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EXECUTIVE SUMMARY

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The aim of this project is to electronically track swordfish (*Xiphias gladius*) captured within New Zealand waters, and to collect data coinciding with their expected subtropical spawning period and subsequent return to temperate waters.

Nineteen pop-off satellite archival transmitting tags (PAT) (Wildlife Computers, Redmond, WA, USA) were deployed on swordfish. Tags were programmed to record data between 66 and 246 days, and 10 tags provided 66–236 days of data. The attachment failed on 5 tags which caused them to transmit prematurely, two mortalities occurred soon after tag and release, and two tags didn't report data back. Two different styles of plastic anchors were used, with the Prince/Musyl nylon anchor providing notably better results.

The crepuscular diving behaviour of swordfish makes estimating geolocation using dawn and dusk light level changes problematic. Geolocations have been estimated by using the SST Kalman filter on data transmitted from 10 tags. These tags yielded between 8 and 37 usable light-level geolocations each, plus the tagging and popup coordinates, giving a total of 251 locations from a combined deployment of 1603 days. On average there are 4.7 locations per month from these tags. To date, the results indicate that the newest generation of Wildlife Computers PAT tags are capable of providing data to track the movement of swordfish. From the small sample size we have at present, it appears to be that fish tagged north of New Zealand came back down the west coast. Fish tagged to the east and northeast returned to those areas or came down the east coast. This may warrant further investigation. There is evidence of foraging site fidelity in New Zealand waters. All tracks plotted show fish leaving the New Zealand region usually to the north and returning to New Zealand. This includes the smaller fish (56 to 80 kg) which may not be sexually mature if female.

1. INTRODUCTION

Commercial catches of swordfish in New Zealand and Australian waters increased rapidly in the 1990s, and catches on the high seas in the southwest Pacific Ocean have expanded at the same time. Experience in the Mediterranean, Atlantic, and North Pacific has shown swordfish stocks to be susceptible to overfishing, and in recent years catch rates and the mean fish size have declined substantially in the southwestern Pacific (Kolody et al. 2006a). As a result of growing concerns regarding the sustainability of this stock and the possibility of local depletion (Davies et al. 2006) an assessment was undertaken to determine the exploitation levels in the region (Davies et al. 2006, Kolody et al. 2006a). However, at the time of the assessment no spatially discrete movement patterns for swordfish were available.

Genetic research using mitochondrial DNA has suggested that there is population heterogeneity in the Pacific, and a separate southwest Pacific stock of swordfish may exist (Reeb et. al. 2000) but little is known about their movement patterns. An understanding of substock structure in the southwest Pacific region is required if this highly migratory species is to be effectively managed.

Data from tagging studies (both conventional and pop-up) can be particularly informative when interpreting CPUE trends and genetic studies (gene flow). Return rates for billfish in mark-recapture programmes are typically about 1%. Large numbers of swordfish would need to be tagged and released using conventional tags to obtain sufficient data on movements. Pop-up satellite archival tags are fishery independent, meaning human intervention is not needed to recover their data. Researchers predetermine data acquisition and transmission parameters before deployment on animals, and the data are automatically recovered via satellite uplinks, thus removing reliance on recapture and tag returns to provide data to researchers.

Two recaptures of conventionally tagged fish have been made from the New Zealand cooperative tagging programme. The first was a 12 kg fish tagged from a Japanese longline vessel 129 nautical miles north of New Zealand in June 1991. It was recaptured in February 2002 just to the west of Wanganella Bank and was estimated to be 160 kg whole weight and 205 cm long. It was caught 250 nautical miles to the west of its release location after 10 years 8 months at liberty. The second swordfish was tagged off eastern New Zealand in February 1996 and was estimated at 20 kg. It was recaptured 8 years 4 months later 113 nautical miles south of its release point. It was estimated to have grown 70 kg during this time. In order to gain information on seasonal movement for adult swordfish, fishery independent technologies such as pop-off satellite tags are likely to provide more information, and in a more timely manner, than conventional tags.

This project aims to investigate seasonal movement patterns and the stock structure of swordfish (*Xiphias gladius*) taken in New Zealand fisheries using electronic tagging technologies.

2. OBJECTIVES

Overall objective

To determine the stock structure of swordfish (*Xiphias gladius*) taken in New Zealand fisheries.

Specific objective

To determine the stock structure of swordfish (*Xiphias gladius*) taken in New Zealand fisheries using electronic tagging technologies.

3. METHODS

Tags

Pop-off satellite archival transmitting (PAT) tags developed and sold by Wildlife Computers (Redmond, WA, USA) were purchased in mid 2006. These tags use the MK-10 generation of hardware and firmware architectures. The tags have four sensors for temperature, pressure, light intensity, and conductivity and they are rated to operate at depths down to 1800 m. Further information about the dimensions and other tag characteristics where given by Sippel (2006).

Tag and release programming

The PAT tags sample and archive temperature, depth, and light level every 20 seconds and summarise these data into two 12 hour bins each day (6 am to 6 pm NZST). Having fewer time bins increases the probability of receiving a high proportion of data for each day. For each 12 hour time bin there are 14 temperature bins, most with 2^{o} C increments and 14 depth bins as detailed in Table 1.

PAT tags have several fail-safe mechanisms, including detection of animal mortality and failure of the tag’s attachment. Tags at constant depths for long periods suggest of animal mortality. Tags at the surface for long periods are indicative of attachment failure, as the positively buoyant tags to float at the ocean’s surface. Tag software was configured to activate fail-safe procedures after 72 continuous hours at constant depth, triggering release of the tether and transmission. A mechanical guillotine which was designed to sever the attachment tether at depths deeper than 1800m (the expected maximum depth of tag operation) was included on the rigging of some tags to prevent destruction of the tag in the event of mortality or animal behaviour which would disable the tag.

The project design supplied to the New Zealand Ministry of Fisheries (MFish) suggested a range of deployment times between 4 and 8 months. These deployment times were shortened part way though the project following information from Heidi Dewer (US National Marine Fisheries Service (NMFS)) that there was a high rate of non-reporting with tag deployment durations of 6 months or more. The possibility of tag malfunction is being investigated in the USA.

Table 1. Temperature and depth bins used in swordfish PAT tags.

Bin	Depth (m)	Temp (^{o}C)
1	-40 to -1.5	0 to 4
2	-1.5 to 1	4.1 to 6
3	1.5 to 5	6.1 to 8
4	5.5 to 15	8.1 to 10
5	15.5 to 50	10.1 to 12
6	50.5 to 100	12.1 to 14
7	100.5 to 200	14.1 to 16
8	200.5 to 300	16.1 to 18
9	300.5 to 400	18.1 to 20
10	400.5 to 500	20.1 to 22
11	500.5 to 600	22.1 to 24
12	600.5 to 700	24.1 to 26
13	700.5 to 800	26.1 to 28
14	>800	28.1 to 60

Tag rigging

The first three tags deployed were rigged with the black plastic tag anchor supplied by Michael Domeier (Pfleger Institute of Environmental Research) with a 25 cm nylon tether (180 kg breaking strain) and stainless steel crimps. Shortly after tagging began, hydroscopic nylon tag heads and the nylon floppers were supplied by Michael Musyl (University of Hawaii) and Eric Prince (NMFS – Miami). These were assembled and used on all other tags. Shrink wrap tubing, printed with a return message and tag ID number (e.g. SWO06-01), was used to cover the trace and crimps. The tag ID numbers do not relate to release order.

Tagging swordfish

Of the 19 tags purchased for this programme, 12 were deployed in 2006 from surface longline vessels northeast of New Zealand between 8 July 2006 and 7 November 2006. Blue Water Marine Research personnel undertook two trips tagging six fish and developed a tagging procedure for MFish scientific observers to use when deploying the remaining tags. For various reasons there were few trips by observers on surface longline vessels in 2007 and only one fish was tagged that year. Five tags were deployed in July and August 2008 and the final tag in September 2009 (Table 2).

Data analysis

The crepuscular diving behaviour typically displayed by swordfish can significantly impair use of light level data, periodically precluding the determination of dawn-dusk periods critical to light-level geolocation. This has been a problem with tracking PAT tagged swordfish in other programmes (Heidi Dewar, NMFS, pers. comm.) and other crepuscular divers such as bigeye tuna and bigeye thresher sharks. Light level geolocations were extracted from PAT records using proprietary software provided by the manufacturer of the tags (Wildlife Computers) which use the dawn and dusk symmetry method, as described by Hill (1994) and Hill & Braun (2001). These location estimates, along with sea surface temperatures simultaneously recorded by the tags, were used as inputs into a state-space Kalman filter (Nielsen et al. 2006) for refinement of error prone raw light-level based estimates. Satellite derived SST data averaged over 3 days (AVHRR-GAC 3 day, 0.1 x 0.1º resolution) were used to cross-reference against tag SSTs for geolocation refinement. Kalman filter model 'kfsst' (Nielsen et al. 2006) was used through 2007. Analysis done in 2008 and 2009 was conducted using 'ukfsst' (Lam et al. 2008). Parameters used in both models included:

- Fix.first=TRUE # Deployment location known with certainty
- Fix.last=TRUE # Pop-off location known with certainty at time of first transmission. No allowance was made for possible drift of tags which released from fish prematurely.
- bsst.active = FALSE # SST bias estimator deactivated.

The kfsst programme also required selection of the degree of satellite SST data smoothing to use for cross-referencing. Three smoothing regimes (1%, 5%, 10%) were used on seven tags analysed during 2007. Different regimes produced results we felt were best on different tags. No single smoothing parameter was best for all tags. In the updated 'ukfsst' model SST smoothing is optimised by the model itself. Post-processing raw light-level geolocations through routines such as Kalman filters significantly improves confidence intervals on location estimates, particularly for latitudes which are subject to numerous sources of variation.

4. RESULTS

ARGOS satellite coverage varies with location. As a result, a satellite may be in range of any given transmitter for only a few minutes each hour, meaning that the amount of data likely to be recovered is difficult to predict. Tags transmit data randomly to maximise the amount of data received and minimise the amount duplicated. For a full description of PAT tag performance see Sippel (2006).

Data retrieved

Seventeen of the 19 tags uploaded data to satellites. Eight PAT tags reported on the programmed date. It appears that attachment failed on seven fish. These PAT tags remained at the surface for 72 hours before releasing their tether and commencing transmission. Two PAT tags reported early after the fish descended over 1800 m. In one the tether was severed by the depth activated release device causing the tag to float to the surface. It began transmitting 9.1 days after it was tagged, providing 6 days of data on the fish and three days of data while it drifted at the surface. The tag transmitted 83 km (45 n. miles) southeast from where it was tagged. It is assumed that this fish died and was sinking at the time the tag released. Two tags failed to transmit. These were two of the five tags programmed to stay on the fish for eight months, the longest deployments attempted.

The tags recorded between 3 and 236 days of data while attached to swordfish (Table 2). Most tags were deployed in winter/spring and successful tags popped-up in spring/summer (Figure 1).

