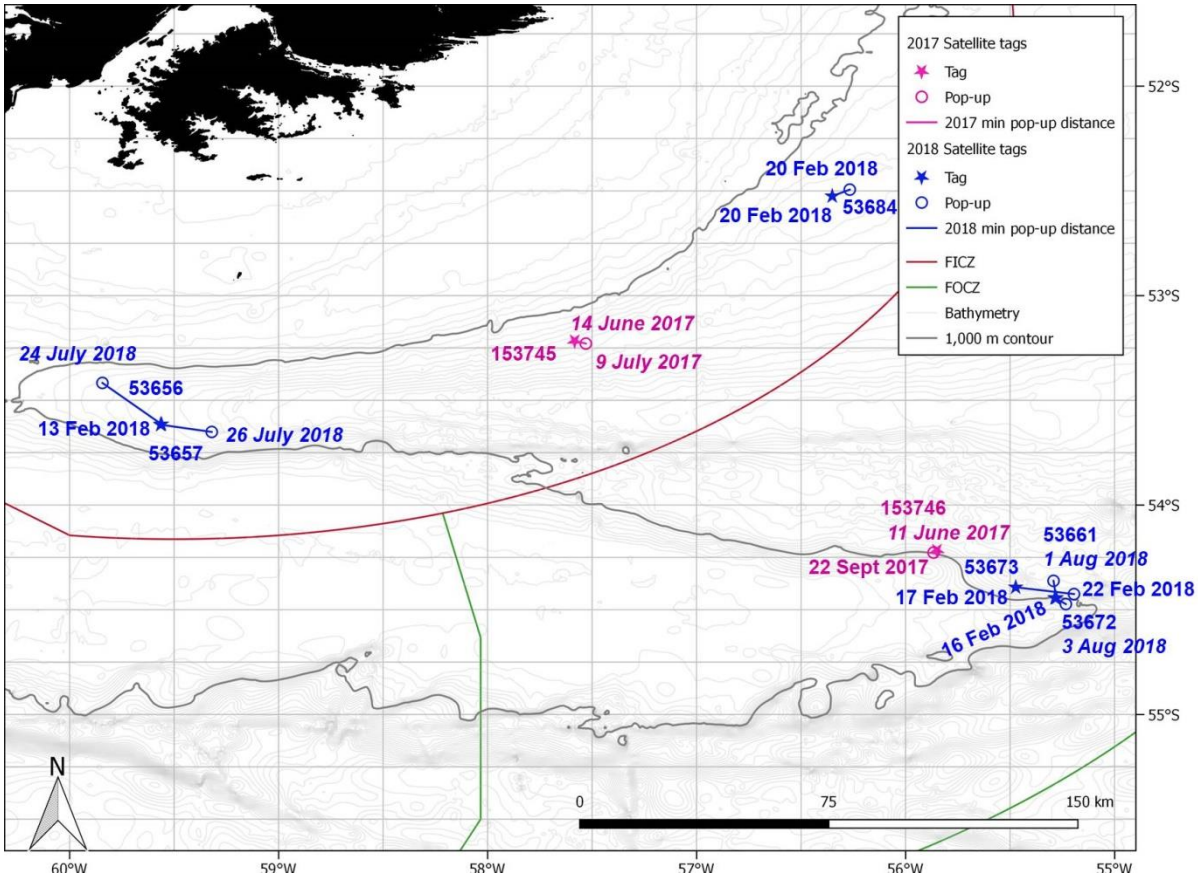

Figure 3. Tagging and pop-up location of tagged fish that travelled less than 30 km, including the two that prematurely popped-up and floated on the surface. The tag numbers, tagging dates and pop-up dates are shown. Dates in italic font are during the presumed spawning season.

Four tags popped up between 120 and 375 km from their tagging locations, two of which remained within the FICZ/FOCZ and two that moved over 300 km and ended up outside of the FICZ/FOCZ (Fig. 4). Three of these four fish moved towards Burdwood Bank, either along its northern slope to the eastern edge (tag #53659) or to its western edge (tags

#53658 and 53678 two tagged). By contrast, one fish tagged during the spawning season in the northern part of the FICZ/FOCZ made a large movement towards the northwest (tag #153748).

