Movements and behaviour of large SBT in the Tasman Sea and Indian Ocean regions determined using pop-up archival satellite tags: a summary of results for 2006-07.

Karen Evans
Toby Patterson

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Abstract

Twenty-one Pop-up Satellite Archival Tags (PSATs) were deployed on large (mean ± SD: 160.5 ± 7.6 cm LCF; range: 151 – 179 cm) southern bluefin tuna (SBT) from chartered Australian longline vessels in the western Tasman Sea between July and August 2006. A further three PSATs were deployed on two smaller SBT (142 cm LCF) and a 160 cm LCF individual from a chartered South African longline vessel in the south-western Indian Ocean in December 2006. A total of 2.1 tonnes of the 5 tonnes of SRP mortality allowance allocated by CCSBT were used by this tagging project during tagging operations. Of the 24 PSATs deployed, 20 have transmitted data to the ARGOS system to date. Average attachment duration of PSATs deployed is currently 146 ± 62 days (range: 23 – 233 days), a considerable improvement on attachment durations from previous years (note: four tags are still at liberty). Displacement of SBT (distance between deployment and pop-up locations) ranged 48.2 – 1,673.9 km for those individuals tagged in the Tasman Sea and 192.6 – 2,861.7 km for those individuals tagged in the south-western Indian Ocean, with one individual tagged in the south-western Indian Ocean undertaking multiple trans-oceanic movements into the south-eastern Atlantic Ocean. The timing of departure of individuals from the Tasman Sea area, as per previous years, varied substantially, with SBT still present in the area throughout November and December and some as late as January and February. Directed cyclic movements between the western Tasman Sea and the eastern Tasman Sea were observed in four fish and were similar to those recorded previously by this tagging program. Individuals tagged in the Tasman Sea demonstrated similar habitat preferences to those tagged in previous years, spending the majority of time in waters less than 300m and 19-21°C. Individuals tagged in the Indian Ocean demonstrated preferences for slightly warmer (20-22°C) and shallower (<10m) waters. All fish tagged regularly utilised eddy/frontal features suggesting that southern bluefin tuna regularly take advantage of such oceanographic features. The data collected by the PSATs have added substantially to our current understanding of movements and degree of residency of SBT in the Tasman Sea region and suggest that this region is of significant importance to this species. Furthermore, the movement patterns of SBT, as recorded by these tags, support the previously suggested hypothesis that fish from the Tasman Sea region are unlikely to contribute to those fish on the Indonesian spawning grounds during the first part of the spawning season across the months September to December.

Keywords: Southern bluefin tuna, Pop-up Satellite Archival Tag, Tasman Sea, Indian Ocean, spatial dynamics.

Introduction

Southern bluefin tuna (*Thunnus maccoyii*) are a large long-lived pelagic predator widely distributed throughout the oceans of the Southern Hemisphere (Caton 1991, Clear et al. 2000). Similarly to other bluefin tunas (*Thunnus thynnus* and *T. orientalis*), southern bluefin tuna (SBT) are highly migratory, undertaking extensive movements throughout temperate foraging grounds and between foraging grounds and tropical spawning grounds (Gunn & Block 2001). Genetic evidence, the distribution of reproductively active individuals and the distribution of larvae suggest southern bluefin tuna (SBT) comprise a single population with spawning limited to an area south of Indonesia in the north-western Indian Ocean (Caton 1991, Grewe et al. 1997, Farley & Davis 1998). Fishery and conventional tagging data suggest a stable, age dependent spatial distribution of SBT and ontogenetic changes in migration patterns (Caton 1991).

Conventional assumptions of dispersal and movements of adult SBT are that individuals forage throughout the temperate waters of the Southern Hemisphere oceans during the austral winter, migrating annually to the spawning grounds of the north-west Indian Ocean across the spring and summer months (Shingu 1978, Caton 1991) before returning to foraging grounds in the following autumn/winter. However, a comprehensive understanding of the movements of SBT throughout their complete life history is lacking and almost nothing is known about the fidelity of fish to discrete fishing grounds or the mixing rates of SBT between these grounds. What we do understand about the spatial dynamics of adult SBT is derived almost exclusively from catch data and from the results of limited conventional tagging programs (most tagging programs have focused on juveniles rather than adults). Such interpretations are inherently biased by spatial and temporal variability in effort and targeting practices (Toscas et al. 2001[1]) and mark-recapture data available are limited in their interpretation of movement patterns. Such data are heavily fishery dependent and rely on accurate reporting of recapture information and minimal non-reporting of recaptures (Hearn et al. 1999, Gunn 2000).