Table 2. Deployment times achieved and distance and direction between release location and pop-off location. Two tags with no pop-off date did not transmit.

Fish Id	Estimated Weight kg	Release location	Pop-off date	Days data from fish	Displacement nmiles	Straight line direction
SWO06-01	60	Kermadec	21/11/2006	15.4	142	NNW
SWO06-02	160	Rumbles	21/07/2006	12.4	85	NE
SWO06-03	56	Rumbles	29/10/2006	111.6	455	NE
SWO06-04	84	Rumbles	30/07/2006	17.7	120	NE
SWO06-05	30	North Cape	13/08/2008	2.7	28	NE
SWO06-06	56	Kermadec	15/11/2006	66.1	100	N
SWO06-07	130	North Cape	15/01/2007	175.7	260	SW
SWO06-08	120	Rumbles	29/01/2009	209.4	1 105	NE
SWO06-09	90	North Cape	15/03/2007	234.7	430	W
SWO06-10	130	North Cape	No	0		
SWO06-11	56	Kermadec	14/02/2007	160.0	180	N
SWO06-12	37	North Cape	27/08/2008	15.5	372	N
SWO06-13	56	Kermadec	14/09/2006	9.1	45	SE
SWO06-14	100	North Cape	24/09/2009	21.2	355	N
SWO06-15	80	Kermadec	14/02/2007	105.3	267	S
SWO06-16	75	Rumbles	5/02/2009	209.4	369	SE
SWO06-17	130	North Cape	14/02/2008	203.1	128	W
SWO06-18	80	Rumbles	15/03/2007	127.7	545	SW
SWO06-19	110	North Cape	No	0		

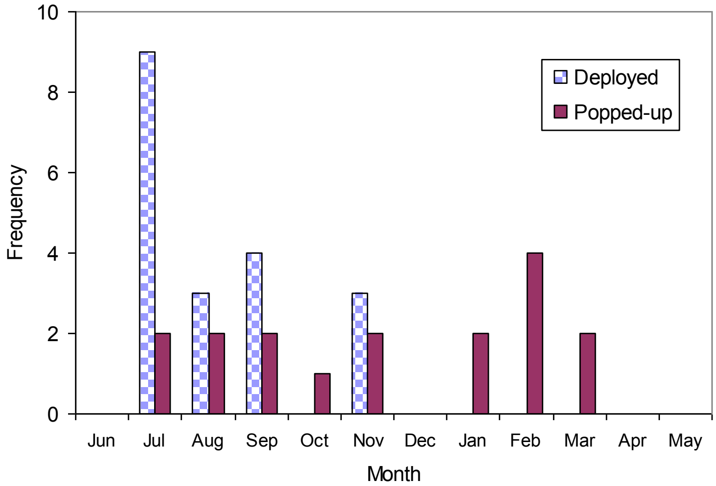

Figure 1: Number of tags deployed and popped-up by month.

The objectives of this project are to investigate movement of swordfish, particularly during and after the assumed spawning period. Off eastern Australia swordfish spawn from September to March with the greatest activity from December to February (Young et al. 2003). PAT tags have not been particularly effective at determining swordfish location from previous projects elsewhere in the Pacific. We were pleasantly surprised to get useful light level geolocation for all longer term deployments.

Geolocation

The short-term deployments (3 to 22 days) have not been analysed for tag derived geolocation estimates as displacement distance and direction (Table 2) give a reasonable estimate of their movement. Ten data sets ranging in duration from 66 to 236 days have been included in geolocation analysis. These tags yielded between 8 and 37 usable light level geolocations each, plus the tagging and pop-up coordinates giving a total of 251 locations. On average, 4.7 locations were obtained per month from these tags (individual tags range from 2.8 to 8.2 locations per month). Confidence intervals around these estimated geolocations are variable, thus some locations are of higher quality than others. The variable results are inherent to light-level geolocations due to the numerous sources of variance in data quality including animal behaviour, cloud cover, biofouling, time of year, true position, and the theoretical limitations of light level geolocation accuracy itself.

The southwest Pacific Ocean region is stratified into four subareas with a north, central, and southern zone in each for the stock assessment model (Kolody et al. 2008a, 2008b). The spatial disaggregation of the regional model aims to take account of consistencies in the seasonal spatio-temporal trends in catch rates in parts of the region, and the spatial distribution of domestic longline fisheries. In 2008 the area boundaries were simplified and qualitative movements from individual tagged fish were incorporated (Figure 2). Figures 3 to 12 show the most plausible tracks from the Kalman filter SST analysis for each fish. Apart from release and pop-off positions, these tracks should be viewed as providing general rather than accurate locations. Some observations from these 10 tracks are:

- fish were tagged in Zone 2C.
- fish moved north of 25^{o} S during the first section of there track.
- fish tagged east (Rumbles) and northeast (Kermadec) of New Zealand returned to areas north or east of New Zealand.
- three fish tagged just north of New Zealand (North Cape) tended to return to the west of New Zealand (Figures 5, 7 & 11).
- two fish returned to Zone 2C or 2S. One was in Zone 3C northeast of New Zealand in January and one was just in Zone 1C northwest of New Zealand in March (Figures 6 & 7).

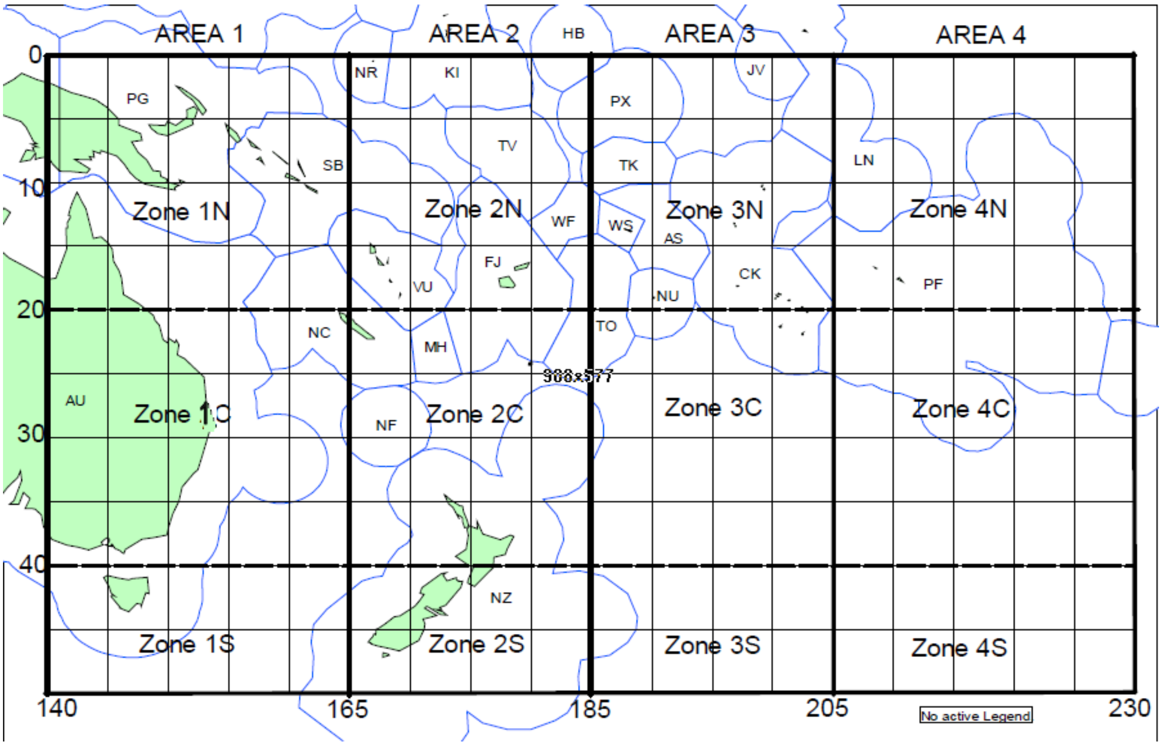

Figure 2: The subareas of the southwest Pacific used in the 2008 swordfish stock assessment models.

Combined tracks are overlaid on bathymetry in Figure 13. Most of the fish tagged east and northeast of New Zealand tended to associate with the Colville Lau Ridge which runs between New Zealand and Fiji. This association is confirmed by pop-off locations just to the west of the ridge by SWO06-06 in mid November and SWO06-11 in mid February (Figure 13). At latitude 22° S combined positions are spread east- west from longitudes166° E to 162° W, a distance of 3300 km (1780 n. miles).

The distribution of locations received from the 10 tracks plotted by month show dispersal away from New Zealand in August September and October (Figure 14). There were three fish tagged north east of the North Island in November and these fish moved north in December while fish tagged in July and August were heading south. The fish that retained there tags into January and February were heading south toward New Zealand or the central Tasman Sea.

Temperature and depth

The PAT tags transmitted quite complete records of binned temperature and depth data. These bins split the day roughly into day and night based on 6 am to 6 pm NZST. However, day length varies with season and latitude and there is a shift in the time of dawn and dusk as longitude changes. Most days these swordfish spent some time at night at or close to the surface, so the maximum daily temperature equates to SST. These data were used in the SST Kalman filter to help refine geolocation especially latitude.

The tags transmit data on the minimum and maximum depth, and six intermediate depths, in each time bin. At each of the eight depths there is a maximum and minimum temperature recorded in the Profile of Depth and Temperature table (PDT). The first set of temperature and depth plots records the maximum and minimum values in each 12 hour bin for fish tagged in July 2006 (Figures 15 and 16). The minimum night time depth was not plotted as it was almost always close to zero and it occasionally overlaid the daytime minimum. Similar plots were made for some of the fish tagged in September and November on a shorter (6 month) time scale (Figures 17 and 18).

Some observations made from these data are as follows.

- Swordfish maximum night time temperature was quite consistent from one day to the next and is useful as a measure of SST that can help calculate latitude.
- Initially SST rises as the fish move north and there is a corresponding increase in maximum depth and decrease in minimum temperature.
- Maximum day time depth and minimum temperature is quite consistent in most fish at 700 to 900 m and 6^o – 8 ^oC.
- Most swordfish (except SWO06-06) made occasional excursions to the surface during the day. This behaviour is more prevalent in larger fish. This may be the "basking" behaviour described from swordfish PAT data off California (Dewar & Polovina 2005).
- Time at the surface during the day during July and early August may be due to dawn coming after 6 am (i.e., it was still dark and some fish were near the surface still).
- SWO06-09 had a period of surface behaviour in September and October. This is time that the fish was further east and dusk would have been before 6 pm NZST.
- No clear reductions in daytime maximum depth are seen when the fish are in the warmest waters when they could be engaged in spawning.
- Recovery of a tag with its detailed archive of data would greatly assist identification of spawning behaviour. There is a NZ$200 reward for returning one of these PAT tags.
- One tag has been recovered near Noosa, Queensland, Australia, but it was from a fish that lost its tag shortly after tagging. No data have been recovered.

5. CONCLUSIONS

Accessing 19 live swordfish of a suitable size for tagging in 2006 was always going to be a challenge. It has taken two years longer than anticipated.

