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# AN INVESTIGATION INTO SWORDFISH STOCK STRUCTURE USING SATELLITE TAG AND RELEASE METHODS

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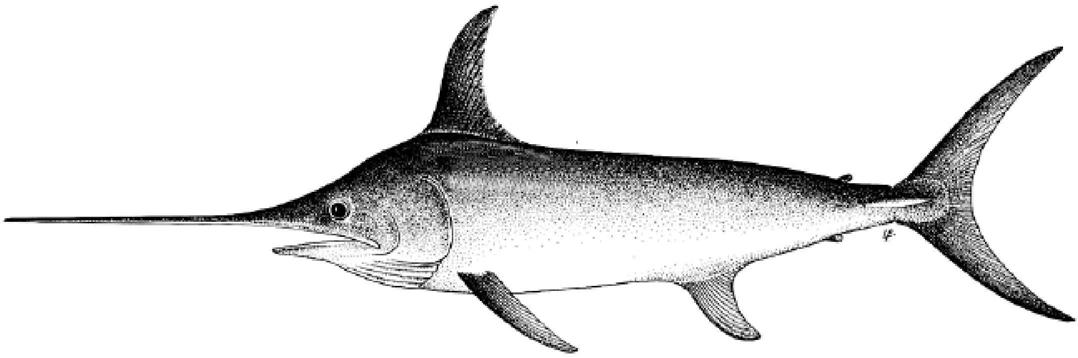
# An Investigation into Swordfish Stock Structure Using Satellite Tag and Release Methods



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**Executive Summary**

The project aims to track swordfish (*Xiphias gladius*) tagged in New Zealand waters using electronic satellite tags over a period when they would be expected to visit sub-tropical spawning grounds and return to temperate waters.

Twelve pop-off satellite archival transmitting tags (PAT) (Wildlife Computers, Redmond, WA, USA) were deployed on swordfish. The attachment failed on three tags, one fish died and one tag did not report. Seven tags provided between 66 and 236 days data. The new nylon tag anchors developed by Musyl and Prince performed better than the black plastic anchors.

Seven data sets have been decoded using the SST Kalman filter. These tags yielded between 8 and 36 usable light level geolocations each, plus the tagging and popup coordinates giving a total of 160 locations. On average there are 5 locations per month from these tags. 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. 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 which 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 are 7 tags still to deploy. Fish will be tagged from New Zealand domestic surface longline vessels in July and August with popup dates 14$^{th}$ February and 1$^{st}$ of March of the following year. Therefore we would be tagging while the fish are still around New Zealand and aiming for 6 or 7 month deployments. We aim to tag swordfish of 80 kg or more split between the North Cape or Three Kings area and the Bay of Plenty or East Cape area.

**Introduction**

Commercial catches of swordfish (*Xiphias gladius*) in New Zealand and Australian waters increased rapidly in the 1990s. In addition, catches on the high seas in the South West Pacific expanded at the same time. Experience in the Mediterranean, Atlantic and North Pacific has shown swordfish stocks to be susceptible to over fishing, and in recent years catch rates and the mean fish size have declined substantially in the South western Pacific (Kolody et al. 2006). 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. 2006). However, at the time of the assessment no spatially discrete movement data were available for swordfish.

Genetic research using mitochondrial DNA has suggested that there is population heterogeneity in the Pacific and a separate South West Pacific stock of swordfish may exist (Reeb et al. 2000) but little is known about the movement patterns of swordfish. An understanding of sub-stock structure in the South-West Pacific region is required if this highly migratory species is to be effectively managed. Knowledge of movement patterns would also contribute to more effective stock assessment of swordfish in the region.

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 around 1%. Large numbers of swordfish would need to be tagged and released using conventional tags to obtain sufficient data on swordfish movement. An Australian pilot tagging programme, with some input from New Zealand fishers, investigated the feasibility of collecting growth and movement data from swordfish that are voluntarily tagged and released by fishers. However, only small swordfish, with low market value, are likely to be released.

Two recaptures of conventionally tagged fish have been made from the New Zealand cooperative tagging program. 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 caught 250 nautical miles to the west of its release location after 10 years 8 months at liberty. 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. The second swordfish was tagged off eastern New Zealand in February 1996 and was estimated at 20 kg at the time of release. 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, alternate technologies such as the use of pop-off satellite tags is likely to be more effective.

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.

## Methods

### Tag and release programming

The pop-off satellite archival tags (PAT) sample and archive temperature, depth, and light level every 20 seconds and summarise these data into two 12 hour bins each day (6am to 6pm 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 will be 14 temperature bins most with 2$^{o}$C increments and 14 depth bins (Table 1).

The tags are also able to release early if they detect that the depth is not changing, indicating that the fish has died and is on the bottom or the tag has fallen out and is on the surface. Premature release would be triggered once 72 hours were spent at the same depth.

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

| Bin | Depth | Temp |
|---|---|---|
| 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 |

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.

**Tag rigging**

The first three tags deployed were rigged with the black plastic tag anchor supplied by Michael Domeier with a 25cm nylon tether (180 kg breaking strain) and stainless steel crimps. Shortly after tagging commenced hydroscopic nylon tag heads and the new nylon floppers were supplied by Eric Prince. 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 always relate to release order.

**Tagging swordfish**

Of the 19 tags purchased for this programme 12 were deployed in 2006 from surface longline vessels north east of New Zealand between 8 July 2006 and 7 November 2006. Blue Water Marine Research personnel undertook two trips tagging 6 fish and developed a tagging procedure for MFish scientific observers to use when deploying the remaining tags. For various reasons there have been few trips by observers on surface longline vessels though we were fortunate that there were still 3 vessels targeting swordfish unusually late in the season.

**Data analysis**

The crepuscular diving behaviour typically displayed by swordfish can significantly impair use of light level data for estimating the geo-position, or even mean that light level changes at dawn and dusk cannot be detected at all. This has been a problem with tracking PAT tagged swordfish in other programmes (Heidi Dewar, NMFS, pers. comm.), and with 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 in (Hill 1994; Hill and Braun 2001). These light level geolocations, along with tag-derived sea surface temperature measurements (sampled within 0-10m depth) were used as inputs into a state-space Kalman filter which refines light level geolocation estimates with a series of recursive equations and cross references with satellite derived sea surface temperature data (Nielsen et al. 2006). We used data averaged over 3 days (AVHRR-GAC 3 day, 0.1 x 0.1º resolution). Filtered geolocation estimates are considered to be much more reliable than raw light level estimates alone, especially for latitude.

**Results**

ARGOS satellite coverage varies with location and is often just a few minutes each hour. The PAT tag transmits a package of data once a minute. Usually there are gaps in the data received. For a full description of PAT tag performance see Sippel (2006).

**Data retrieved**

Eleven of the twelve tags uploaded data to satellites. Six PAT tags reported on the programmed date. It appears that attachment failed on three fish. These PAT tags remained at the surface for 72 hours before releasing their tether and commencing transmission. One PAT from SWO06-13 reported early after the fish descended to 1880 m were the tether was severed by the depth activated release device and the tag floated to the surface. It began transmitting 9.1 days after it was tagged but three days of this would have been while the tag floated at the surface before triggering the premature release software. The tag transmitted 83 km (45 nmiles) southeast from where it was tagged. It is assumed that this fish died and was sinking at the time the tag released. One tag failed to transmit. It had been released in July and was programmed to pop-off on 15 March 2007, after 240 days.

