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Movement and residency of adult SBT in the Tasman Sea and on their spawning grounds south of Indonesia using pop-up archival tags: a summary of results for 2004

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Abstract

Twenty Pop-up Satellite Archival Tags (PSAT) were deployed on adult-sized SBT (mean ± sd: 174.1 ± 5.3cm LCF; range: 169 - 189cm) from Australian longline vessels in the western Tasman Sea between June and August 2004. Thirteen SBT on which PSATs were deployed were also tagged with conventional tags and another 146 SBT were tagged with conventional tags only (mean ± sd: 154 ± 17.23cm, range: 56 - 183cm). A total of 5.6 tonnes of the 15 tonnes of SRP mortality allowance allocated by CCSBT were used by this tagging project during 2004. The average number of fish landed per month was 9 ± 24.3 (range: 1 – 19 fish) constituting 697 ± 604.9 kg (range: 76 – 1,416kg) landed per month. Eighteen of the 20 PSATs deployed transmitted data to the ARGOS system. Attachment durations were considerably improved relative to previous years with 65 % of all tags remaining attached beyond 60 days and 55 % beyond 90 days. The average attachment duration for PSATs was 98.8 ± 70.3 days (range: 2 - 206 days). The data collected by the PSATs have provided an unprecedented insight into the movement of large SBT within the Tasman Sea and into the Southern Ocean. Several long distance movements were recorded and one SBT migrated from the Tasman Sea to the spawning grounds south of Indonesia. Displacement of SBT (distance between deployment and pop-up locations) ranged 96 to 4,559 km. The time spent by individuals in the western Tasman Sea varied substantially. Directed cyclic movements between the western Tasman Sea and the coastal waters of New Zealand were observed in two fish. A number of SBT remained in the western Tasman Sea until at least October, suggesting that SBT may not be transient visitors to the region and may demonstrate some residency to the western Tasman Sea. Furthermore, movement patterns suggest that those fish tagged are unlikely to have been amongst the first pulse of spawning fish on the Indonesian spawning grounds during the months of November and December.

Introduction

In order to define the population structure of southern bluefin tuna (SBT), knowledge of the spatial dynamics of adult SBT is required. Furthermore, defining the movements of spawning-age individuals and any variability associated with this is important in determining the egg-production of those fish that comprise the SBT stock. However, the movement patterns of adult SBT in Australian waters are largely unknown. In addition, the degree and nature of the movements of these fish whilst they are present within the Tasman Sea are also largely unknown.

One hypothesis is that the movement patterns of adult-sized SBT in Australian waters were thought to comprise of movements into the western Tasman Sea for the winter months followed by a movement out of the area and towards the spawning grounds in August and September. Such hypotheses are largely based on the results of conventional tagging programs and CPUE data and therefore lack important information on the movement patterns of individuals between release and recapture positions.

Pop-up satellite tagging of adult-sized SBT provides a means by which the movement patterns of such fish can be determined, allowing such hypotheses to be tested. Defining such movements also provides important information required for the spatial management of SBT catches within those fisheries operating within Australian waters and provides us with insights into possible interactions with fisheries operating outside Australian waters.

From it's inception in 1998, the CSIRO has deployed 36 pop-up satellite tags (PSAT) on adult-sized SBT (>165 cm) in waters off the east coast of Australia as part of a program investigating the movement patterns of adult-sized SBT in Australian waters. This paper presents the results of this program for the 2004-2005 season.

Methods

Deployments

Tagging operations were conducted onboard the commercial longliner 'Thylacine' which was chartered for the period 27th of June to 29th of August, 2004.

Southern bluefin tuna of a size greater than 165 cm (and therefore considered to be of adult size) were caught on commercial pelagic longline gear using between 400 and 500 hooks and a soak time of four hours. Tuna were brought on board the vessel using a customised cradle and their length's measured. A PSAT was attached to each fish using a 180 kg, 1.8 mm diameter monofilament leader and a nylon umbrella dart anchor (manufactured by PEIR[1] – see Domeier et al. 2003). The umbrella dart was inserted into the dorsal musculature and through the pterygiophores of fish immediately adjacent to the second dorsal fin, following the methodology of Block et al. (1998). A secondary anchor was attached through the dorsal musculature behind the primary anchor to prevent wear on the monofilament leader caused by movement of the tag through the water. Maximum depth cut-off devices (RD-1800, Wildlife Computers, Redmond, WA) were fitted to all PSATs, ensuring that tags detached prior to encountering implosion depths (i.e. should tagged animals die and sink below 1,800m). All PSATs were programmed to stay attached to the fish for 365 days. Thirteen of those fish on which PSATs were deployed were additionally tagged with a pair of conventional tags (manufactured by Hallprint Tags, Australia) either side of the dorsal fin and in a position above the PSAT attachment site. A further 146 SBT of varying sizes less than 165 cm were tagged with conventional tags only.