The new nylon tag anchors developed by Musyl, West and Prince performed well considering these fish were tagged over the side of the boat in difficult conditions at times. The results to date indicate that the newest generation of Wildlife Computers PAT tags are capable of providing data to track the movement of swordfish.

Consistent crepuscular diving behaviour makes estimating geolocation from light levels problematic. These swordfish regularly spend most daylight hours below 600 m and this depth increased at lower latitudes where water temperature and water clarity are higher. Activity near the surface at night provides a measure of SST that can help calculate latitude.

From the small sample size we have at present there appears to be a different pattern of movement for fish tagged north of New Zealand from those tagged to the east and northeast. This may warrant further investigation. Four fish spent some time outside Area 2. Two went east into Area 3, one went west into Area 1 and one fish spent time in Areas 1, 2, and 3. There is evidence of foraging site fidelity in New Zealand waters. All tracks plotted show fish moving well north of the New Zealand region and all but two fish returned to Zone 2C or 2S. One was in Zone 3C northeast of New Zealand in January and one was just in Zone 1C northwest of New Zealand in March. This includes the smaller fish (56 – 80 kg) which may not be sexually mature if female.

Some of data were available from the swordfish tagging Australia at the time of the 2006 southwest Pacific swordfish stock assessment models as reported to the Western and Central Pacific Fisheries Commission (Kolody et al. 2006a, 2006b, Davies et al. 2006). Satellite tag data from this project were used when re-assessing the model boundaries and for the 2008 stock assessments (Davies et al. 2008, Kolody et al. 2008a, 2008b).

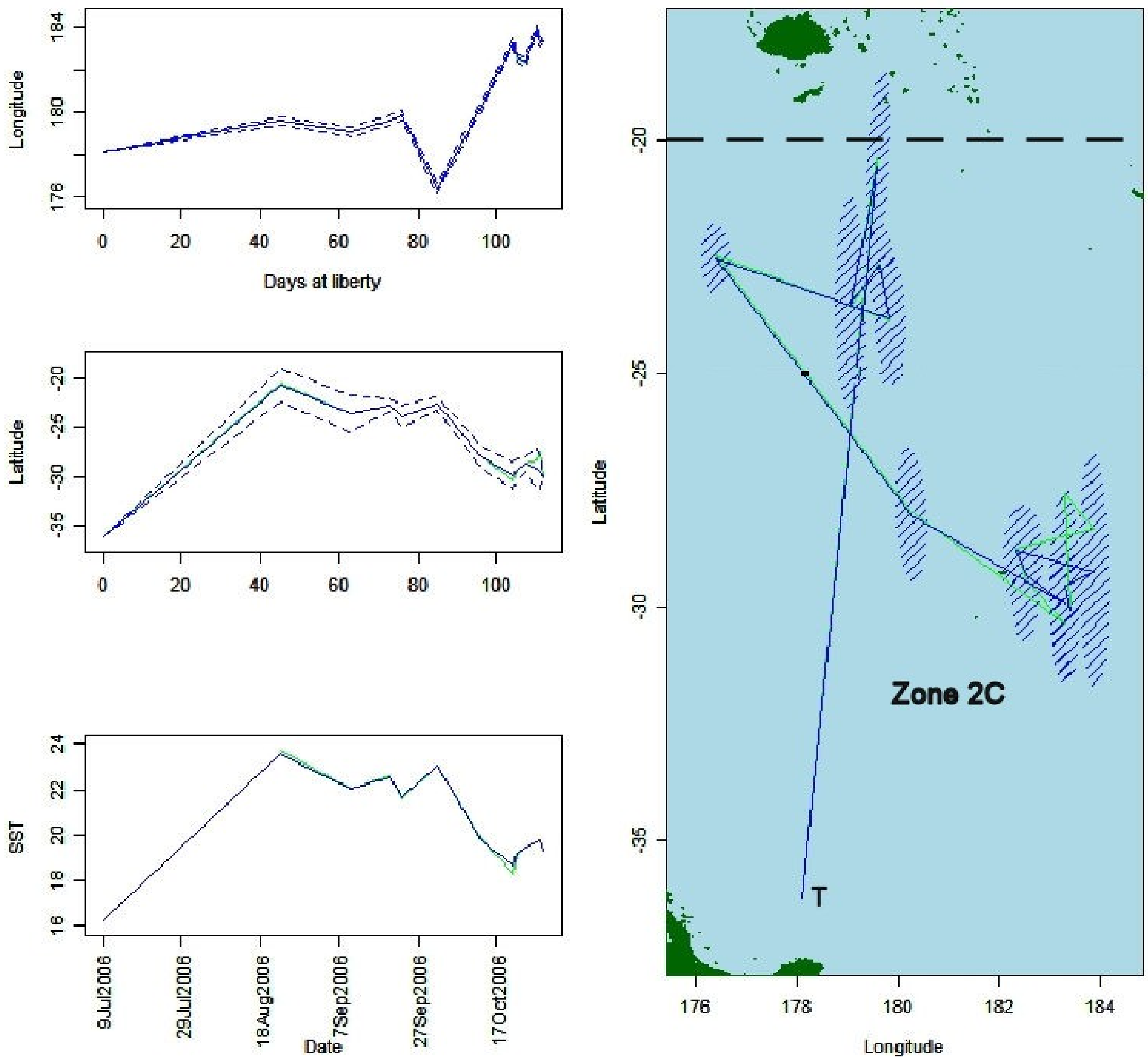

Figure 3: SST Kalman filter plot from SWO06-03 light level geolocation data, tagging location (T) and boundaries of sub-areas used in the stock assessment model marked. A 56 kg fish tagged 09-07-2006 pop-off 29-10-2006.

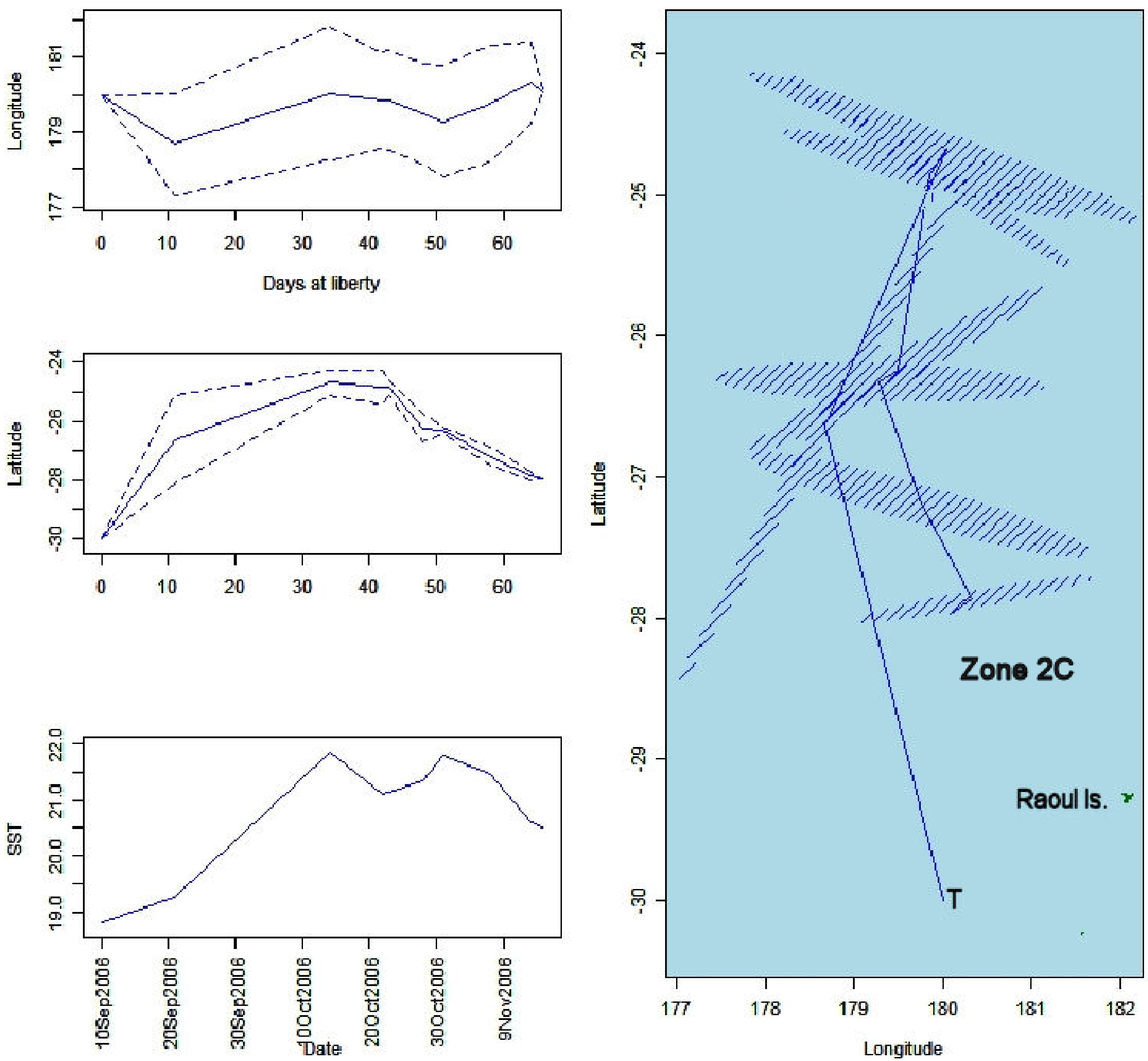

Figure 4: SST Kalman filter plot from SWO06-06 light level geolocation data, tagging location (T) and boundaries of sub-areas used in the stock assessment model marked. A 56 kg fish tagged 10-09-2006 pop-off 15-11-2006.