In order to further our understanding of (i) movements of adult sized SBT in the Australian region, (ii) fidelity of SBT caught in the eastern Australian fishery to the western Tasman Sea region and (iii) mixing with adjacent areas to the Australian Fishing Zone (AFZ), an electronic tagging program was initiated in 2001 utilising pop-up satellite archival tags. Pop-up satellite archival tags transmit data on movement and behaviour without needing to be recovered, thereby providing fishery independent methods for assessing movement and habitat preferences in pelagic fish (Gunn & Block 2001). In 2006, this program was extended to include tag deployments in the Indian Ocean in an effort to (i) determine movement patterns of fish caught off the eastern South African coast (ii) their fidelity to this area and (iii) their connectivity with those fish moving from the Tasman Sea to the spawning grounds south of Indonesia. This paper provides an update on tagging operations in the western Tasman Sea region and also reports on those tag deployed in the south-west Indian Ocean region during 2006.

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[1] Toscas PJ, Venables WN, Thomas M, Polacheck T (2001) Modelling catch and effort in the southern bluefin tuna fishery. Working paper CCSBT-CPUE/0203/BGD/02 presented to the 6th meeting of the Extended Scientific Committee of the Commission for the Conservation of Southern Bluefin Tuna, 28-31 August 2001, Tokyo, Japan.

Methods

Tag deployments

Pop-up satellite archival tags (PAT4, Wildlife Computers, Redmond USA) were deployed on large SBT in the western Tasman Sea during July and August 2006 and in the south-western Indian Ocean during December 2006. Experimental procedures associated with animal handling, tag attachment and animal release have been described in detail in Gunn et al. (2006[2]). Fish were caught during commercial longline operations with those considered in good condition lead into a tagging cradle and then lifted on board the vessel. Fish were measured (cm LCF) and a PSAT attached via two anchors; the first inserted into the dorsal musculature at the base of the second dorsal fin and the second inserted into the dorsal musculature in line with the dorsal finlets. After attachment of the PSAT, the fish and cradle were lowered back into the water, allowing the fish to swim away from the vessel and a position of release recorded via the vessels GPS.

Data and analyses

The PSATs were programmed to record ambient temperature, pressure (depth) and light level at 60 second intervals. Tags were programmed to release 364 days after deployment at which time they float to the ocean surface and transmit their archived data via the ARGOS satellite service (Service Argos, Toulouse, France). Due to limited transmission power and satellite receiver bandwidth, data collected by the PSATs are summarized before transmission – we set all tags to summarise their data into eight hour time periods. The summary data for each time period consisted of distributions of the proportion of time spent within preset depth and temperature bins and temperature-depth profiles (Gunn et al. 2006[2]). Each tag also transmitted a mean sea surface temperature for each day at liberty.

Daily positions derived from each tag were calculated using a combination of light and temperature data. Longitude was estimated using proprietary software (WC-GPE.1.02.0000, Wildlife Computers, Redmond, USA) and latitude was calculated using those methods detailed in Gunn et al (2006[2]).

Histograms of summary depth and temperature data were examined to determine time spent at depth and temperature and qualitative comparisons were made between those fish tagged in the Tasman Sea and those tagged in the Indian Ocean. Interpolated depth-temperature sections were constructed from PDT profiles collected by the tag. These profiles provided a coarse examination of the water masses traversed over the deployment. Qualitative comparisons were then made between those fish tagged in the Tasman Sea and those tagged in the Indian Ocean.

[2] Gunn JS, Evans K, Patterson TA, Carter TI (2006). Examining the movement and residency of adult SBT in the Tasman Sea and on their spawning grounds south of Indonesia using pop-up archival tags. CSIRO Marine and Atmospheric Research report to the Department of Agriculture, Fisheries and Forestry.