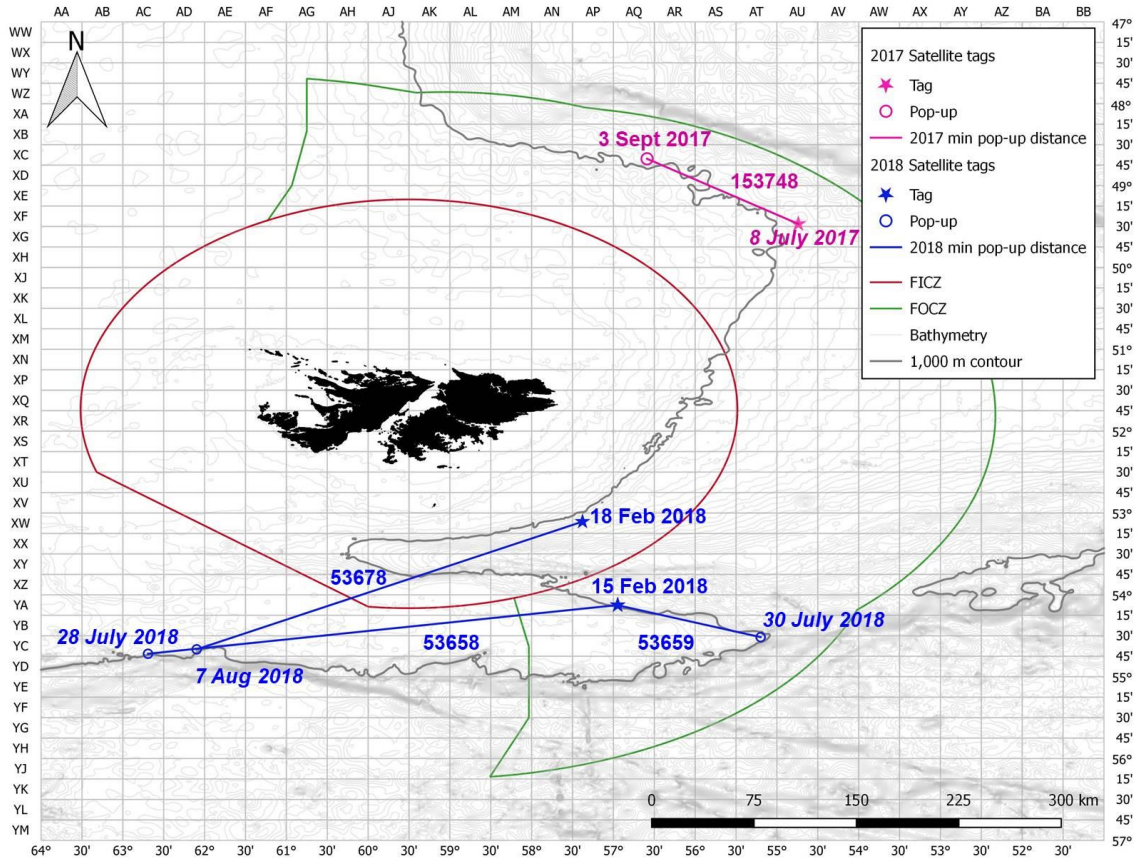

Figure 4. Tagging and pop-up location of tagged fish that travelled more than 100 km. The tag number, tagging date and pop-up date are shown. Dates in italic font are during the presumed spawning season.

The minimum pop-up distance of the two fish that travelled over 300 km (tags #53658 and #53678) is likely an underestimation. In order to have travelled only 349 and 378 km, these two tags would have had to travel straight across the top of Burdwood Bank (Fig. 4), bringing them to depths of 200 m, a very unlikely situation for toothfish of these sizes. For example, none of the fish tagged in this study or in the study by Brown et al. (2013) moved to depths shallower than 800 m, and over 90% of their time was spent in depths of 1,000 m or more. These two fish also likely did not travel to their final location in an anti-clockwise direction travelling west along the north edge of Burdwood Bank. This itinerary would have still forced them to move to depths shallower than 400 m. Much more likely is that these toothfish travelled in a clockwise direction from their tagging location, moving to the eastern edge of Burdwood, before going west along the southern slope of Burdwood Bank. This would have allowed them to reach the pop-up location while staying below 800 m at all times (Fig 4). If this is the case, both of these fish would have moved over 700 km.