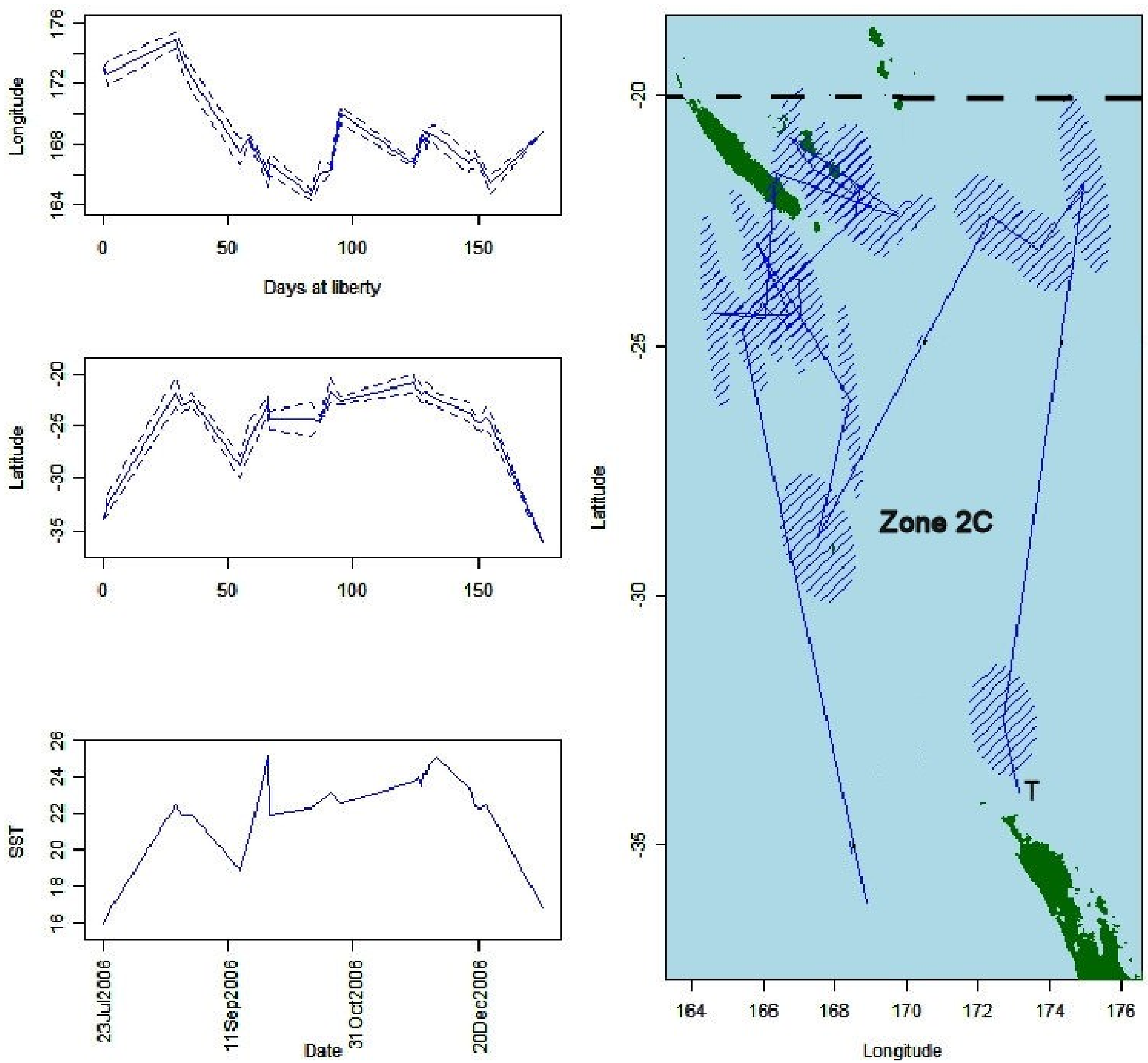

Figure 5: SST Kalman filter plot from SWO06-07 light level geolocation data, tagging location (T) and boundaries of sub-areas used in the stock assessment model marked. A 130 kg fish tagged 23-07-2006 pop-off 15-01-2007.

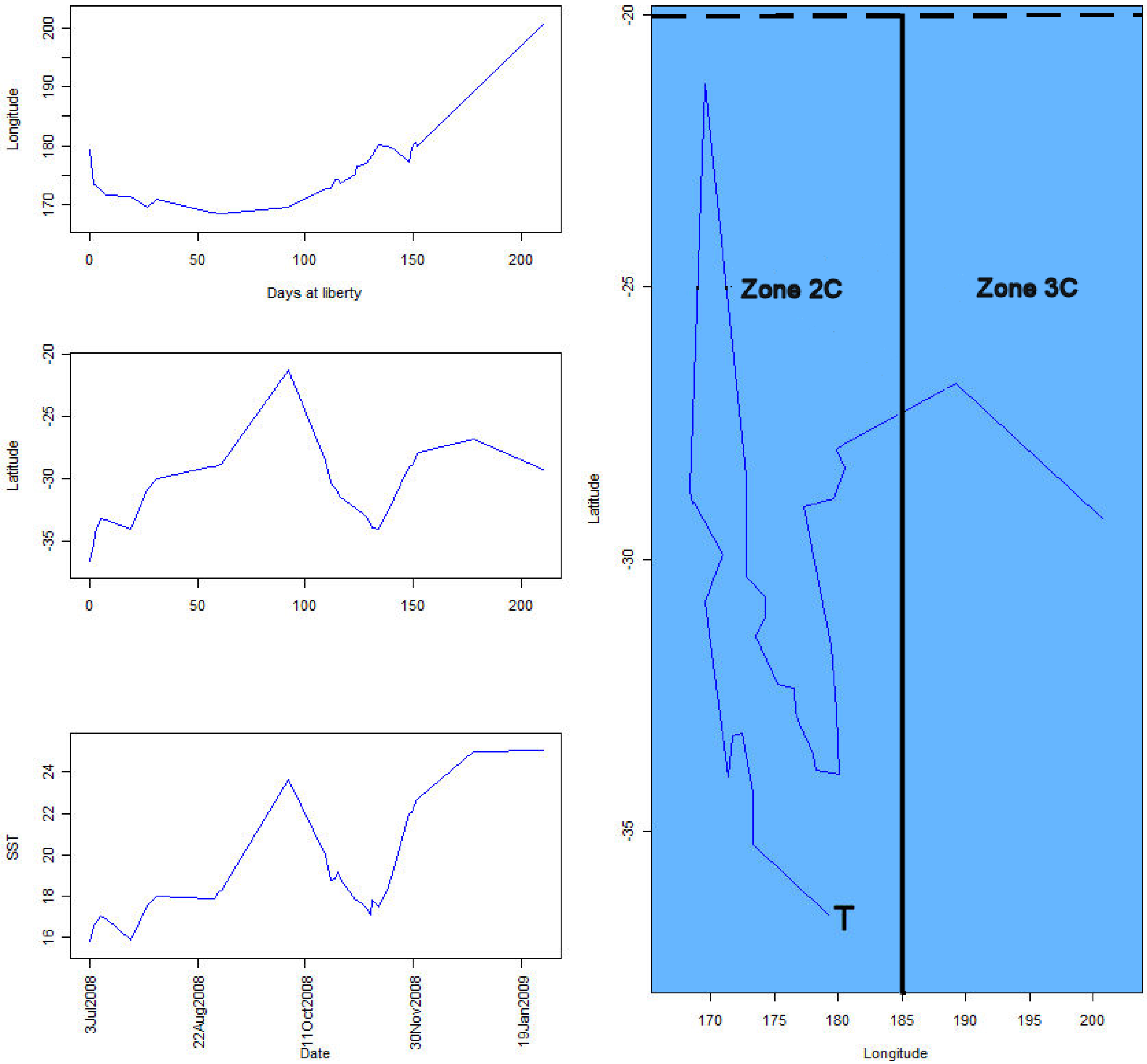

Figure 6: SST Kalman filter plot from SWO06-08 light level geolocation data, tagging location (T) and boundaries of sub-areas used in the stock assessment model marked. A 120 kg fish tagged 03-07-2008 pop-off 29-01-2009.

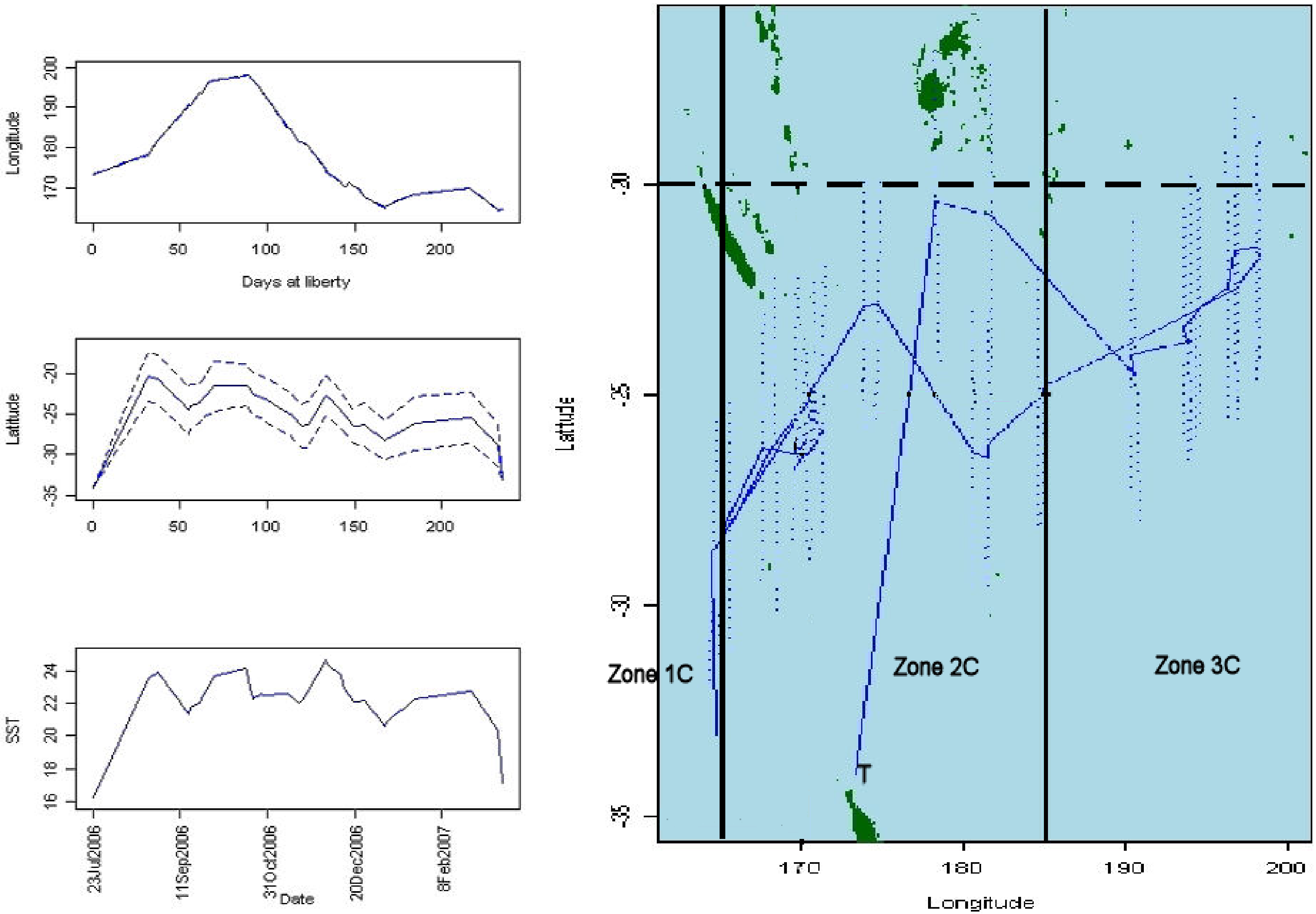

Figure 7: SST Kalman filter plot from SWO06-09 light level geolocation data, tagging location (T) and boundaries of stock assessment sub-areas marked. A 90 kg fish tagged 23-07-2006 pop-off 15-03-2007.