Results

Tag deployments and attachment rates

A total of 21 PSATs were deployed on SBT 151 – 179 cm LCF (mean ± sd: 160.5 ± 7.6 cm) in the western Tasman Sea (Figures 1 and 2). A further three PSATs were deployed on two SBT of 142 cm LCF and one SBT 160 cm LCF in the south-western Indian Ocean (Figures 1 and 2). A total of 2.1 tonnes of the 5 tonnes of SRP mortality allowance allocated by CCSBT were used by this tagging project during tagging operations.

To date, data have been received from 20 of the total 24 PSATs released, with the remaining four PSATs still at liberty. All PSATs for which data have been collected detached prematurely, with periods of attachment ranging 23 – 233 days (mean ± sd: 146 ± 62 days). Trends in the overall rate of tag detachment demonstrated a similar negative exponential relationship to previous years however, tag loss was not as high in the first 50 days of deployment or during the period of 100-150 days after deployment compared to deployments in 2001-2005 (Figure 3).

Movements

Tasman Sea

Individuals tagged within the western Tasman Sea demonstrated variable rates of residency, with those recorded moving out of the area doing so 118 to 164 days after tag deployment. The earliest an individual moved out of the Tasman Sea and into the Southern Ocean was late November with the majority of individuals that were recorded to leave the Tasman Sea before tag detachment moving out of the region throughout December (Figure 4). Four individuals were still located in the Tasman Sea at the time of tag detachment in December and January and one individual was still in the Tasman Sea region when its tag detached in late February. Four individuals were observed to undertake movements east of the deployment area into the central Tasman Sea and as far as 165°E before returning to waters of the western Tasman Sea. Of these, one individual then moved south and into waters west of Tasmania (144.5°E) and one moved into waters south-east of Tasmania before tag detachment. A further eight SBT moved south of the deployment area and into waters west of Tasmania and of these, two moved west of 140°E. One individual traveled as far as 138.5°E before its tag detached in late January and the other traveled as far as 134°E where it stayed for approximately one month before the tag detached in mid-March (Figure 4). Of those individuals at liberty greater than 118 days (n = 14), size (length) did not appear to be related to the duration of time spent within the Tasman Sea region and therefore the timing of movement out of the area (Figure 5). Total displacement distances (distance between deployment and pop-up locations) ranged 48.2 – 1,673.9 km.

Indian Ocean

Individuals tagged in the south-western Indian Ocean demonstrated varying degrees of movement with all individuals spending considerable time in waters 35-45°S (Figure 4). Both 142 cm fish remained in the south western Indian Ocean while the 160cm fish made two distinct excursions west and into the south-east Atlantic Ocean returning to the south-west Indian Ocean in between each. On both occasions the fish moved up the west coast of Africa to an area at about 26-28°S off the Namibian coast before moving further south west on the second occasion and crossing the Greenwich median before its tag detached (Figure 4). Total displacement distances (distance between deployment and pop-up locations) ranged 192.6 – 2,861.7 km.

Behaviour

Individuals tagged in the Tasman Sea demonstrated similar temperature and depth preferences to those tagged in previous years (Figure 6). Individuals largely preferred depths shallower than 300 metres and spent the majority of time in waters 18-21°C with a mode of preferred temperature at 20°C. Individuals spent time in waters deeper than 200m and cooler than 18°C in association with movements into the eastern Tasman Sea (e.g. tag 53644; Figure 7) and movements southwards into the Southern Ocean (e.g. tag 53271; Figure 7).

Individuals tagged in the south-eastern Indian Ocean demonstrated a higher tendency to spend time in warmer, surface waters (Figures 6 and 7), preferring depths of less than 10m and temperature of 20-22°C. However, individuals also spent time in deeper (greater than 600m) and colder waters (less than 10°C) than those demonstrated by SBT tagged in the Tasman Sea.

Discussion

Although we are yet to achieve full deployment of tags for the period of a complete year[*], tag attachment durations were substantially improved from those in 2001-2005. Combining all datasets from tags during the period 2001-2005, this program has now achieved records from 36 individuals of greater than 90 days duration post-deployment, 19 individuals of greater than 150 days post-deployment and 5 individuals greater than 200 days post-deployment. This increased duration of records from the 2006 deployments has provided for a significant building of our current understanding of movements and degree of residency of SBT in the Tasman Sea region and new insights into the movements of SBT in the Indian Ocean.