**Table 2: Deployment times achieved and distance and direction between release location and pop-off location.**

| Fish Id | Estimate Weight kg | Release location | Pop-off Date | Days data from fish | Displacement nmiles | Straight line direction |
|---|---|---|---|---|---|---|
| SWO06-13 | 56 | Kermadec | 14/09/2006 | 6 | 45 | SE |
| SWO06-02 | 160 | Rumbles | 21/07/2006 | 9 | 85 | NE |
| SWO06-01 | 60 | Kermadec | 21/11/2006 | 13 | 142 | NNW |
| SWO06-04 | 84 | Rumbles | 30/07/2006 | 15 | 120 | NE |
| SWO06-06 | 56 | Kermadec | 15/11/2006 | 66 | 100 | N |
| SWO06-15 | 80 | Kermadec | 14/02/2007 | 106 | 267 | N |
| SWO06-03 | 56 | Rumbles | 29/10/2006 | 110 | 455 | NE |
| SWO06-18 | 80 | Rumbles | 15/03/2007 | 128 | 545 | S |
| SWO06-11 | 56 | Kermadec | 14/02/2007 | 160 | 180 | N |
| SWO06-07 | 130 | North Cape | 15/01/2007 | 176 | 260 | SW |
| SWO06-09 | 90 | North Cape | 15/03/2007 | 236 | 430 | W |
| SWO06-10 | 130 | North Cape | NA | NA | | |

The tags recorded between 6 and 236 days of data while attached to swordfish between July 2006 and March 2007 (Table 2). Data retrieval worked well for eleven tags which transmitted for about 12 days each, until their batteries died. The objectives of this project are to investigate movement of swordfish, particularly during and after the assumed spawning period. 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 (6 to 15 days) have not been analysed for tag derived geolocation estimates. Seven data sets have been decoded using the SST Kalman filter for deployments between 66 and 236 days. These tags yielded between 8 and 36 usable light level geolocations each, plus the tagging and pop-up coordinates giving a total of 160 locations. On average we have 5 locations per month from these tags (individual tags range from 2.8 to 8.2 locations per month). Some of these are not “high quality” locations due to vertical movements during twilight periods which complicates light based geolocation.

The south-west Pacific Ocean region is stratified into 6 sub-areas in the stock assessment model (Kolody et al. 2006). 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 (Figure 1). Figures 2 to 8 show the most plausible tracks from the Kalman filter 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 7 tracks are:

- All fish were tagged in sub-area 4;
- All fish moved north initially into sub-area 1;

- All fish tagged east (Rumbles) and northeast (Kermadec) of New Zealand returned to sub-area 4;
- The 2 fish tagged just north of New Zealand (North Cape) in July moved into sub-area 1 (and one fish moved east into sub-area 6) then to sub-area 3 (New Caledonia or Norfolk Is.). Toward the end of the tracks (January and March) both fish were heading south toward area 5.

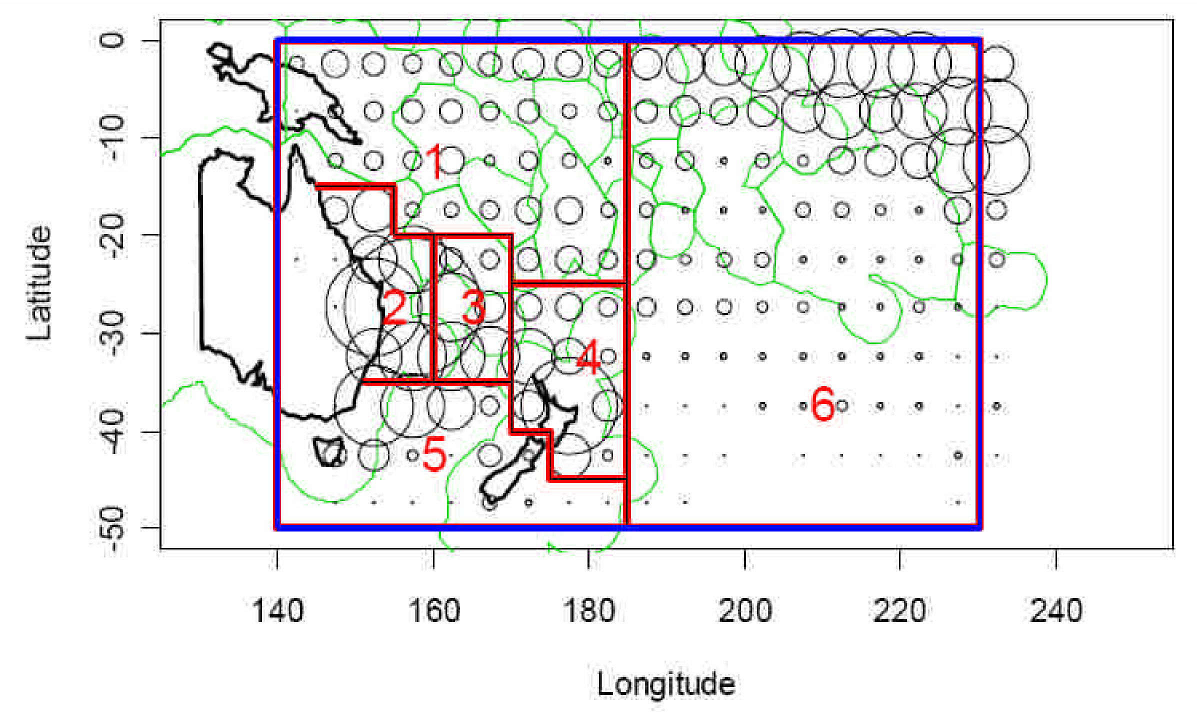


**Figure 1: The six sub-areas of the southwest Pacific used in the swordfish stock assessment model.**

Tracks from all 7 fish are overlaid on seabed bathymetry in Figure 9. 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 9). At latitude 22$^{o}$ South positions are spread from longitudes 166$^{o}$E to 162$^{o}$W a distance of 3300 km (1780 nautical miles).

**Temperature and depth**

The PAT tags transmitted quite complete records of temperature and depth in each 12 hour bins. These bins split the day roughly into day and night based on 6am to 6pm 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 and for evaluating some of the tracks generated by that model by comparing it to satellite remote sensed SST.

The tags transmit data on the minimum and maximum depth, and 6 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 record the maximum and minimum values in each 12 hour bin for fish tagged in July 2006 (Figures 10 and 11). The minimum night time depth was not plotted as it was almost always close to zero and it tended to overlay the daytime minimum at times. Similar plots were made for fish tagged in September and November on a shorter (6 month) time scale (Figures 12 and 13).

Some observations made from these data are:

- 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 $6^o$ to $8^o$ C;
- All 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 in PAT tagged swordfish off California (Dewar & Polovina 2005);
- Time at the surface during the day during July and early August may be due to dawn coming after 6am;
- 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 6pm NZST;
- No clear changes in daytime maximum depth are seen when the fish are in the warmest waters and 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$400 reward for returning one of these PAT tags.

**Discussion**

Accessing 19 live swordfish of a suitable size for tagging in 2006 was always going to be a challenge. It was disappointing to have PAT tags on just one MFish observer trip on a surface longliner in the North Island during August and September. Fortunately for the tagging programme a new fishing company continued targeting swordfish in the Kermadec area during October and November. A number of compliance issues arose with those vessels and maintaining support for the tagging project was difficult at times.

Twelve tags were deployed with 7 providing data for between 2 and 8 months. The new nylon tag anchors developed by Musyl and Prince performed well. 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. 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 to those tagged to the east and northeast. This may warrant further investigation.

There are 7 tags still to deploy. Fish will be tagged from New Zealand domestic surface longline vessels in July and August with pop-up dates 14 February and 1st of March of the following year. Therefore we would be tagging while the fish are still around New Zealand and aiming for 6 or 7 month deployments. We aim to tag 3 or 4 fish at North Cape or Three Kings area and 3 or 4 in the BOP or East Cape area.

**Acknowledgements**

Many thanks to the skippers that assisted in providing fish in good condition for this project in particular Ben Turner, Kim Buckland and the fleet manager for M & B Fishing Hamish Black. Thanks to the scientific observers who tagged fish Rick Guild, Rob Coy and the assistance of Howard Reid. Thanks also to Shandy Buckley who extracted and plotted the temperature and depth data. Nick Davies and Lynda Griggs of NIWA have contributed to the success of this project. This project was funded by the Ministry of Fisheries under contract SWO2002/1B.