Estimation of position

In addition to point-to-point movements between release and pop-up positions, PSATs transmit data that allows for post-hoc geolocation derived estimates of latitude and longitude, thereby allowing a movement path to be estimated. Longitude was calculated using proprietary software (Wildlife Computers, Redmond WA). Previous studies investigating the accuracy of light level geolocation estimates have demonstrated that estimates of latitude are less accurate than those of longitude (Welch and Everson 2001, Teo et al 2004). In an effort to address the problems associated with the calculation of latitude using light-based geolocation techniques, estimates of daily latitude were derived by comparing surface temperatures recorded by PSATs with remotely sensed sea surface temperatures (SST) along a longitudinal strip derived from the light-based longitude estimates. For each longitude, the median SST latitude of all candidate latitudes was chosen. Matches between 30^{o} and 50^{o}S were used except for positions in February and January when fish may have been on the spawning grounds south of Indonesia.

[1] Pfleger Institute of Environmental Research, Oceanside California, USA.

Results

Deployments

A total of 20 PSATs and 159 pairs of conventional tags (CTs) were deployed on SBT during June-August 2004 (Figure 1). Average (± sd) size of fish on which PSATs were deployed was 174.1 ± 5.3cm LCF (range: 169 - 189cm) and 154 ± 17.2cm LCF, (range: 56 - 183cm) for those on which conventional tags were deployed (Table 1, Figure 2). The majority of tags were released in July and August on fish 125 – 175 cm LCF (Table 2). The average number of fish landed per month was 9 ± 24.3 (range: 1 – 19 fish) constituting 697 ± 604.9 kg (range: 76 – 1,416kg) landed per month. A total of 5.6 tonnes of the 15 tonnes of SRP mortality allowance allocated by CCSBT were used by this tagging project during 2004 (Table 3). The average attachment duration for PSAT tags was 98.8 ± 70.3 days (range: 2 - 206 days; Table 1). Two tags detached almost immediately after two days at liberty, and another three detached between ten and 14 days (Figure 3). The greatest rate of tag detachment occurred between 100 and 150 days post-deployment, with roughly 60 % of tags detaching from fish during this period. A further two tags did not transmit to the ARGOS system, one of which washed ashore and retrieved thereby allowing the collection of those data recorded by the tag.

Recoveries from deployments in previous years

Two conventional tags released in 2002 and 2003 were recaptured during 2004 (Table 1). Time at liberty was 357 and 675 days and distance displaced was 232.9 and 893.4 km respectively.

General movements

Of the 19 tags from which data were retrieved two tags (10 %) were observed to travel from the Tasman Sea across southern Australia and into the Indian Ocean with one PSAT recording movement into the area of the spawning grounds south of Indonesia (Figure 5). Six (30 %) of the tags documented movements into the central Tasman Sea, seven (40 %) documented movements into the south Tasman Sea and three (20 %) documented movements into the Southern Ocean. The average straight line distance between release locations and ARGOS reported popup locations was 23.4 km.day^{-1} (range: 6 - 103.5, Table 1; Figure 5).

Movements recorded for each month tags were at liberty demonstrated considerable variability in the timing of movement away from western Tasman Sea waters (Figure 6). Most individuals demonstrated periods of residence in particular areas and some evidence of directed movement between these sites. Two fish undertook trans-Tasman movements spending time in waters off New Zealand’s south island, before returning to waters off the south coast of NSW and the frontal regions of the East Australia Current before moving into waters east of Tasmania. Fish were predominantly confined to the western Tasman Sea during July and August, moving into central, southern and eastern Tasman Sea waters and as far as the Great Australian Bight (GAB) in September.

The one SBT that undertook movements into the area of the spawning grounds south of Indonesia was resident in the GAB during December for some time before continuing on to Western Australian waters in January. Data collected by this tag are sparse during the month of January but its pop-up position (17.7^{o} S, 111.1^{o} E) in early February suggests that movement of this fish between the waters to the west of Cape Leeuwin (estimated position

33.4° S, 108.7° E) to the area of the spawning grounds only took one month. This represents a daily straight –line movement of $25km.day^{-1}$.