Movements

Records of movement in SBT collected in 2006 support previous suggestions raised by this program that the Tasman Sea region is of significant importance to large SBT, with individuals utilising this area for substantial periods of the year (Patterson et al. 2005[3]). As observed in previous years, oceanic waters west of Tasmania also appear to be important to this species and at least some of the population move throughout the Tasman Sea between fishing areas managed by Australia and those off the west coast of New Zealand.

Detailed records of movement in SBT inhabiting southern Indian Ocean waters were recorded for the first time as part of tagging operations in 2006. Similarly to SBT tagged in the Tasman Sea, SBT in the Indian Ocean undertook movements of substantial scales, demonstrating connectivity between ocean basins consistent with the results of genetic analyses investigating the stock structure of SBT (Grewe et al. 1997). No SBT tagged in the

[*] Note that four tags had not completed their set deployment period of 364 days at the time of writing.
3 Patterson T, Gunn J, Evans K, Carter T. (2005). 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. Working paper CCSBT-ESC/0509/29 presented to the 10th Meeting of the Extended Scientific Committee (SC10) 29 August-3 September, and 5-8 September 2005, Taipei, Taiwan

Indian Ocean demonstrated movements into regions north of 35°S, however we cannot rule out the potential for Indian Ocean fish migrating to the spawning grounds in the early months of the season (August to November) and returning to the southwest Indian Ocean by December (when tagging operations occurred). Davis et al. (2003[4]) reported evidence for temporal partitioning of individuals on the spawning ground in relation to size with individuals 140-159 cm more likely to be caught in the first half of the spawning season.

Records of movement spanning greater than 150 days in duration have been greatly enhanced by deployments in 2006, allowing for further investigation of the timing of potential migration of fish from the Tasman Sea region to the spawning ground. No SBT tagged in the Tasman Sea region in 2006 demonstrated clear, directed movement to the spawning grounds south of Indonesia. Although restricted by premature detachment periods, those data collected from the 2006 deployments support the previously suggested hypothesis that fish from the Tasman Sea region are unlikely to contribute to those fish on the Indonesian spawning grounds during the first part of the spawning season across the months September to December. The furthest west any individual tagged in 2006 travelled to was 134°E. If we assume continued movement of this individual west at similar movement rates to those recorded by fish that have been observed to move to the area of the spawning grounds (see Gunn et al. 2006[2]), it is unlikely this fish would have arrived on the spawning ground until at least April, well after the main period of the spawning season as defined in Farley and Davis (1998).

Current management of the SBT stock assumes annual cyclical migration of adults between the spawning grounds of the north-west Indian Ocean across the austral spring and summer months and temperate foraging grounds in the austral autumn and winter months. While our data are somewhat restricted by premature detachment periods, it could be postulated that at least some proportion of the SBT population foraging in the Tasman Sea region do not migrate to the spawning grounds on an annual basis. Alternative suggestions as to why this program has failed to record more than one individual migrating to the spawning ground include (i) timing of movement to the foraging ground is highly variable and spatially structured with a significant proportion of individuals foraging in the Tasman Sea region migrating to the spawning grounds during the later months of the season (March-May) and those in the Indian Ocean region migrating during the earlier months of the season (August-November); periods not currently covered by our tagging results; (ii) tagging alters migration behaviour or (iii) individuals tagged are yet to contribute to the spawning population (i.e. are immature).

While some further data may be obtained from the four fish still currently at liberty, our ability to discern the timing of migration of adult sized SBT or indeed the possibility of the occurrence of skipped spawning is still somewhat limited by small sample sizes and collection of a dataset that can be considered to be representative of the broader population. Although it is possible that the procedure of tagging and the physical impact of carrying a tag may affect the behaviour of individuals, there is little clear evidence of abnormal behaviour in tagged individuals and it is unlikely that a similar significant behavioural change would occur in all individuals tagged. Considerable efforts were made to ensure that all individuals tagged were of a large enough size to capture the movements of mature fish. All individuals tagged were of similar size to those observed on the spawning ground (Davis and Farley

[4] Davis T, Farley J, Bravington M, Andamari R. (2003). Size at first maturity and recruitment into egg production of southern bluefin tuna. CSIRO Marine Research report to the Fisheries Research and Development Corporation Project No 1996/106.