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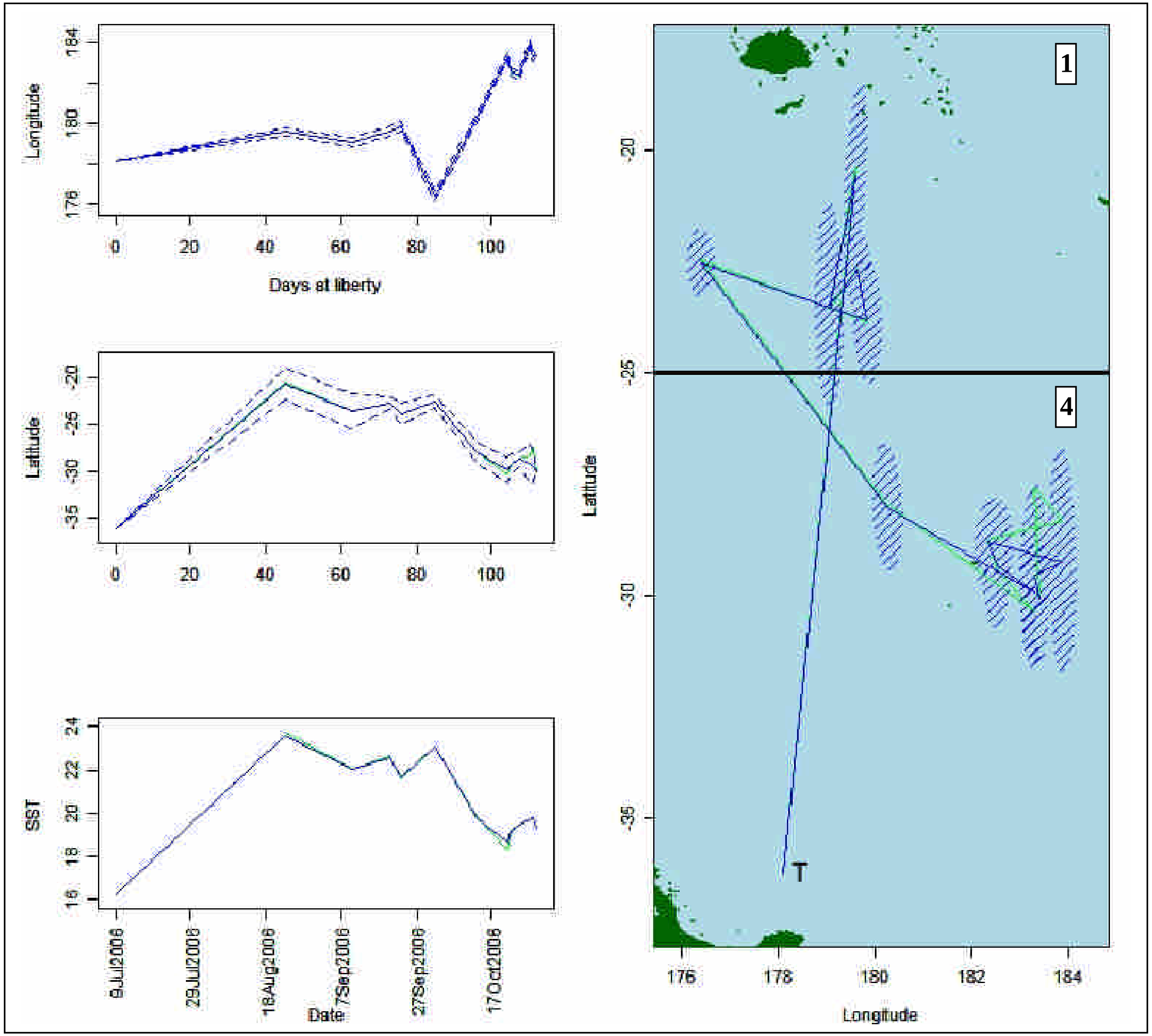



**Figure 2: SST Kalman filter plot from SWO06-03 light level geolocation data, tagging location (T) and boundaries of sub-areas used in the stock assessment model marked. A 56 kg fish tagged 09-07-2006 pop-off 29-10-2006.**

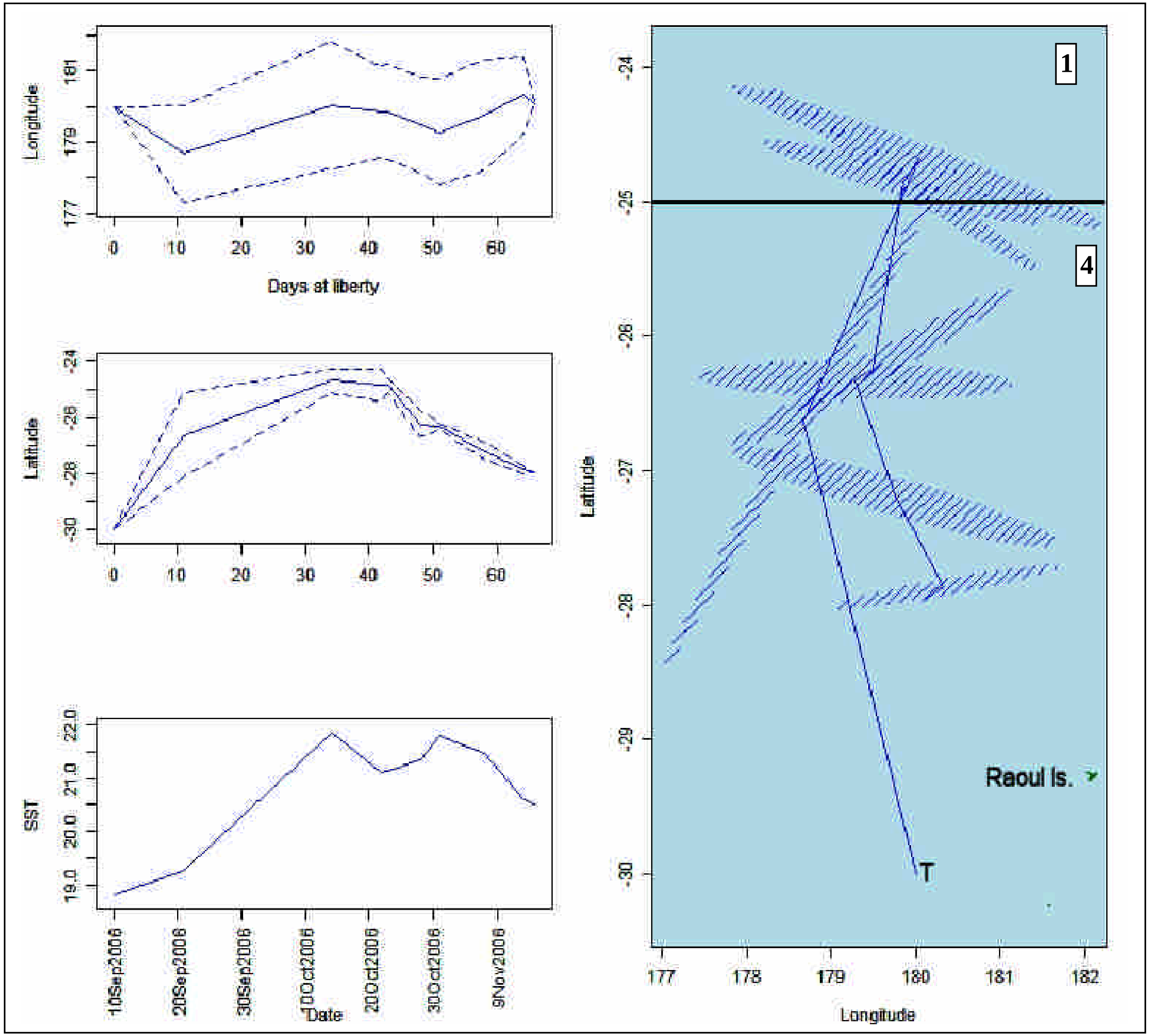



**Figure 3: SST Kalman filter plot from SWO06-06 light level geolocation data, tagging location (T) and boundaries of sub-areas used in the stock assessment model marked. A 56 kg fish tagged 10-09-2006 pop-off 15-11-2006.**