There did not appear to be a strong relationship between the size of the fish and their movement paths. All fish tagged were within the size range commonly seen on the spawning grounds indicating that they had the capacity for spawning.

Discussion

While at least 19 of the 20 tags deployed did not remain attached to fish for the full 365 originally programmed, the attachment durations achieved from those tags deployed in 2004 demonstrate that significant progress has been made since PSAT tags were first attached to large SBT in 1998. These deployments have enabled the documentation of the movement of SBT from the Tasman Sea into the Southern Ocean and have provided greater insight into of the residency patterns of adult-sized SBT in the Australian region.

General movements

The data collected by PSATs deployed in 2004 suggests that SBT are resident in the Tasman Sea for a large proportion of the year with many of those fish tagged remaining in the area between June and November. Movement patterns of SBT in this area have previously been regarded to comprise of a brief visit to the frontal zones of the East Australian Current (EAC) in the Tasman Sea prior to a return into the Southern Ocean. Whether the movement patterns of the small number of fish tagged in 2004 are representative of the larger population is unclear – more data is required to evaluate such a hypothesis.

A major uncertainty in the population dynamics of SBT is whether mature fish spawn every year. While it is impossible to determine from those data presented here whether or not SBT are obligate annual spawners or otherwise, the data suggests that fish in the Tasman Sea are unlikely to have been part of the first pulse of fish onto the spawning grounds in November and December (Farley & Davis, 1998). The movement patterns of those fish tagged in 2004 suggest that many may have migrated to the spawning grounds during the second spawning period in January and February.

Common to the movement of all fish that moved into waters west of Tasmania was a period of residency in the eastern GAB. The area south of Cape Leeuwin similarly also appears to be an area of residence for adult-sized SBT. These areas are close to places where juvenile fish tend to aggregate. While it is unclear if these areas are visited annually and of what importance they are to the fish, both areas are considered to be oceanographically dynamic regions. The eastern GAB is known to be the site of upwelling events and the Indian Ocean south west of Western Australia is influenced by the Leeuwin Current. Potentially, this region may be similar to the EAC and the frontal systems in the region may be important in aggregation of prey species.

It is important to note that while the estimated movement tracks suggest that the vast majority of locations derived from this study were within the AFZ, this observation is subject to the quality of those locations estimated. Due to the coarse scale resolution of geo-position data these movement patterns should be considered as preliminary until more comprehensive latitude estimation has been developed.

Detecting alternative migration routes to the spawning ground

It is conceivable that SBT might migrate northward from the Tasman Sea, into the Coral Sea and through the Torres Strait to reach the Indonesian spawning grounds. However a number of aspects of those data collected by the PSATs suggest that at least amongst those fish tagged as part of this study this is unlikely to have occurred. If fish had moved northward from the Tasman Sea and into the Coral Sea it would be expected that those water temperatures recorded by the PSATs would have been reflective of the warmer waters temperatures experienced by fish in this area. It could be hypothesised that perhaps the cooler waters recorded by the tag and incorporated into the SST matching algorithm may be the result of an individual successively diving deeper while moving northward and therefore remaining in colder water. However, the matching algorithm used to generate latitude estimates incorporates only those temperatures recorded by the tag in surface waters (waters between 0-5m), thereby suggesting such diving behaviour is unlikely to have occurred and a biasing of estimates in this way is unlikely. While a number of raw latitude estimates placed some fish at locations in north-eastern Australian waters, these tended to be isolated events (i.e. were not indicative of a directed and consistent movement) and therefore can be considered as obvious outliers associated with erroneous SST-based latitudes. However, the level of uncertainty associated with SST based latitude estimates highlight the need for more rigorous methods in both the calculation of position estimates and in filtering multiple candidate positions to produce the "most likely" track.

Implications for the spatial dynamics of mature SBT

The results of the 2004 PSAT deployments, while providing a more comprehensive understanding of the movement patterns of adult-sized SBT, are still too limited to allow for definitive statements about the spatial dynamics of SBT, particularly with regard to their migration from the Tasman Sea to those spawning ground south of Indonesia. However, these results highlight two important findings:

(i) That adult SBT are resident in the Tasman Sea for a large part of the year

(ii) That many of those SBT tagged in 2004 are unlikely to have undertaken movements associated with the first pulse of fish into waters associated with the spawning grounds south of Indonesia.