In addition to the distance travelled, the overall direction of the tagged fish differed between individuals. The overall directional bearing between tag and pop-up locations show that the longest movements were made in a generally western direction (Fig. 5), though one movement of 120 km was made in a south-eastern direction. Interestingly, no tagged fish

moved in a generally north-eastern direction (Fig. 2), which is the direction of the prevailing ocean currents.

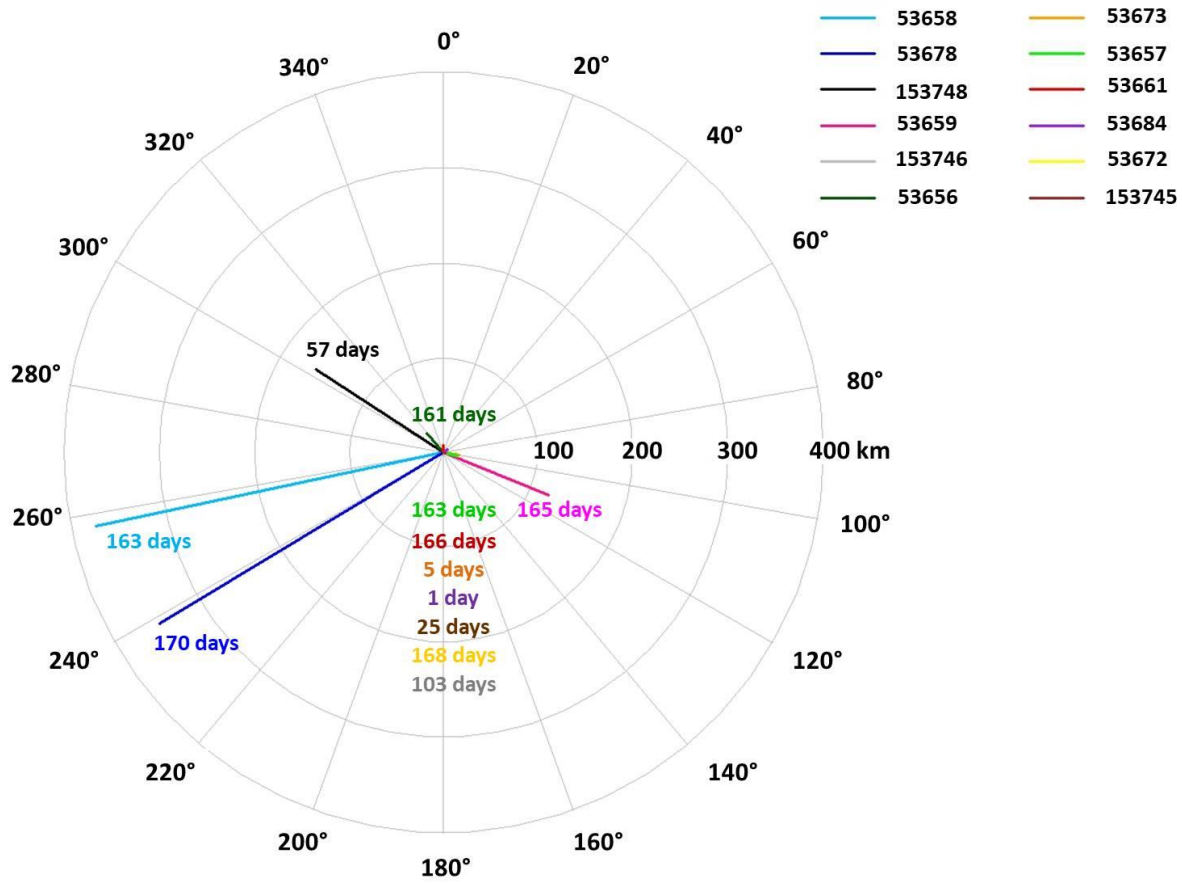

Figure 5. Radar plot of the bearings and distances between tagging and pop-up locations for the twelve tags that reported. The direction of each line corresponds to the initial bearing (in degrees) of the tagged fish. The length of the line is proportional to the distance traveled (in km). Number of days the tags were at liberty is noted on the graph (colours corresponding to the legend).