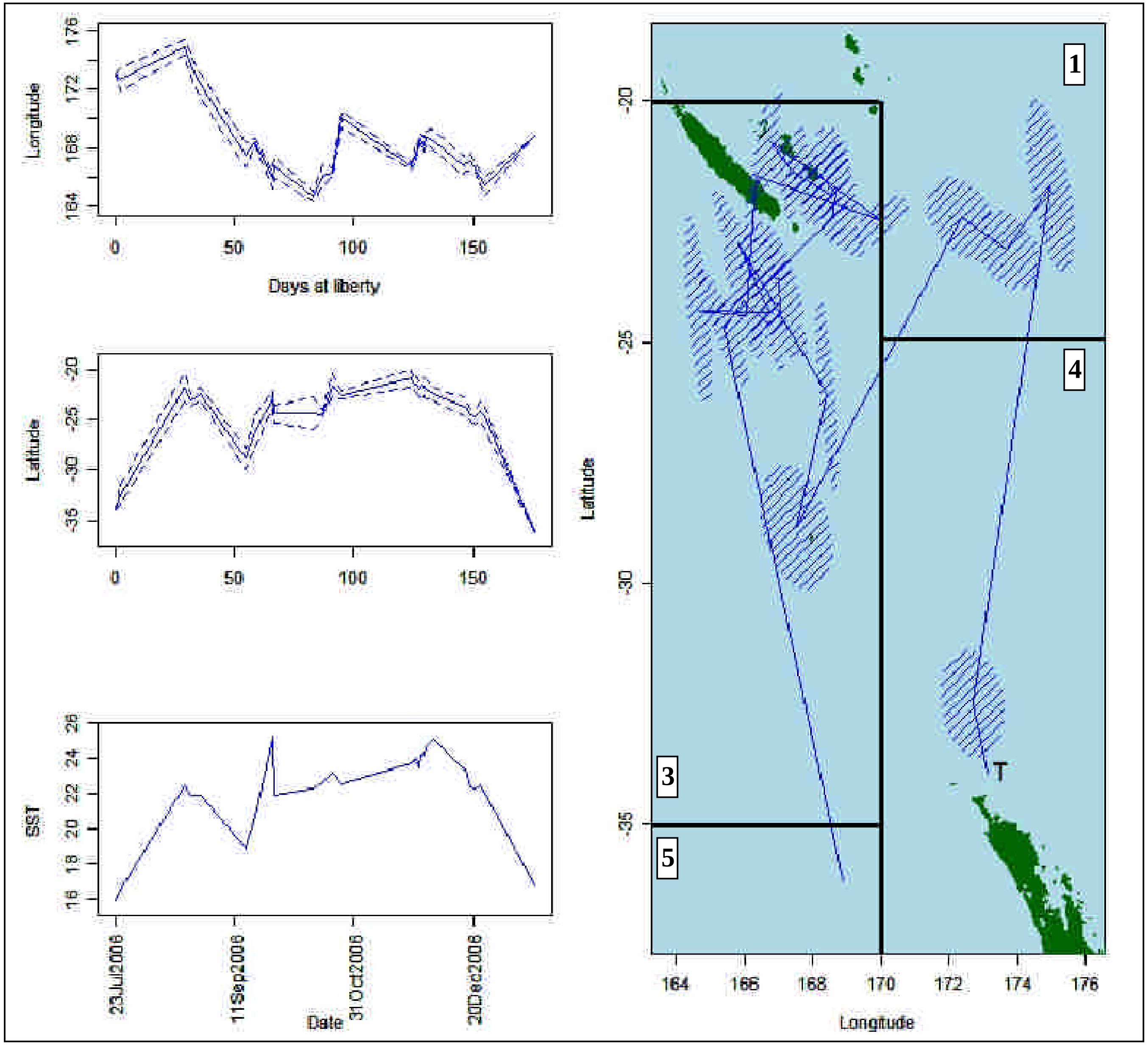
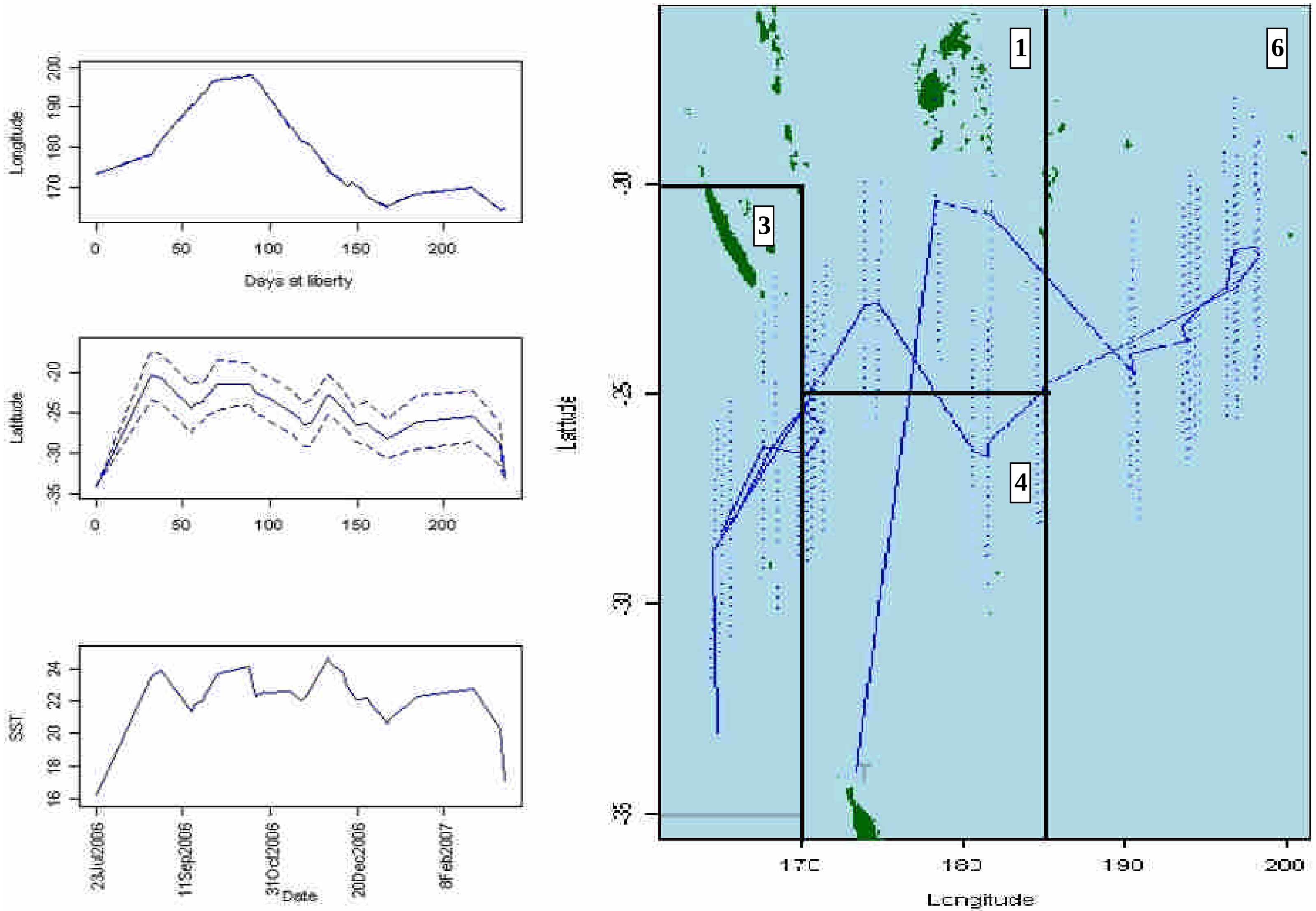



**Figure 4: SST Kalman filter plot from SWO06-07 light level geolocation data, tagging location (T) and boundaries of sub-areas used in the stock assessment model marked. A 130 kg fish tagged 23-07-2006 pop-off 15-01-2007.**