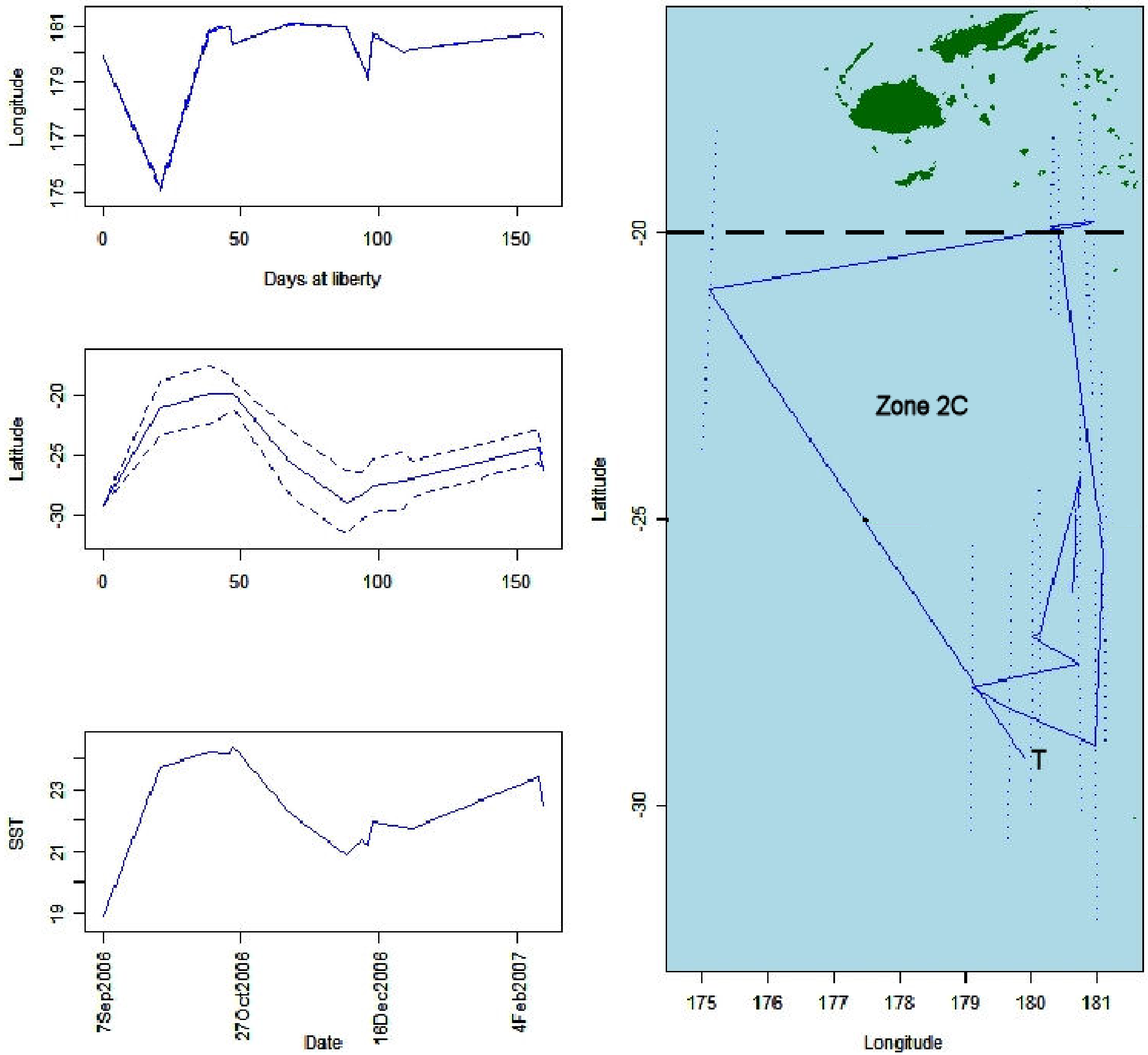

Figure 8: SST Kalman filter plot from SWO06-11 light level geolocation data, tagging location (T) and boundaries of sub-areas used in the stock assessment model marked. A 56 kg fish tagged 07-09-2006 pop-off 14-02-2007.

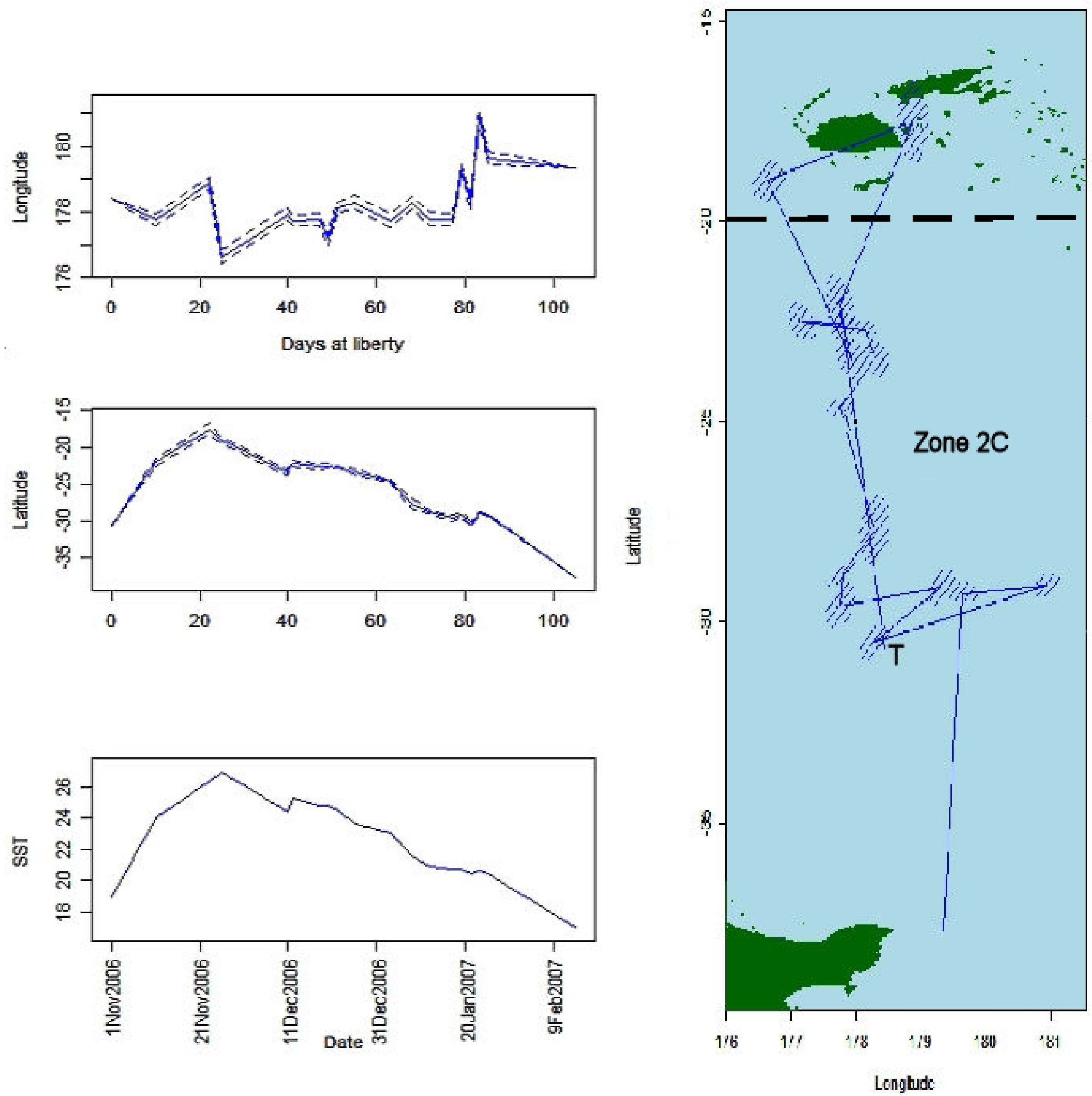

Figure 9: SST Kalman filter plot from SWO06-15 light level geolocation data, tagging location (T) and boundaries of sub-areas used in the stock assessment model marked.
An 80 kg fish tagged 01-11-2006 pop-off 14-02-2007.

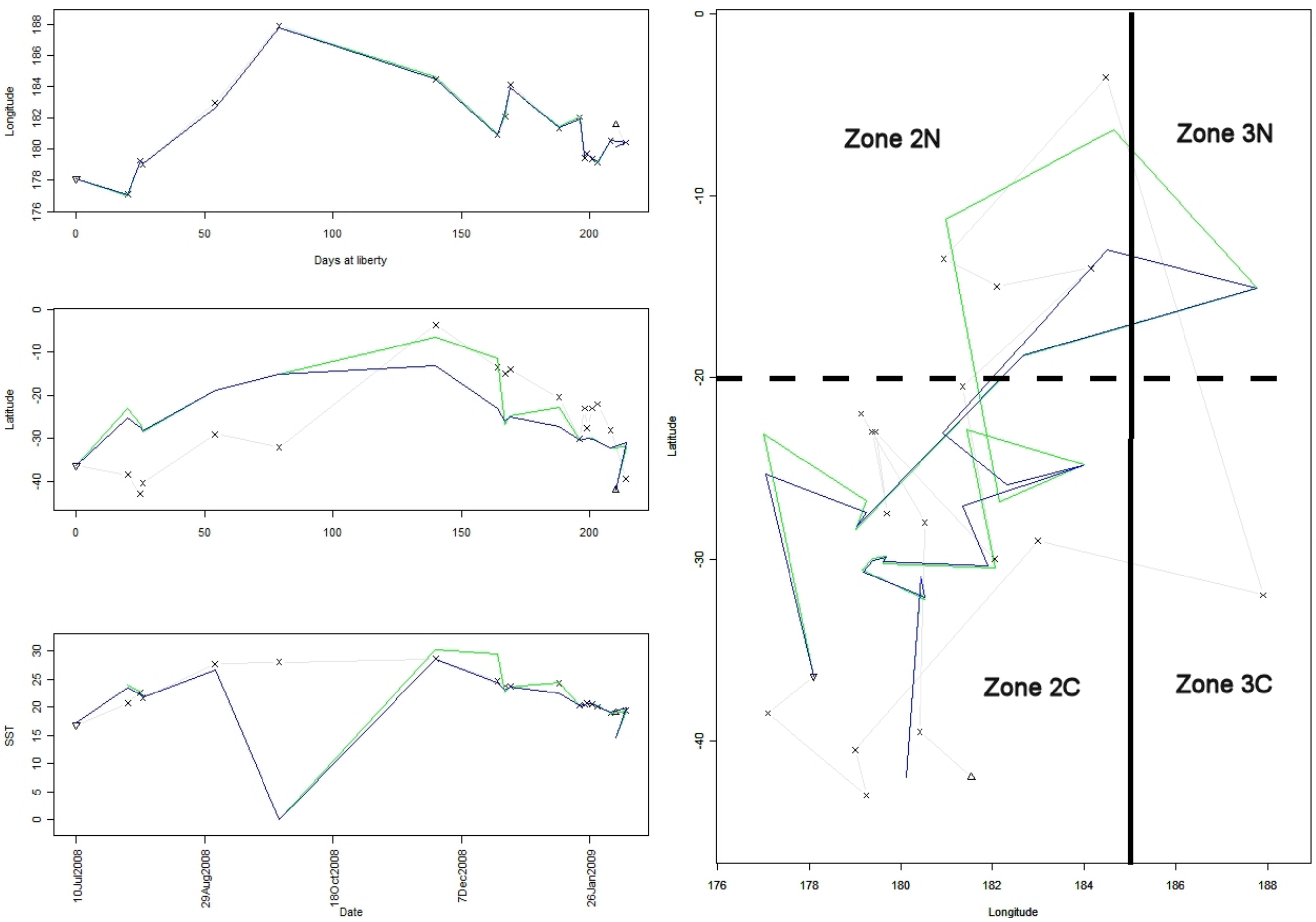

Figure 10: SST Kalman filter plot from SWO06-16 light level geolocation data, tagging location (T) and boundaries of sub-areas used in the stock assessment model marked. A 75kg fish tagged 01-11-2006 pop-off 14-02-2007