Statistical analyses on the tag and pop-up locations showed no significant relationship in any of the parameters examined. Differences in the length of the fish tagged did not explain the variation in the total distance travelled ($F_{1,10}<0.01$, $p=0.98$), or the variation in the direction in which it swam ($F_{1,10}=1.4$, $p=0.26$). The amount of time the tag was attached on the fish also did not explain the total distance travelled ($F_{1,10}=1.37$, $p=0.27$) or the direction of the movement ($F_{1,10}=2.38$, $p=0.15$). The distance travelled was also not explained by the direction of the movement ($F_{1,10}=1.16$, $p=0.31$).

Once a satellite tag pops up, it transmits its location and archived data over a period of about a week. The transmitted archived data provided depth and temperature information for three tags deployed in 2017 (Fig. 6). All of the temperatures experienced by the tagged toothfish in 2017 were between 2.4 and 2.8°C (except at the very beginning and end of the deployment when the tag was traveling between the surface and bottom). This narrow temperature range is consistent with the temperatures at depth around the Falkland Islands.

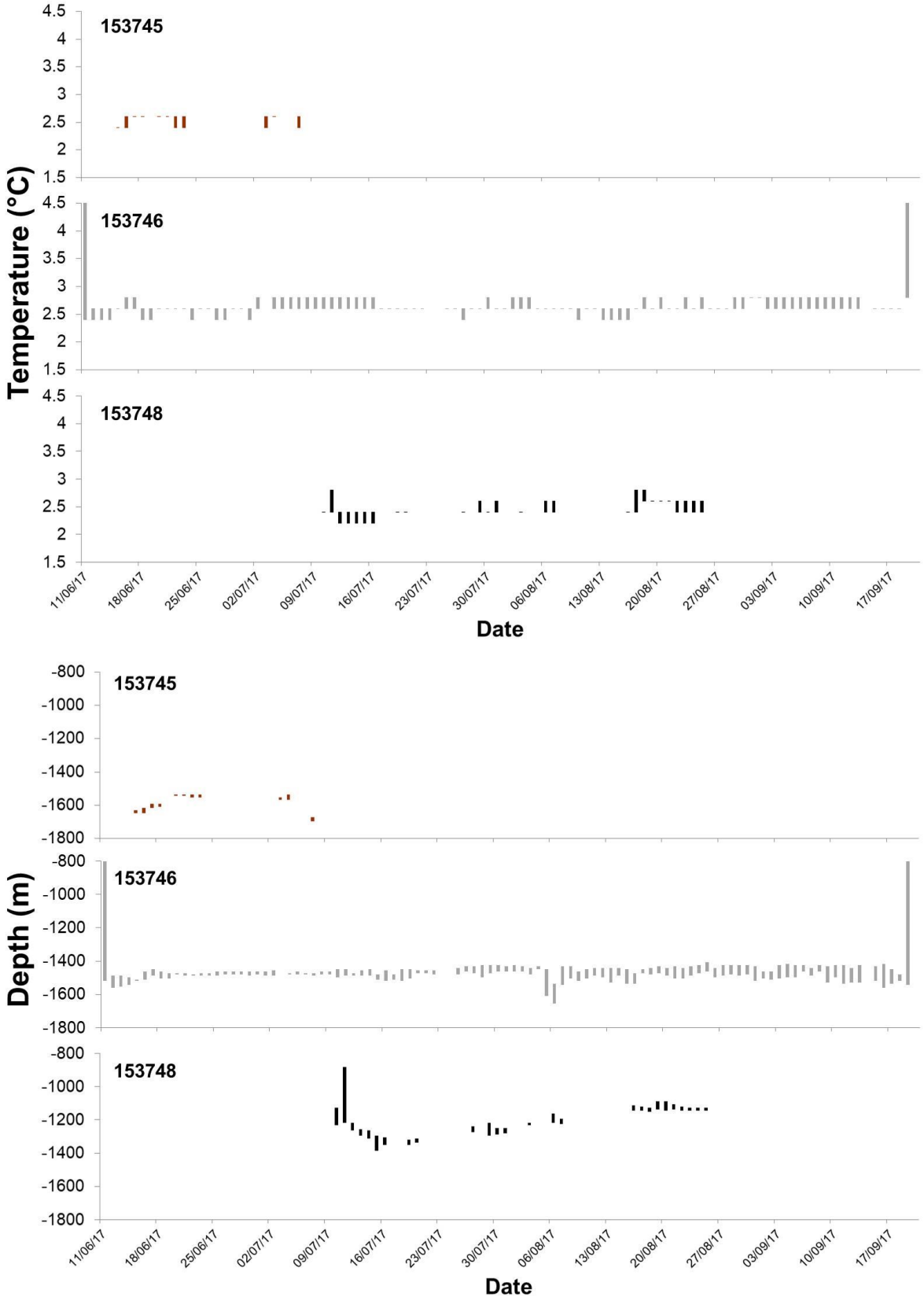

Figure 6. Temperature (top) and depth (bottom) occupancy of the 2017 tagged toothfish while at liberty. Ranges between daily minimum and maximum temperatures and depths shown for the duration of the deployments.

Depth readings from the three 2017 tags showed that the tagged toothfish spent the majority of their time below 1,000 m depth. One fish (tag #153745) seemed to remain around 1,600 m depth, one fish (tag #153746) around 1,500 m, and one fish (tag #153748) around 1,200 m (Fig. 6). One notable exception is tag #153748, which recorded a minimum depth of 880 m on 11 July, 2017. The associated maximum depth on that day was 1,216 m, in line with the maximum depths recorded before and after that day. Therefore, it does not seem that this toothfish relocated to a shallower depth for that whole day, but simply made an excursion to shallower water layers for less than 24 hours. This behaviour may indicate a period of spawning soon after the fish was tagged and released. It was also associated with a slight increase in temperature to a maximum of 2.8°C whereas other days before and after had a maximum of 2.4°C.