Given the failure of most tags to remain attached for the complete attachment duration, it is difficult to conclude whether the fish tagged as part of this study were likely to be part of those fish comprising the second spawning activity peak on the Indonesian spawning grounds, during the months of January and February. However if we consider the movement rates calculated from those individuals tagged as indicative of accurate movement rates, and these appear consistent through time, it seems highly likely that SBT are capable of moving from waters south of the Australian continent to the spawning grounds in time for the second spawning peak.

Summary of major results

- Considerable improvement in PSAT attachment duration was achieved in the 2004 season.

- Individuals demonstrated substantial variability in the period spent in the western Tasman Sea.

- Cyclical movements between the western Tasman Sea and the coastal waters of New Zealand were observed in two fish.

- Some SBT remained in the western Tasman Sea until at least October suggesting that SBT may not be the transient visitors to the region as previously thought.

- One individual was documented to undertake movements from the western Tasman Sea, into the Southern Ocean and west into the Indian Ocean entering those waters associated with the spawning grounds south of Indonesia February 2005.

- It appears unlikely that any of the fish tagged in the Tasman Sea would have been present in the first spawning pulse on the Indonesian spawning grounds in November and December.

- Two areas appear to be aggregation points for adult-sized SBT; south of the South Australian/Victorian region and to the south and east of Cape Leeuwin.

- Further collection of data and improved geolocation methods are required to confirm these preliminary observations.

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Table 1. Release and pop-up locations for 2004 PSAT deployments and 2004 conventional tag returns.

Tag Serial number	Release			Recapture/Popup			Displacement (km)	Daily displacement (km.day^{-1})	LCF (cm)
	Date	Latitude (°S)	Longitude (°E)	Date	Latitude (°S)	Longitude (°E)			*Length at recapture
Conventional tags									
507103/04	19/08/2002	35.1	151.9	24/06/2004	42.4	168.6	893.5	1.3	150*
506805/06	14/07/2003	16.2	150.8	05/07/2004	35.5	155.5	232.9	0.7	
Pop-up satellite tags									
02P0213	27/06/2004	34.2	151.9	21/10/2004	40.7	149.1	767.1	6.6	176
03P0342	5/07/2004	34.2	152.9	15/07/2004	30.4	155.8	499.2	49.9	173
03P0343	5/07/2004	34.2	152.9	4/09/2004	33.4	157.9	465.0	7.6	182
03P0341	5/07/2004	34.1	152.8	13/12/2004	42.8	153.4	964.7	6.0	174
03P0351	12/07/2004	34.7	153.2	14/07/2004	34.0	155.2	207.0	103.5	183
03P0349	12/07/2004	34.7	153.2	26/07/2004	32.5	154.6	271.5	19.4	175
03P0350	12/07/2004	34.7	153.2	3/02/2005	17.7	111.1	4559.9	22.1	169
03P0356	13/07/2004	34.6	153.3	15/07/2004	33.6	155.1	201.0	100.5	169
03P0353	13/07/2004	34.7	153.3	8/11/2004	43.3	150.3	989.7	8.4	174
03P0355	13/07/2004	34.7	153.3	19/11/2004	42.5	163.9	1271.4	9.9	169
03P0352	13/07/2004	34.7	153.3	14/01/2005	34.9	111.9	3751.2	20.3	170
03P0357	14/07/2004	34.7	153.2	Failed to transmit – data recovered					176
03P0358	15/07/2004	34.6	153.2	29/07/2004	34.5	152.1	95.9	6.9	173
03P0373	30/07/2004	35.0	152.0	13/12/2004	44.6	146.6	1165.0	8.6	171
03P0374	30/07/2004	34.9	152.0	Failed to transmit					189
03P0370	31/07/2004	35.0	152.0	15/11/2004	44.6	158.7	1212.7	11.3	169
03P0368	8/08/2004	34.7	152.7	29/12/2004	41.5	144.1	1062.5	7.4	172
03P0369	8/08/2004	34.8	153.0	15/01/2005	44.2	146.3	1193.6	7.5	173
03P0367	28/08/2004	36.4	152.9	30/12/2004	43.0	149.4	791.3	6.4	170
03P0366	29/08/2004	36.4	152.9	27/11/2004	40.8	133.6	1743.2	19.4	175

Table 2. Numbers of SBT tagged by month and length class.

Deployment Month	Length Class (cm LCF)						Month Total
	50-75	75-100	100-125	125-150	150-175	175-200	
June	0	0	0	1	0	1	2
July	1	0	0	37	76	3	117
August	0	3	1	13	13	1	31
September	0	1	2	6	0	0	9
Sum by Length	1	4	3	57	89	5	

Table 3. SRP Mortality Allowance usage for 2004. Locations are given by 5^{o} grid square.