**Figure 5: 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.**



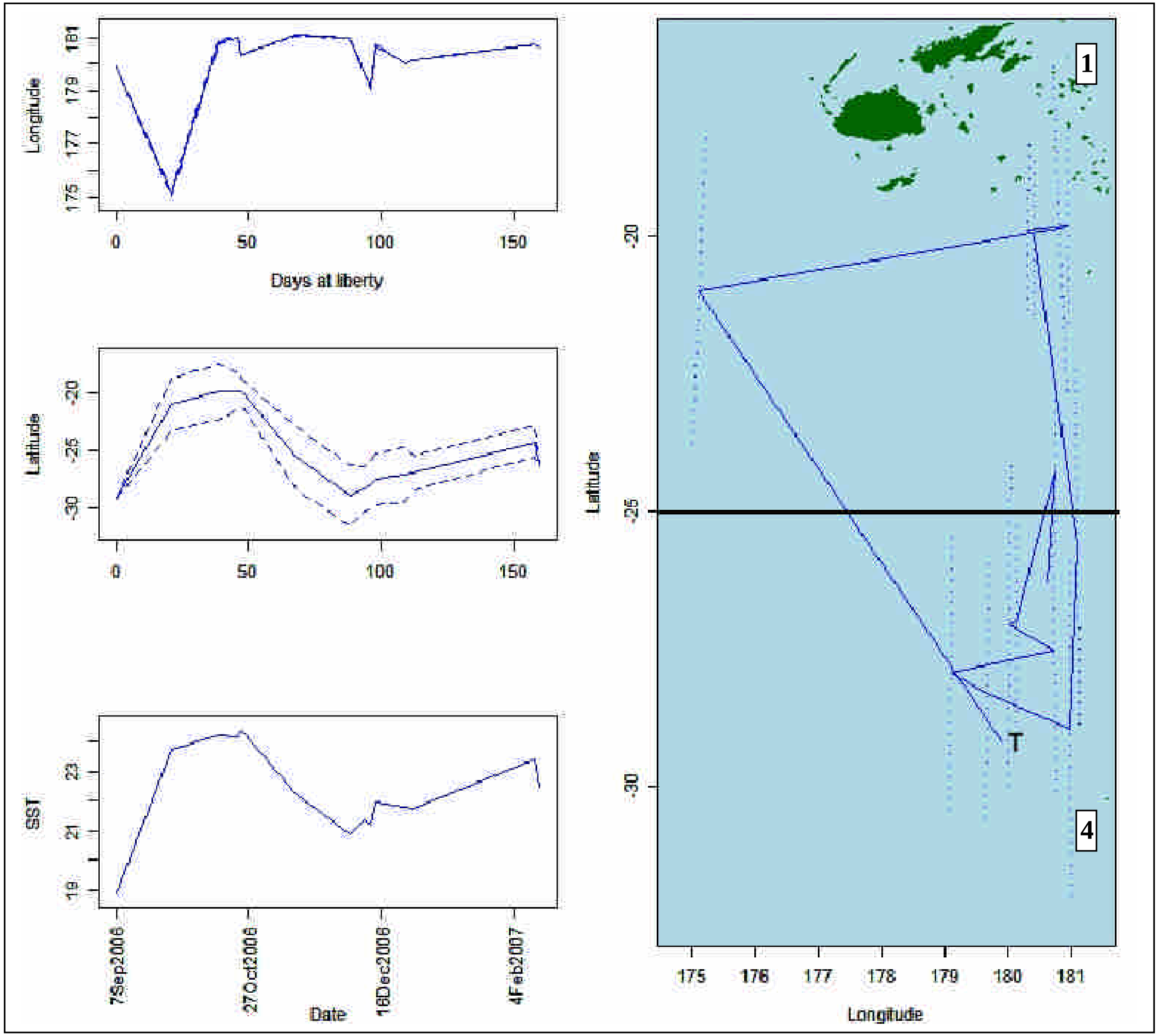



**Figure 6: SST Kalman filter plot from SWO06-11 light level geolocation data, tagging location (T) and boundaries of sub-areas used in the stock assessment model marked. A 56 kg fish tagged 07-09-2006 pop-off 14-02-2007.**

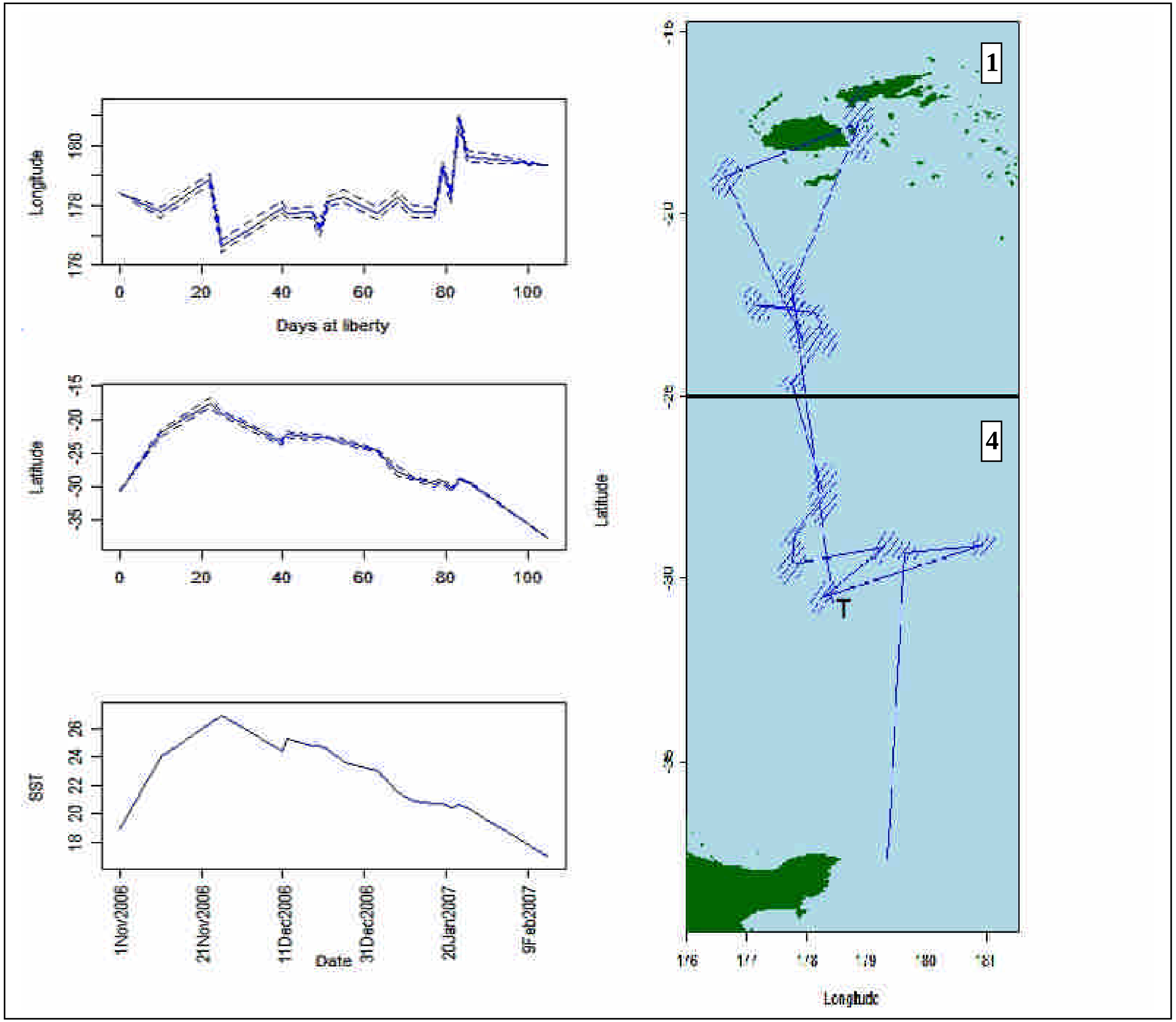



**Figure 7: SST Kalman filter plot from SWO06-15 light level geolocation data, tagging location (T) and boundaries of sub-areas used in the stock assessment model marked. An 80 kg fish tagged 01-11-2006 pop-off 14-02-2007.**