For the tags deployed in 2018, only temperature information was available, for the last 100 days at liberty. These toothfish experienced temperatures between 2 and 4.5°C (Fig. 7), although it is important to note that the temperature sensors on these tags had a resolution of 0.5°C. Nevertheless, these toothfish seem to have experienced warmer temperatures than those tagged in 2017, possibly due to seasonal differences in deployment. Unfortunately, the tags deployed in 2018 did not have depth sensors on them, but it is possible that the increases in temperatures were associated with decreases in depth, as was seen on tag #153748. In that case, tagged fish could have made several excursions to shallower, warmer waters, especially during the spawning season in June, July and August (Fig. 7).

Conclusions

PSAT tagging was successful and provided valuable fishery-independent data on movement patterns and habitat occupancy of toothfish around the Falkland Islands. Although the majority of toothfish seem to have high site fidelity, we also found evidence of long range (over 100 km) movements both within the FICZ/FOCZ and out of the FICZ/FOCZ. Many of these movements seem to be associated with the spawning seasons and locations.

When the information obtained from this study is added to the previous PSAT tagging effort by Brown et al. (2013), the coverage of PSAT tagging across the zone is fairly extensive (Fig. 8). Two areas of the FICZ/FOCZ still require some tagging effort: the very north of the zone (north of 50°S, and west of 57°W) and straight east of the Falkland Islands (between 51°S and 53°S). These two areas may be of particular interest because none of the satellite tagging so far has found toothfish moving across the 53°S latitude line (this study, Brown et al, 2013, Randhawa et al., 2017). Of the over 2,600 toothfish tagged so far with conventional tags, only one was found to move across the 53°C latitude. Therefore movement across this latitude seems to be quite rare, and as Burdwood Bank is a known spawning area south of that latitude, we suggest that there could be another spawning area in the north as well. Further PSAT tagging could potentially indicate the general area of this spawning area.