Month	Whole weight (kg)	Numbers	Latitude (°E)	Longitude (°E)
June	305.4	3	30	150
July	928.4	10	30	150
July	1,191.7	17	30	150
July	76.0	1	35	150
August	1,416.8	19	30	150
August	935.0	11	30	150
August	487.4	8	35	150
September	234.8	3	35	150
Total	5,575.5	72		

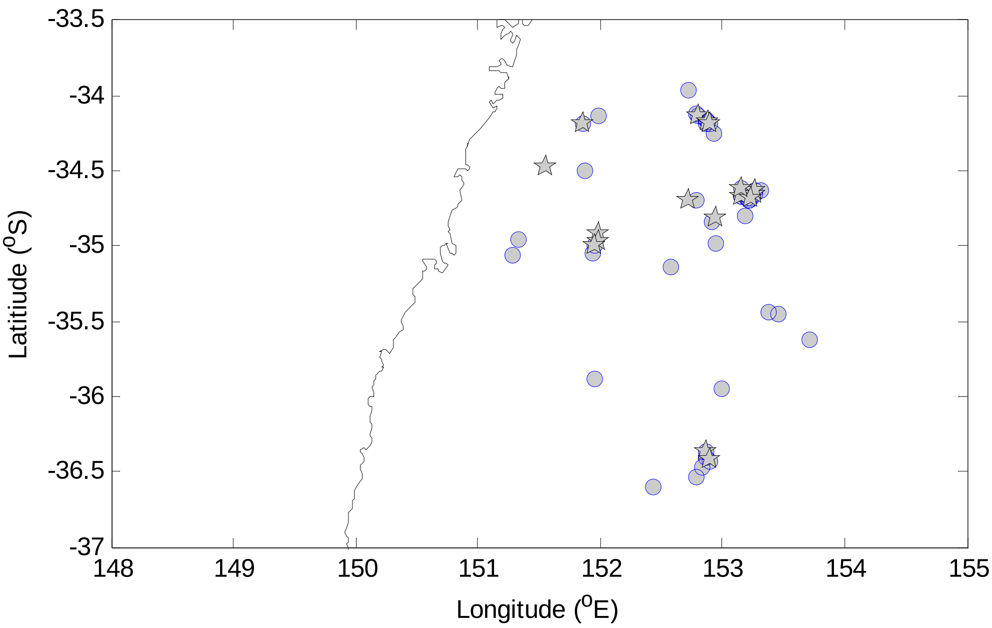

Figure 1. Release positions for PSAT (stars) and conventional tags (circles) deployed in 2004.

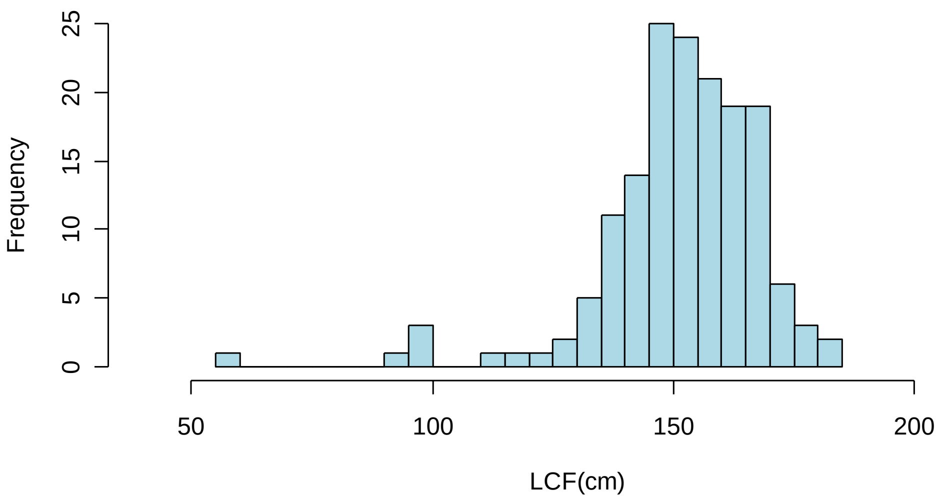

Figure 2. Length distribution of SBT tagged in 2004.