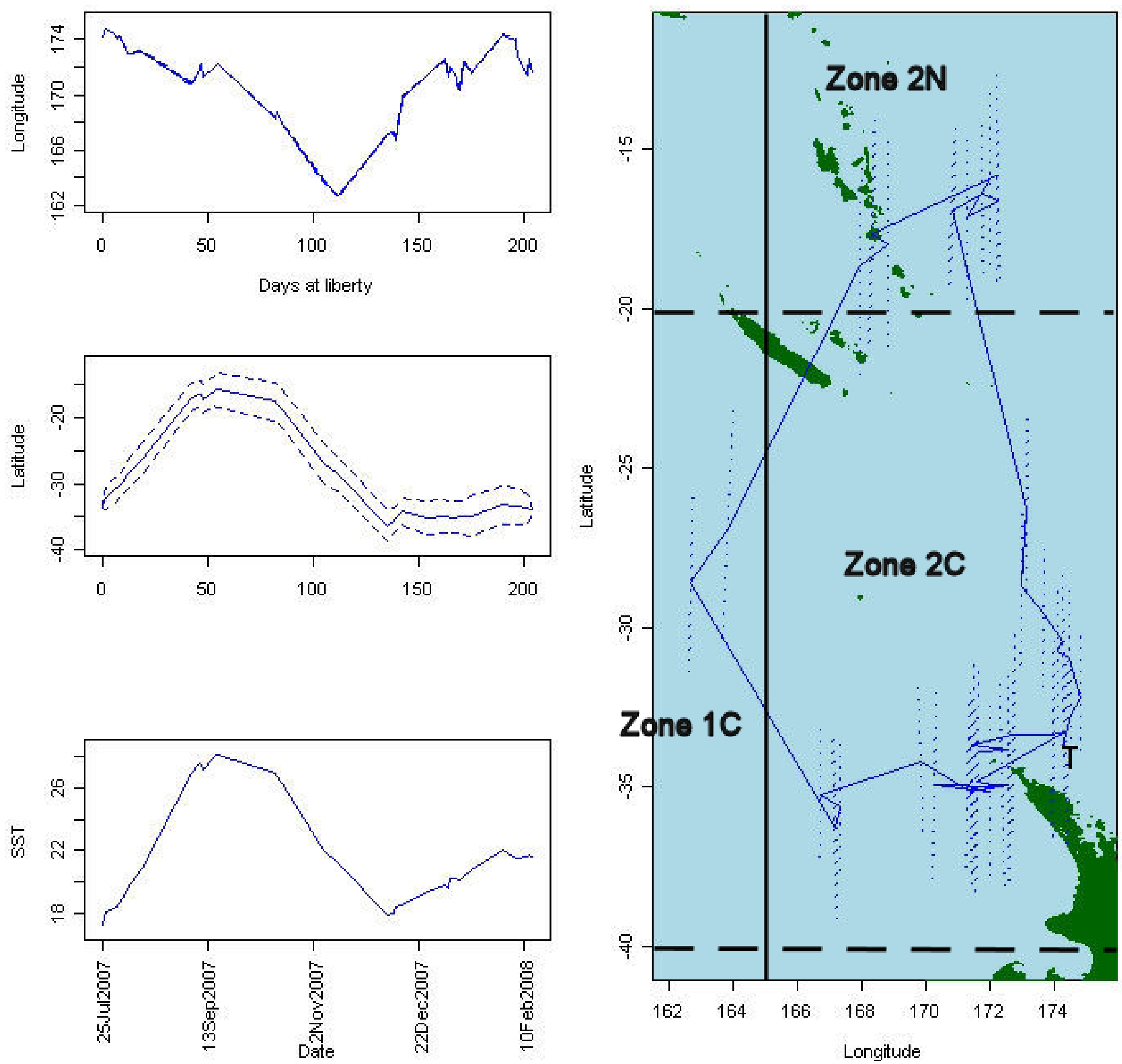

Figure 11: SST Kalman filter plot from SWO06-17 light level geolocation data, tagging location (T) and boundaries of sub-areas used in the stock assessment model marked. A 130 kg fish tagged 25-07-2007 pop- off 14-02-08.

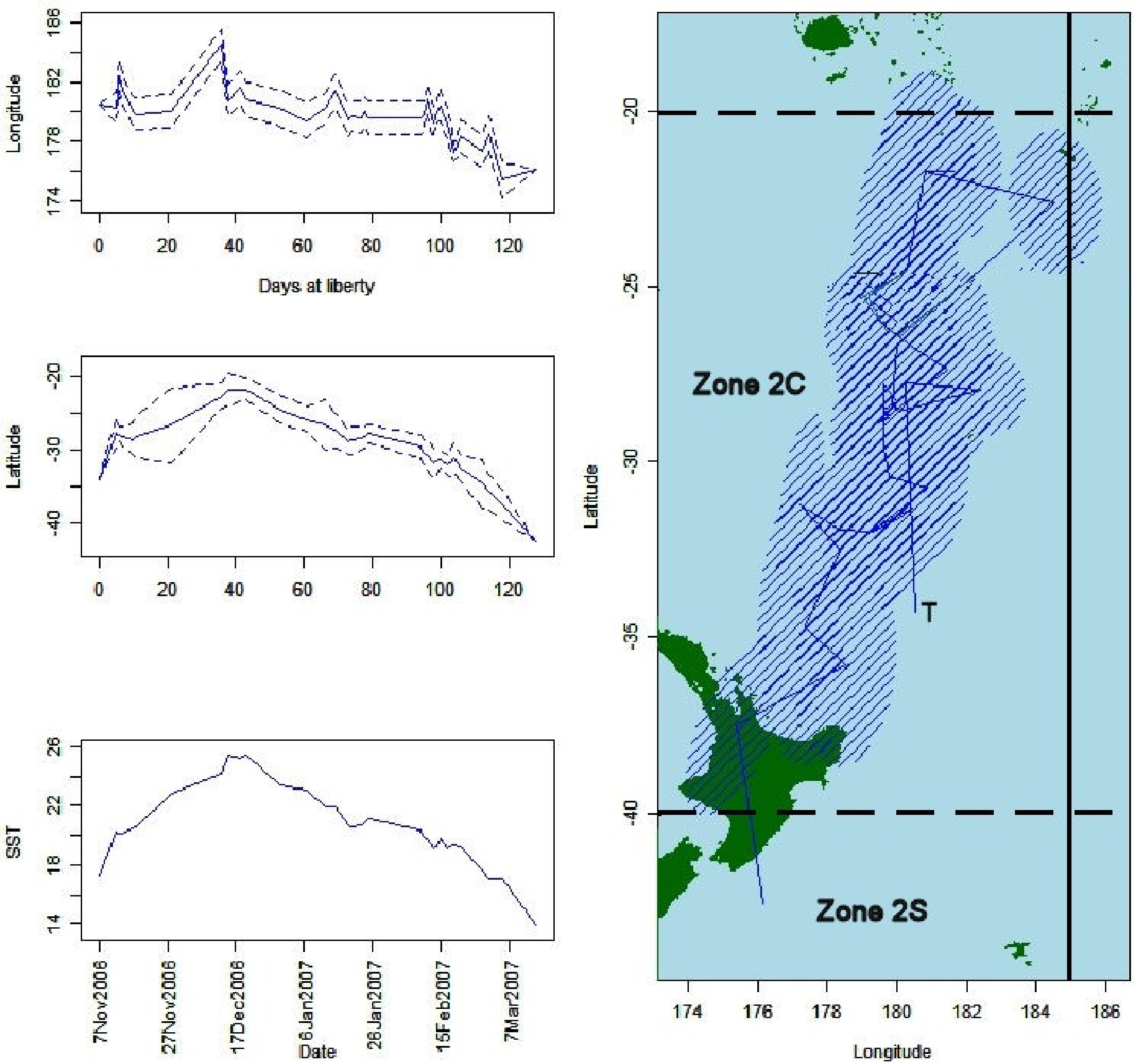

Figure12: SST Kalman filter plot from SWO06-18 light level geolocation data, tagging location (T) and boundaries of sub-areas used in the stock assessment model marked. An 80 kg fish tagged 7-11-2006 pop-off 15-03-2007.