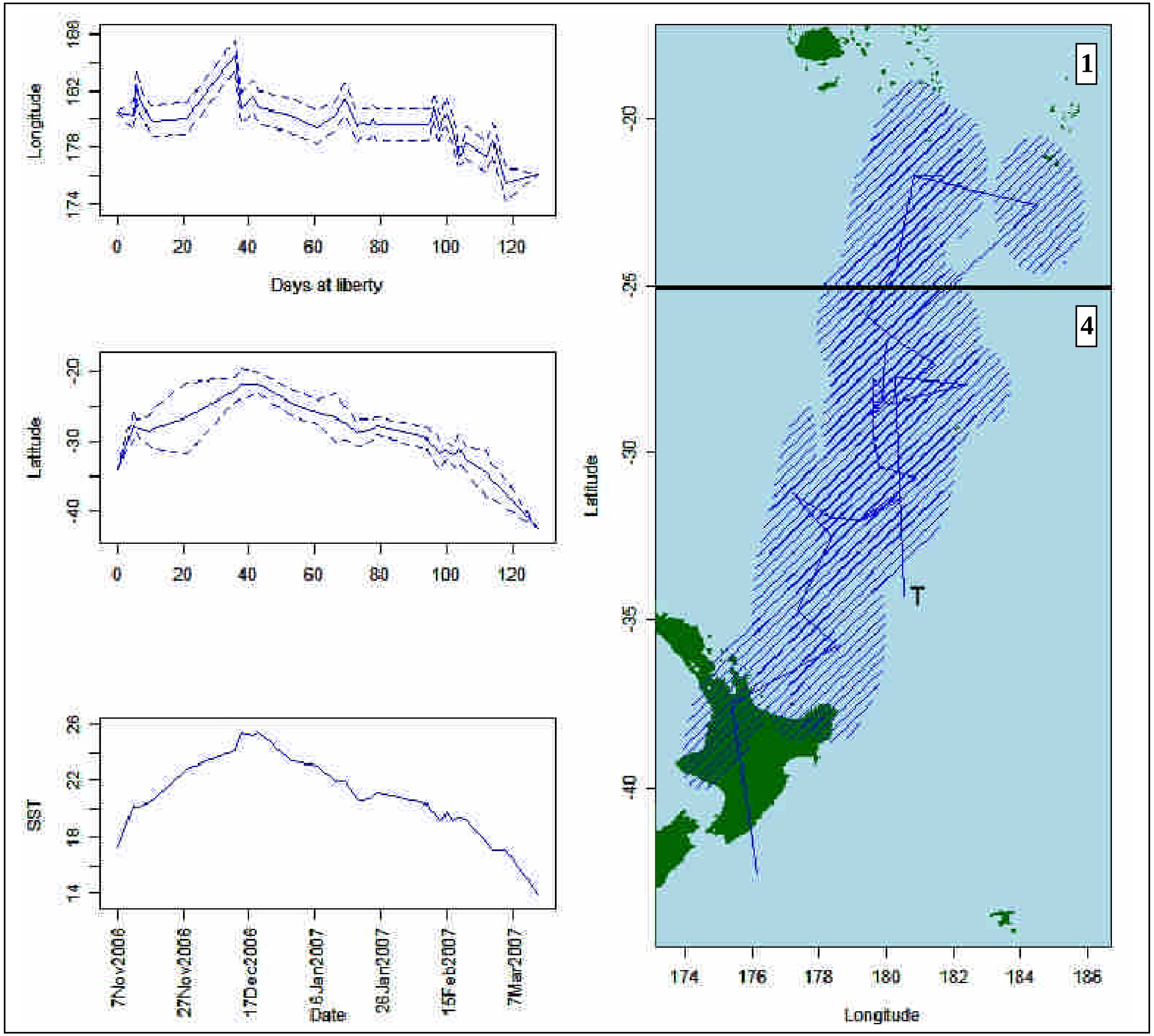



**Figure 8: SST Kalman filter plot from SWO06-18 light level geolocation data, tagging location (T) and boundaries of sub-areas used in the stock assessment model marked. An 80 kg fish tagged 7-11-2006 pop-off 15-03-2007.**

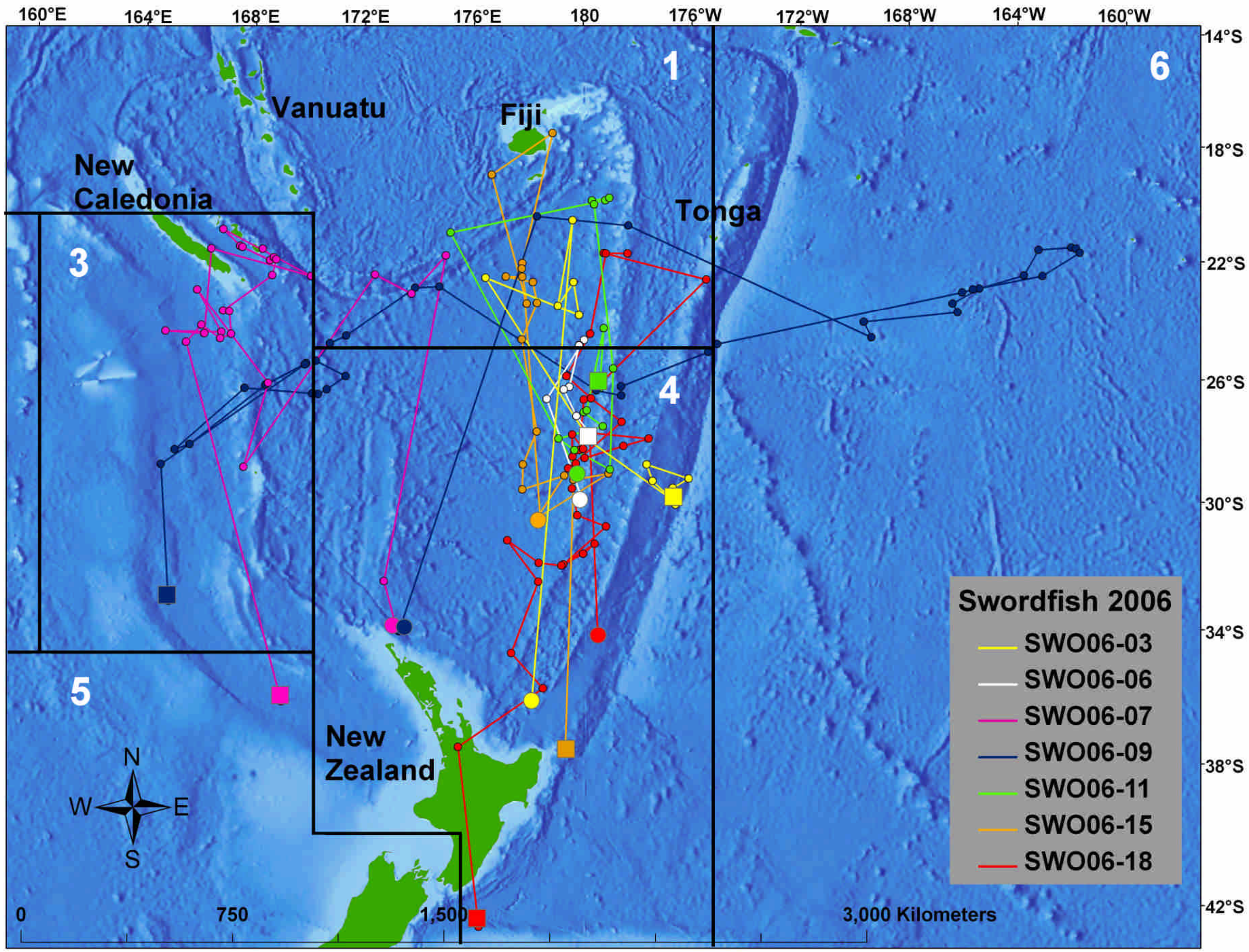



**Figure 9: Plot of SST Kalman locations for the 7 tags deployed for 66 days or more. Circle is the release position and square is the pop-off location, Boundaries of sub-areas used in the stock assessment model marked.**