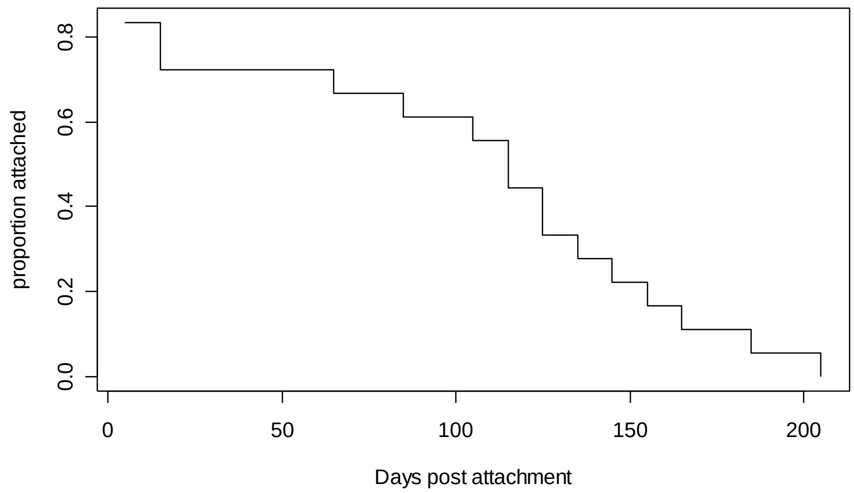

Figure 3. Detachment rate through time for PSATs deployed in 2004.