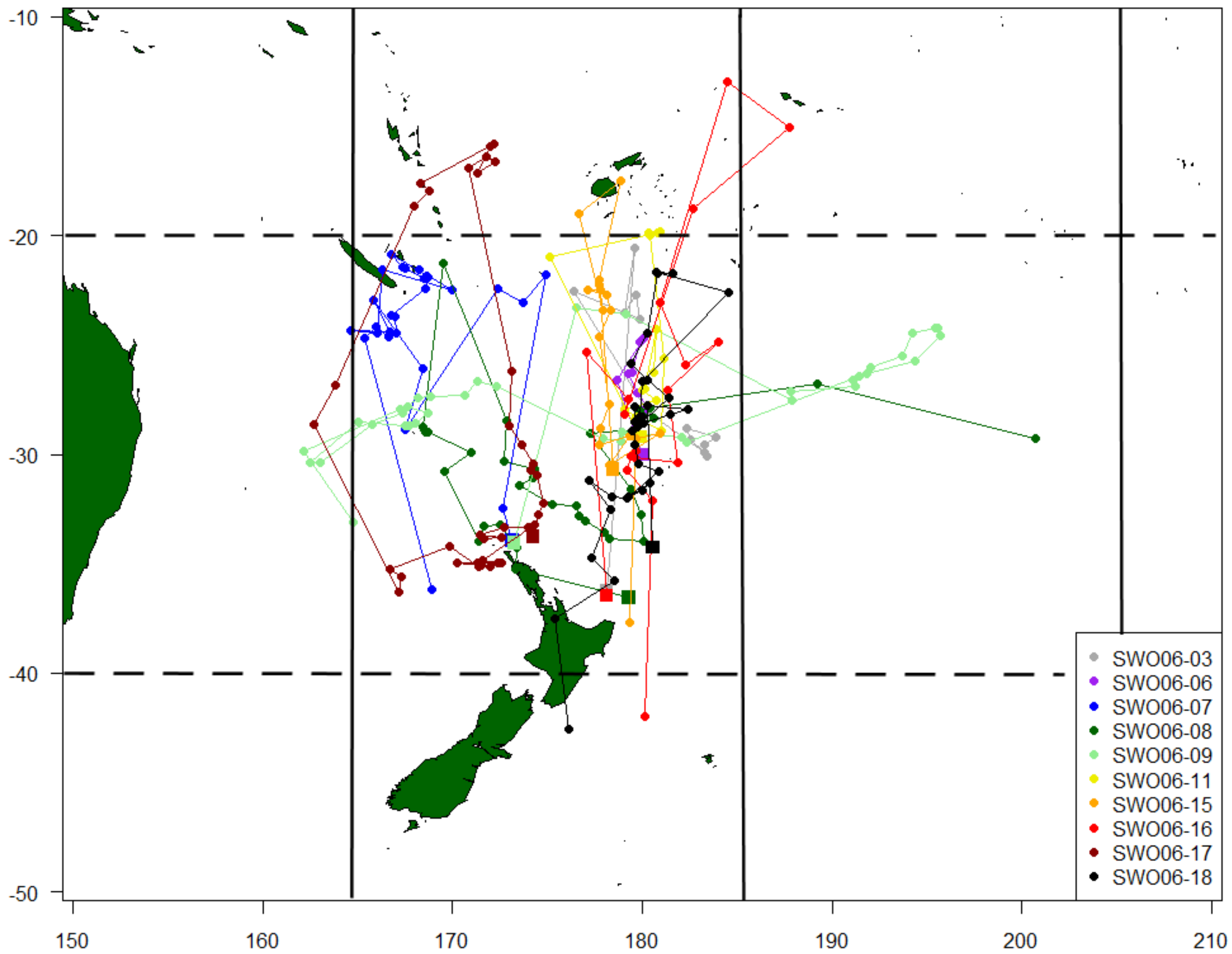

Figure 13: Plot of SST Kalman filter locations for 10 tags deployed for 66 days or more. Square is the release position. Boundaries of zones used in the 2008 stock assessment model marked with most activity in zone 2C.

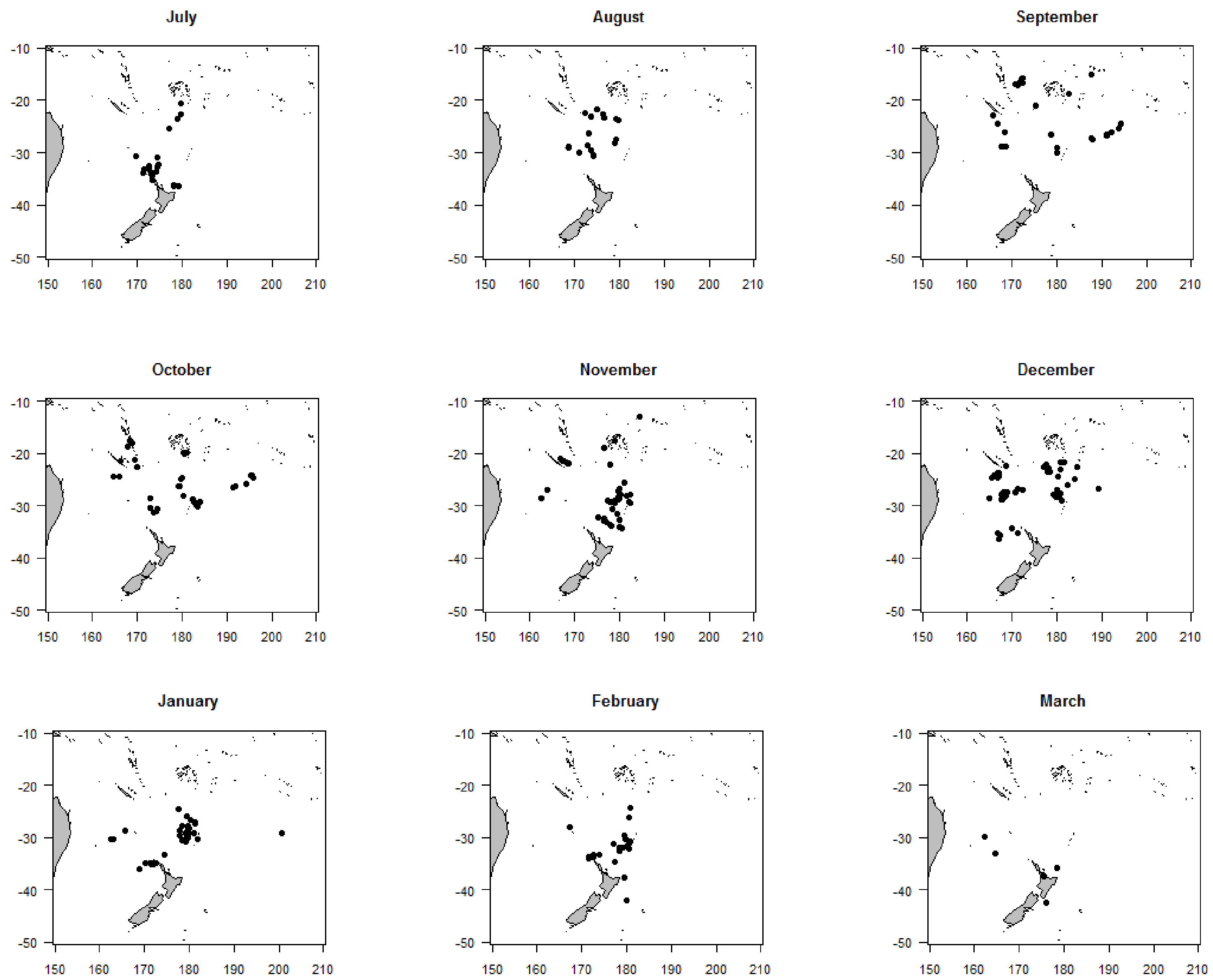

Figure 14: Plot of SST Kalman filter locations by month for 10 tags deployed for 66 days or more.

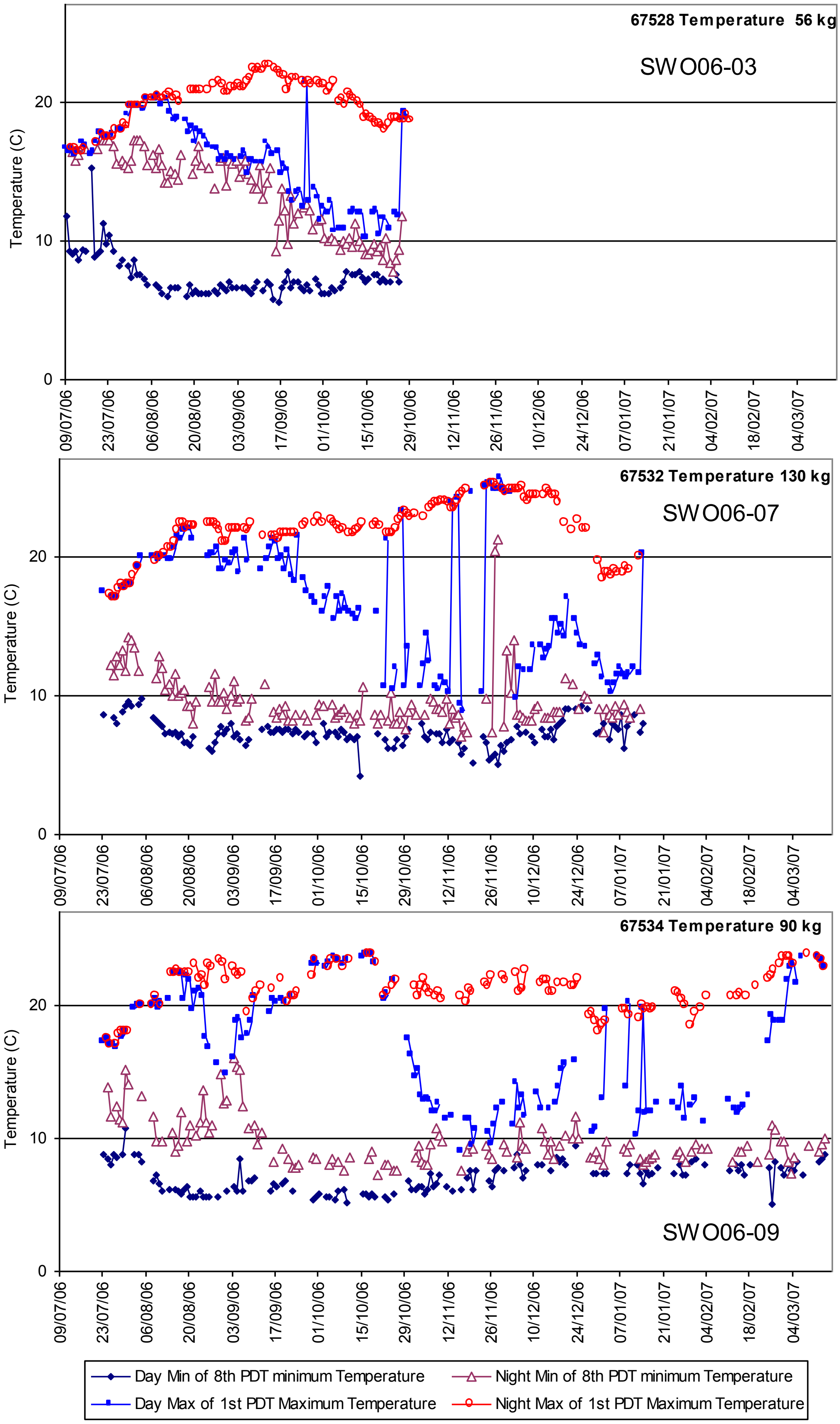

Figure 15: Maximum and minimum temperatures recorded in each 12 hour bin for fish tagged July 06.