It is therefore recommended that tagging efforts on toothfish continue, both with conventional and PSAT tags. For PSAT tags, we recommend tagging toothfish in the two areas mentioned above, during non-spawning times with tags that will pop up around during the spawning season (July-August). PSAT tags with depth sensors on them would be particularly useful as spawning in toothfish is suggested to be associated with short-term vertical movements (Brown et al., 2013).

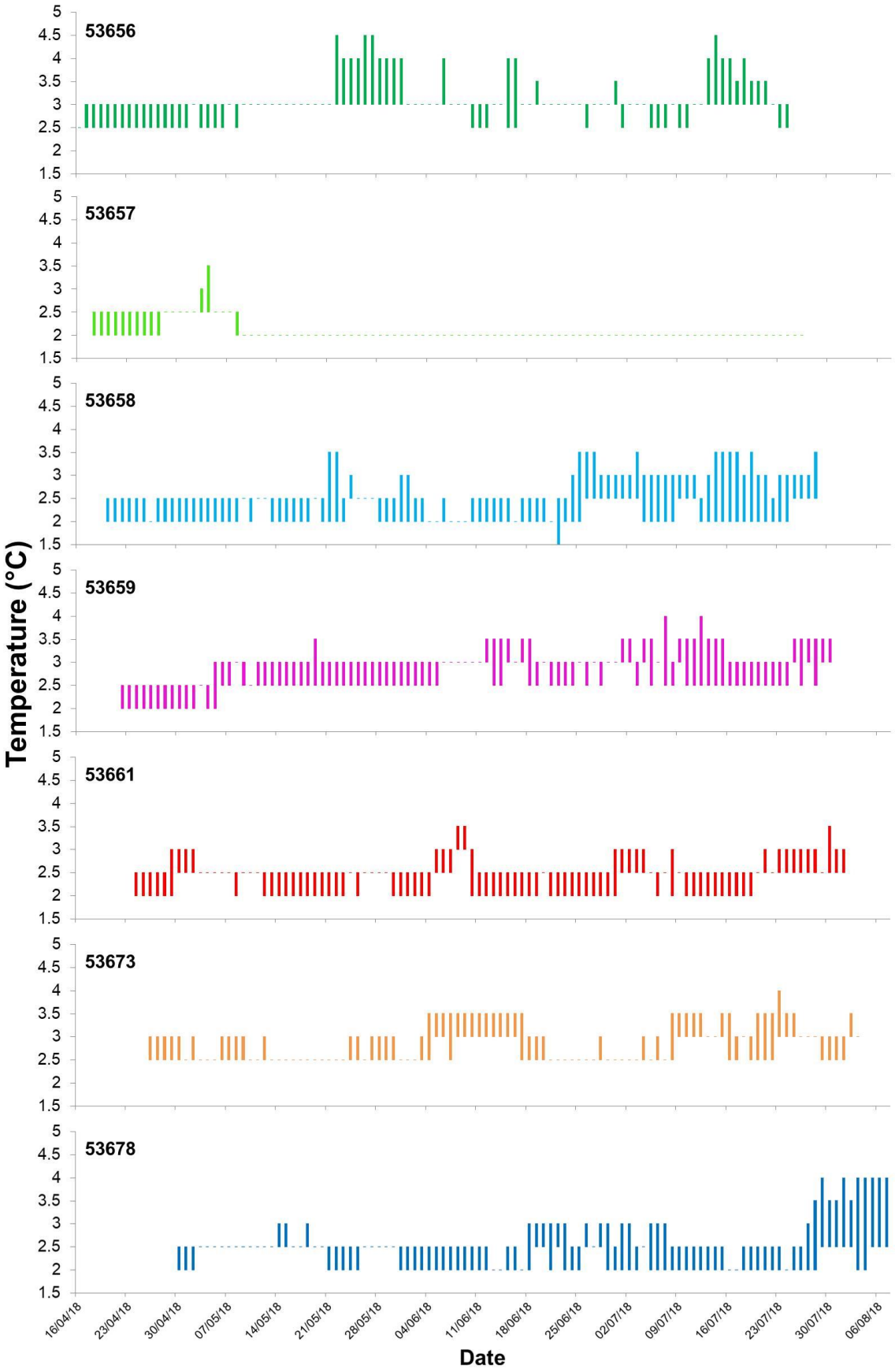

Figure 7. Temperature occupancy of the 2018 tagged toothfish while at liberty. Ranges between daily minimum and maximum temperatures shown for the 100 days before pop-up.