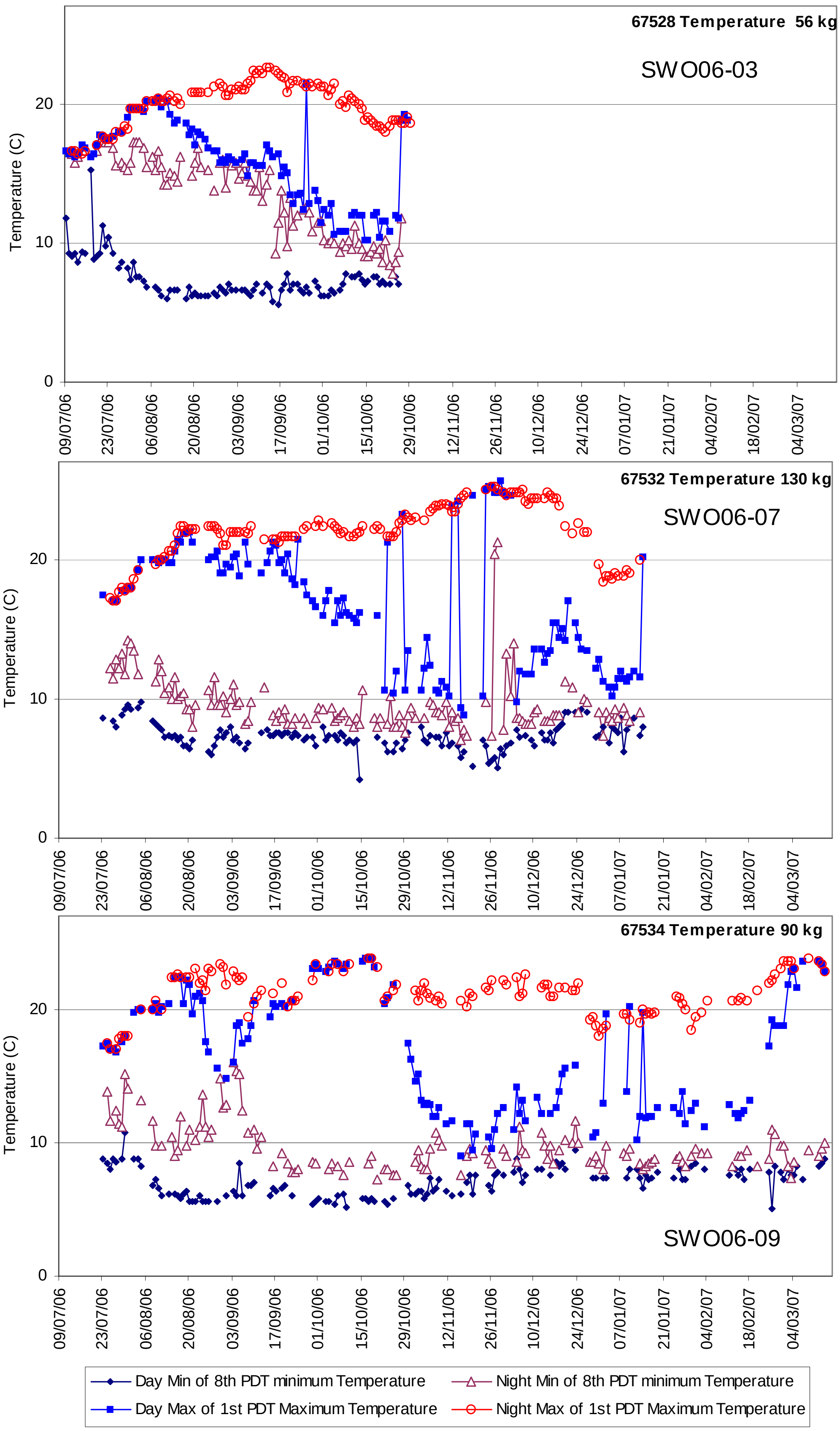



**Figure 10: Maximum and minimum temperatures recorded in each 12 hour bin for fish tagged in July 06.**

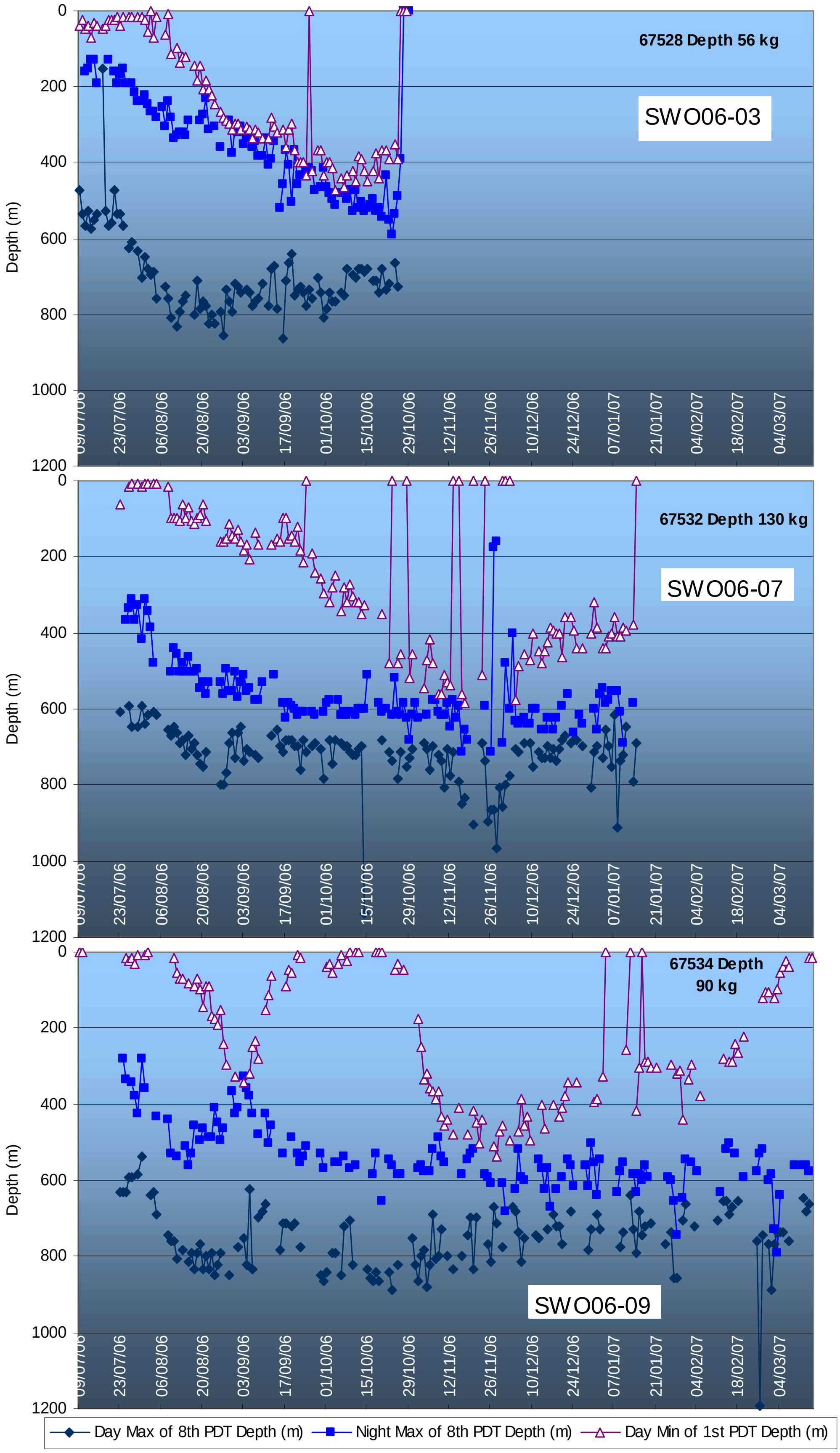



**Figure 11: Maximum and minimum day time depths and maximum depth at night recorded in 12 hour bins for fish tagged in July 06.**