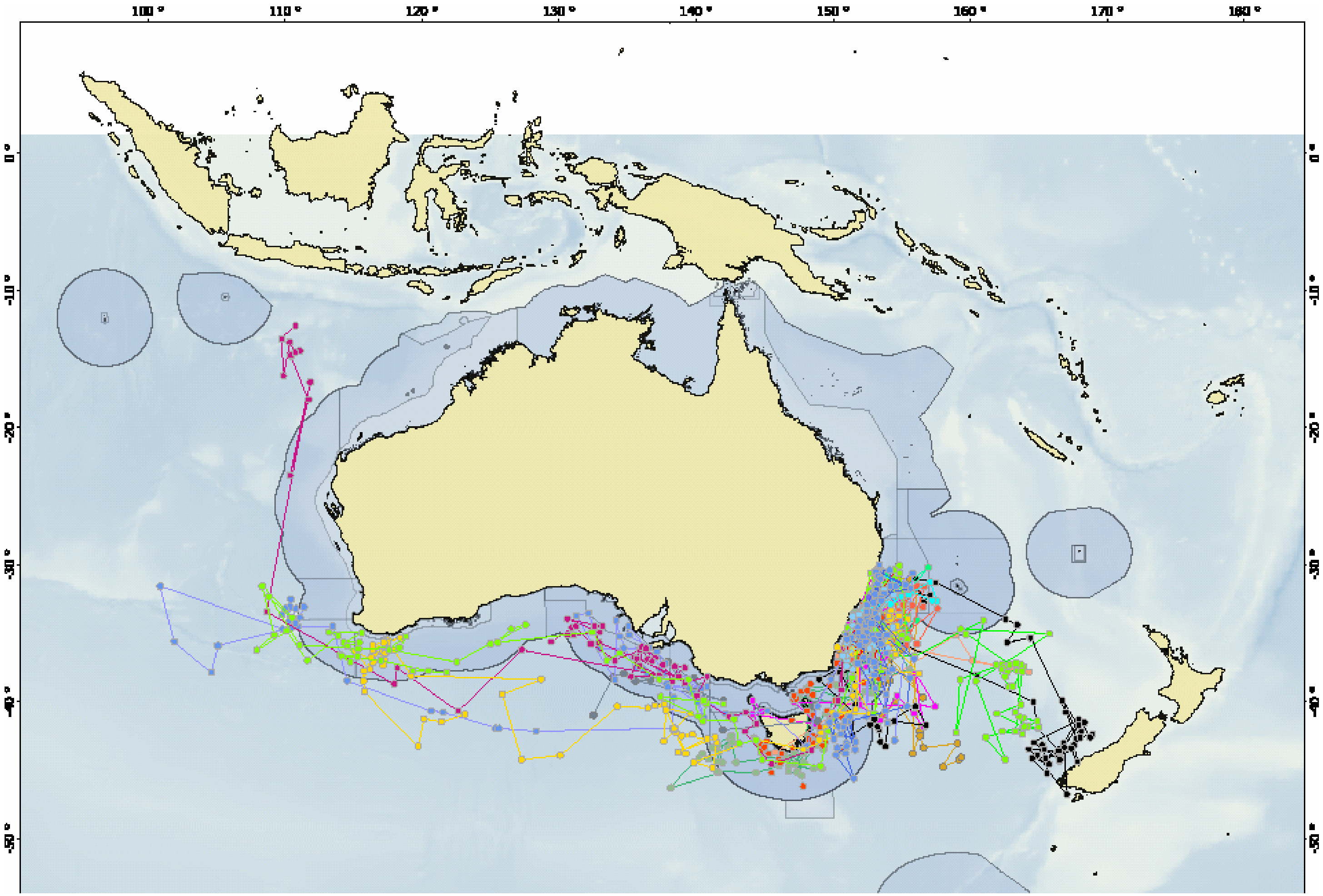

Figure 4. Tracks of SBT derived from geoposition data calculated from light data collected by PSATs deployed in 2004 in relation to the AFZ. Individual fish are represented in a different colour.

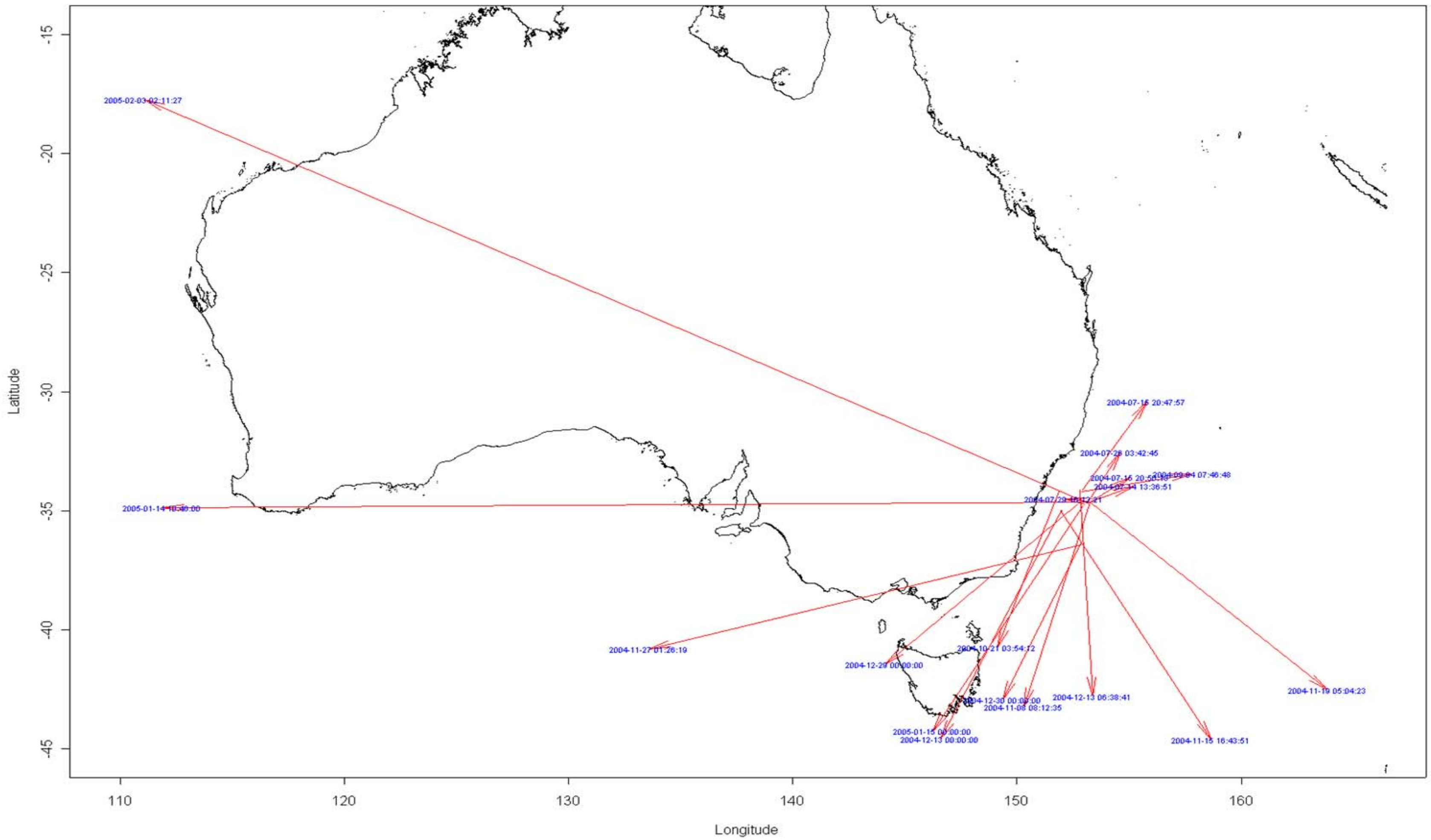

Figure 5. Straight line movements between release and popup locations for PSATs deployed on SBT in 2004.