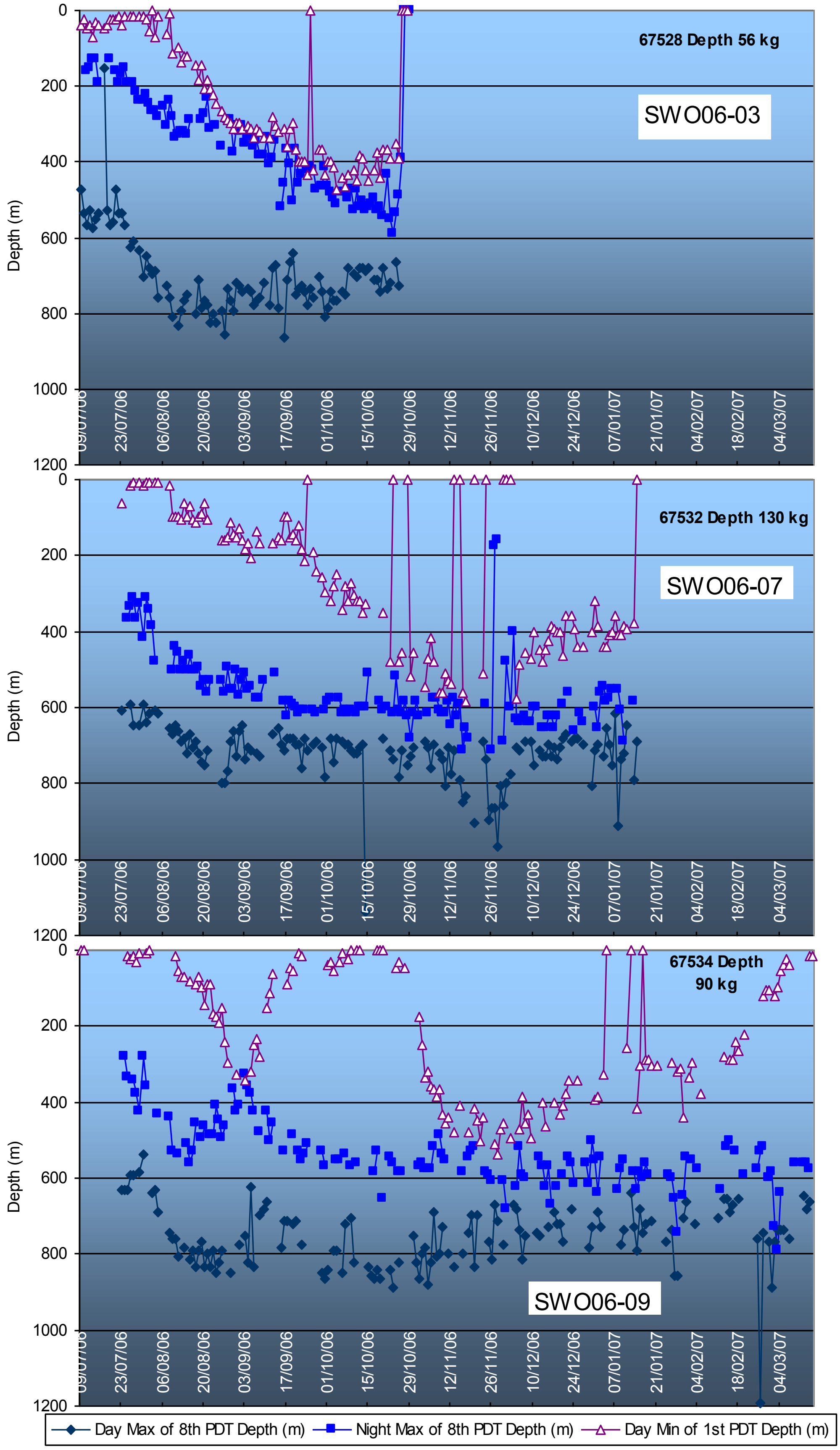

Figure 16: Maximum and minimum day time depths and maximum depth at night recorded in 12 hour bins for fish tagged in July 06.

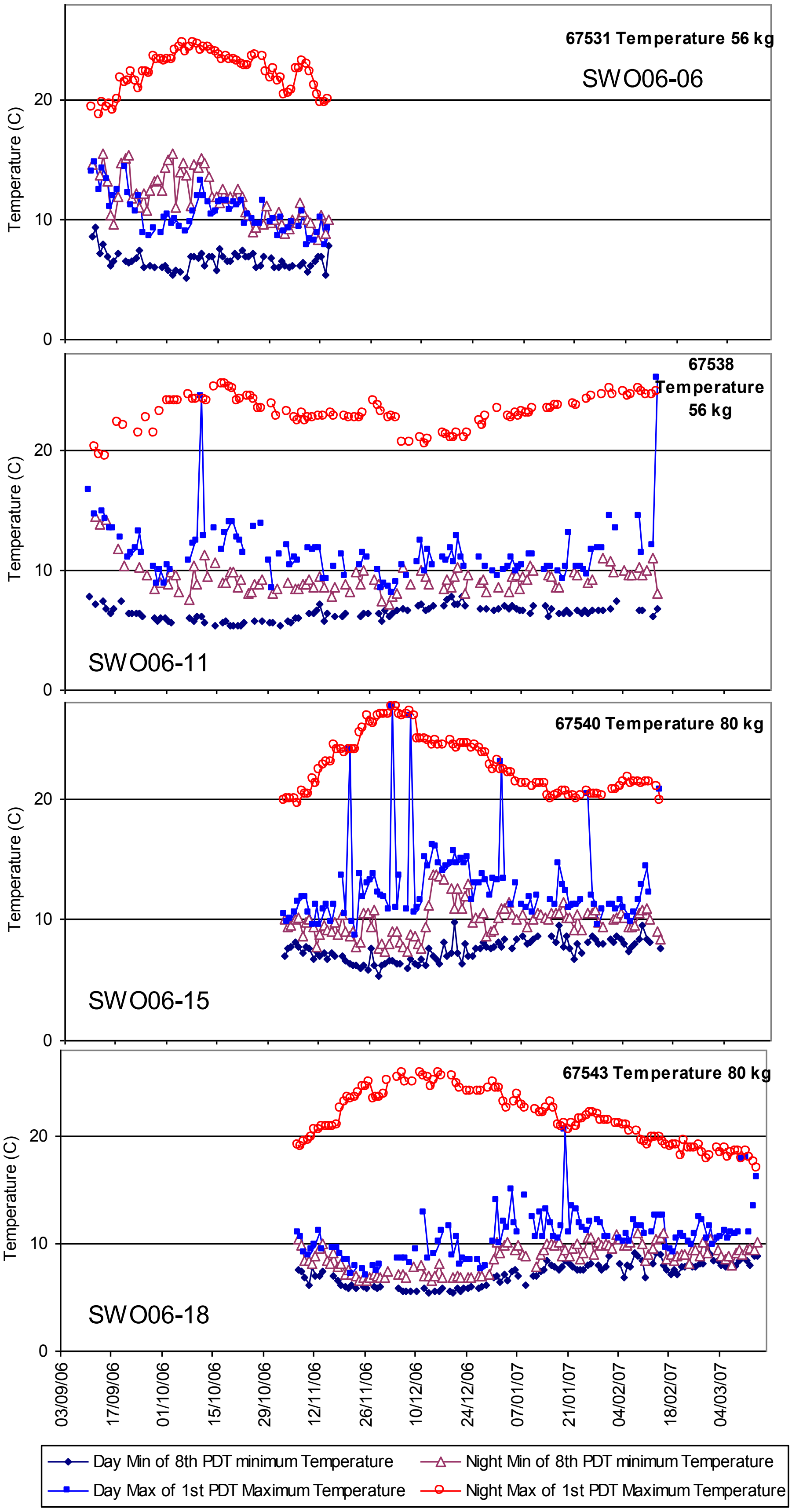

Figure 17: Maximum and minimum temperatures recorded in each 12 hour bin for fish tagged in September and November 2006.

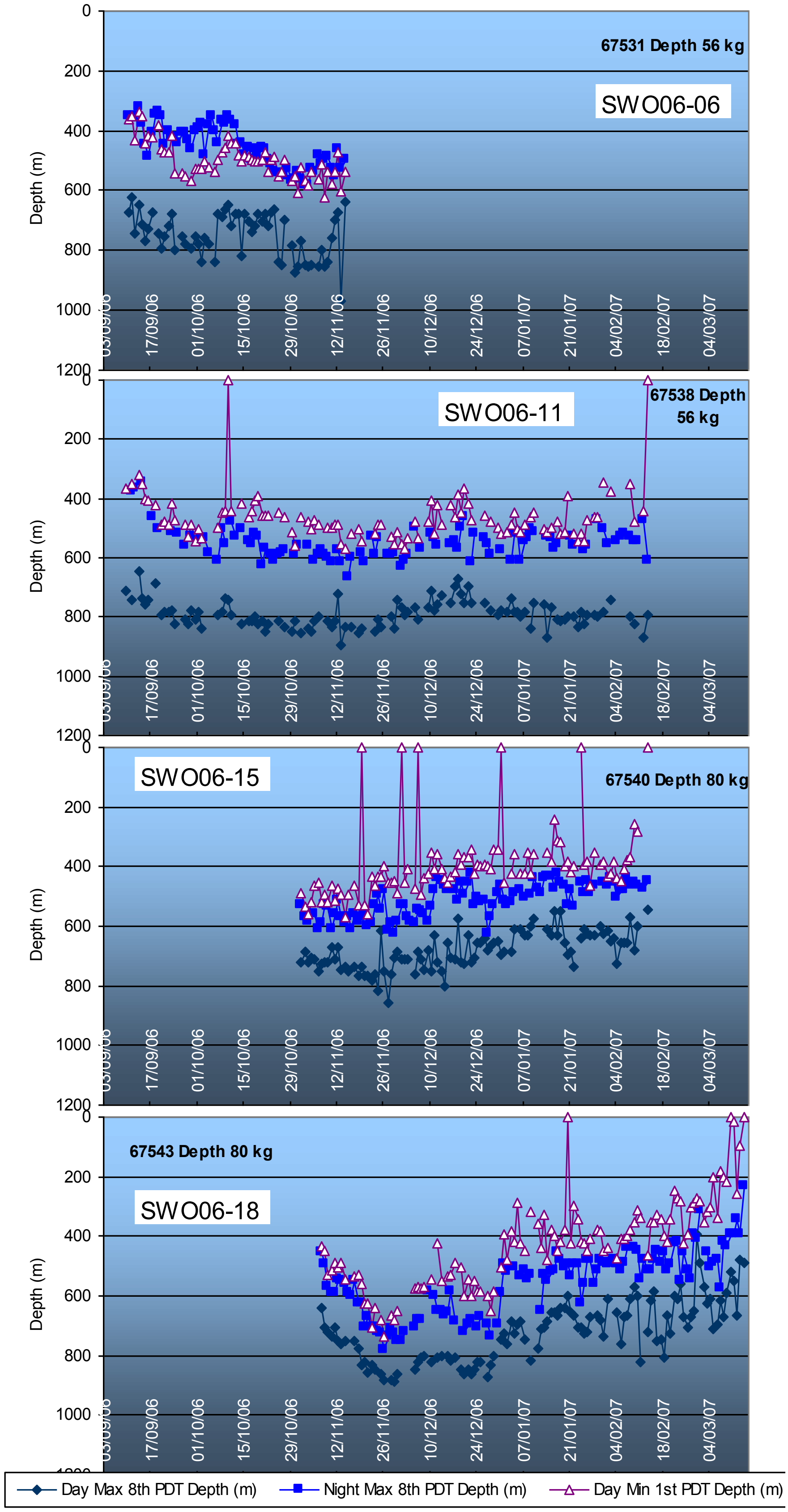

Figure 18: Maximum and minimum day time depths and maximum depth at night recorded in 12 hour bins for fish tagged in September and November 2006.

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