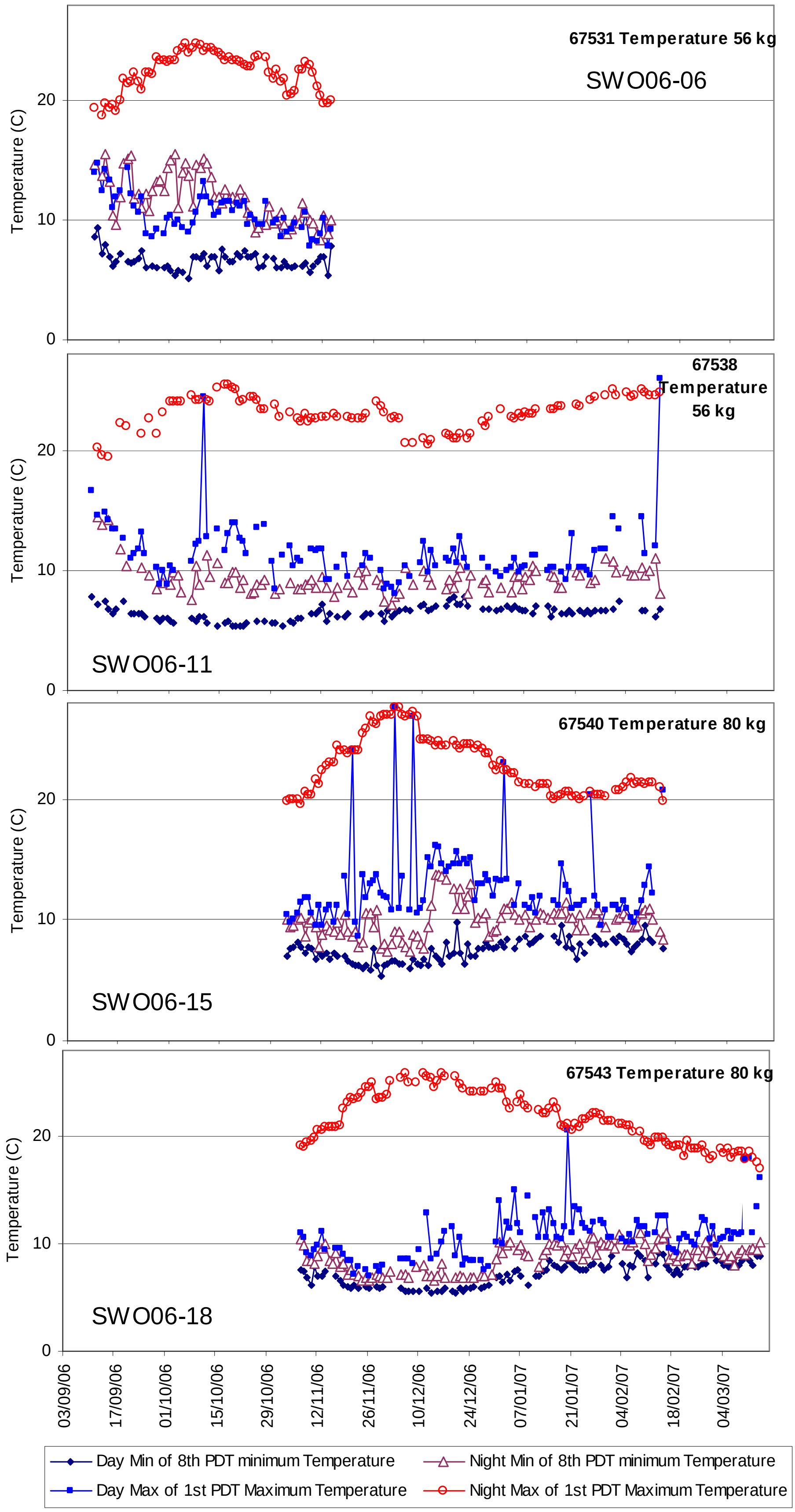



**Figure 12: Maximum and minimum temperatures recorded in each 12 hour bin for fish tagged in September and November 2006.**

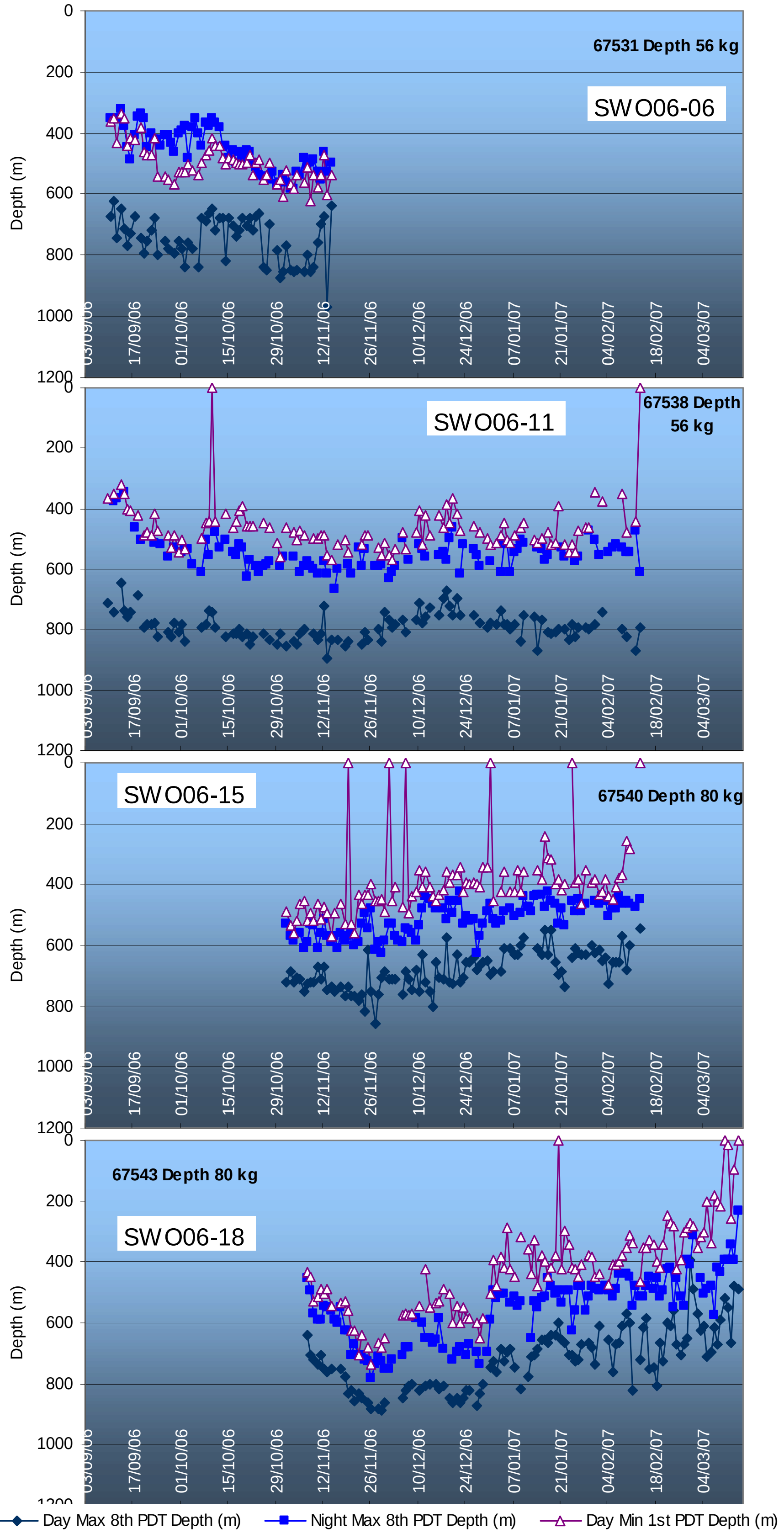



**Figure 13: Maximum and minimum day time depths and maximum depth at night recorded in 12 hour bins for fish tagged in September and November 2006.**