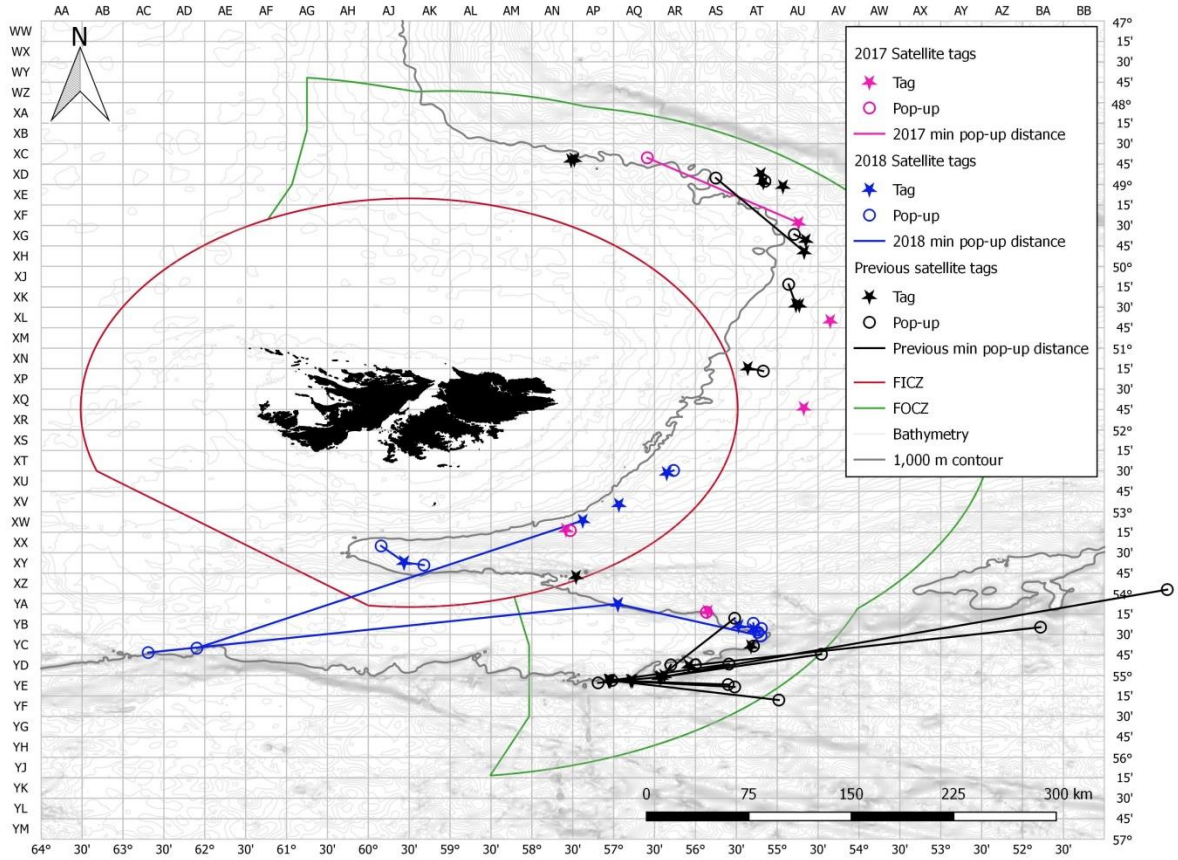

Figure 8. Tag and recapture locations of all PSAT tags deployed so far in the FICZ/FOCZ.

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