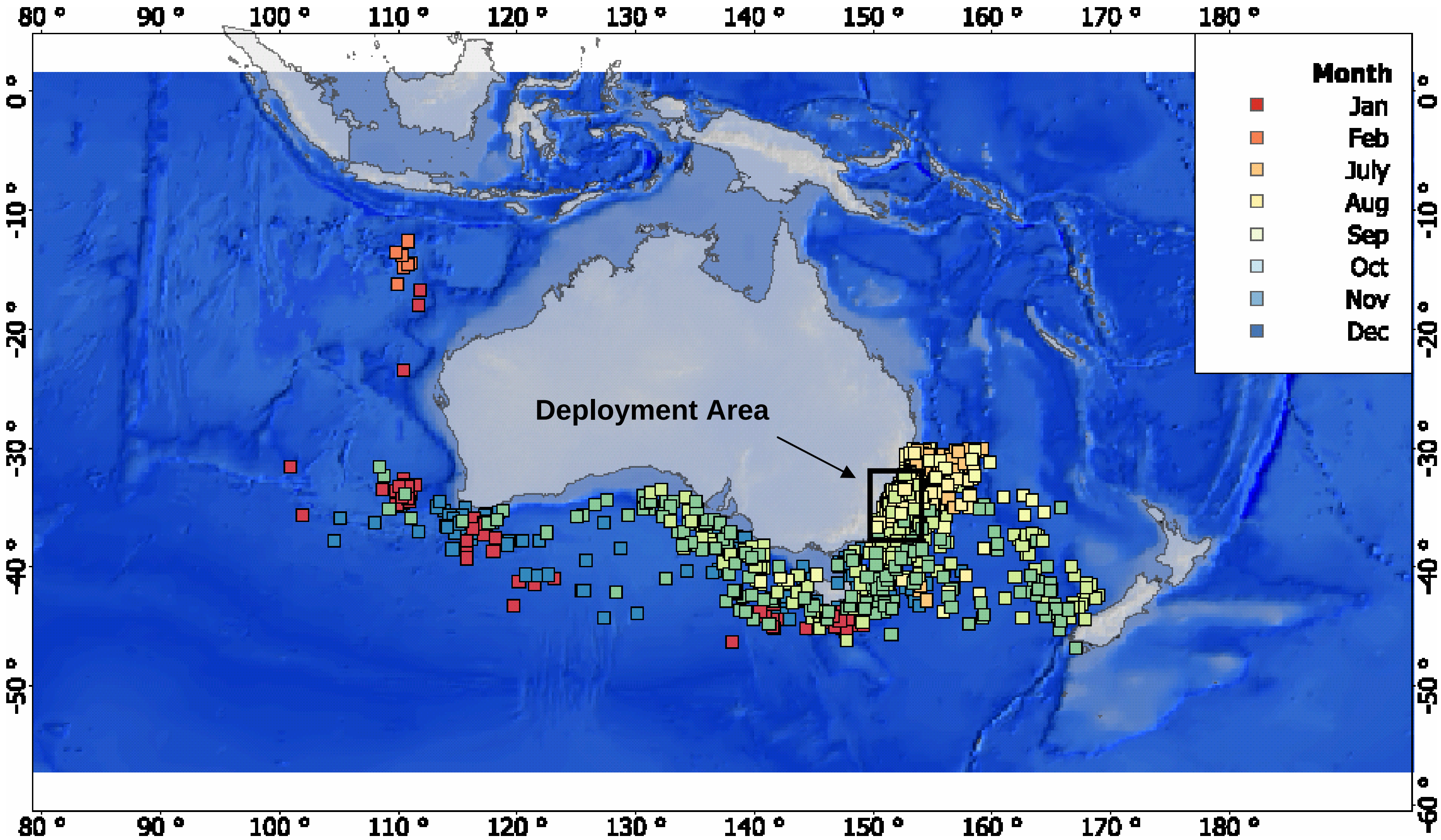

Figure 6. Movement of SBT from the tagging area in the Tasman Sea off NSW by month.