2000) and the majority (20 of 24 tagged) were larger than the mean length at which 50% of fish are considered mature (Davis 1995[5]). It must be noted however that although these comparisons support our argument that fish tagged by this program are representative of the mature population of SBT, care must be taken as data on length at maturity and distributions of lengths on the spawning ground are inherently biased by sampling design. Considerable further commitment involving longer attachment durations is required before definitive statements regarding the spatial dynamics of SBT and the representativeness of tagged individuals of the population can be made.

Behaviour

Individuals tagged within this study, as in previous years of tagging, have demonstrated a physiological capacity that enables an enlargement of their thermal niche, thereby facilitating an ability to capitalize on dispersed prey concentrations across a wide depth and temperature range.

Individuals tagged in the Tasman Sea region were observed to move between warm waters of 19-20°C and those less than 18°C, suggesting regular utilization of warm core eddies within the East Australian Current (EAC). Movement out of the region of the EAC were clearly discernable with individuals encountering cooler surface water temperatures as they moved either east and into the central and western Tasman Sea or south and into the Southern Ocean. Regular encounters with warm water fronts are notable outside of the EAC region, suggesting that southern bluefin tuna regularly take advantage of such oceanographic features.

The warmer temperatures encountered by those fish tagged in the south-east Indian Ocean may be the result of individuals inhabiting waters associated with strong current features, similar to individuals tagged in the Tasman Sea utilizing waters of the EAC. The presence of warm waters of greater than 18°C to depths of approximately 200m suggests these fish are regularly utilizing waters associated with the Agulhus Current. This oceanographic feature is the western boundary current of the south Indian Ocean and runs down the eastern African coast, penetrating as deep as 800m (Beal & Bryden 1999). The current continues around the tip of Africa before it encounters waters associated with the counter-clockwise sub-tropical gyre and waters associated with the flow feeding the Antarctic Circumpolar Current and turns back on itself and flows eastward as the Agulhas Return Current (Quartly & Srokosz 1993). All fish were noted to utilise warm waters as far east as 53°E and may have been taking advantage of the eddy systems associated with the Agulhas Return Current. A component of the Agulhus Current also feeds into the Benguela Current on the west coast of Africa and is possibly the warm water “conveyor belt” the individual observed to move into the south Atlantic travelled along both times it visited the region of the Benguela Current. Also notable was the movement of one SBT across distinct frontal regions whilst in the south-eastern Indian Ocean region. These may have been associated with movements of the fish south and across the south subtropical front (Belkin & Gordon 1995).

Tuna have been widely documented to associate with frontal areas and transition zones (Reddy et al. 1995; Block et al. 2001; Royer et al. 2004; Schick et al. 2004). Frontal areas are often associated with biomass maxima, concentrating chlorophyll production and associated secondary productivity and it has been hypothesised that SBT use warm-core eddies and the

[5] Davis TLO. (1995) Size at first maturity of southern bluefin tuna. Working paper CCSBT/95/9 presented to the Scientific Committee of the Commission for the Conservation of Southern Bluefin Tuna, 10-19 July 1995, Shimizu, Japan.

warm side of fronts as thermal refuge after periods of foraging in colder waters (Gunn & Young 2000). Use of such oceanographic features to trade-off forage availability against thermoregulatory requirements has been postulated for other species of tuna elsewhere (Neill 1976, Sund et al. 1981), while others have hypothesised that this association is strictly related to the aggregation of forage species only (Brill & Lutcavage 2001, Brill et al. 2002, Royer et al. 2004) and is not used for thermoregulatory requirements. Whether or not this association has links to thermoregulatory requirements, the long forays into cool water demonstrated by SBT, both in the Tasman Sea region and the south-west Indian/south-east Atlantic Oceans in this study represent a physiological capability which may allow this species to capitalise on prey concentrations (when they are present) by maximising the amount of time spent in these frontal and eddy regions.

The data collected as part of this study represent a major step towards reducing uncertainty about the spatial dynamics of large SBT across the southern regions of its distribution. At the same time, it raises further questions as to the reproductive schedule of participants in the spawning stock and the location of other important foraging areas for this species both in the Australian and the African regions. Despite the limitations of the technology used to collect these data (limited attachment durations and therefore data collection periods, variable reporting rates, limited data transmission/reception capacities and inaccuracies in estimating position associated with geolocation methodology), determining such aspects of the life history of this species independent of the fishery would be difficult without the use of PSATs. Further tagging utilising this technology is encouraged to resolve questions on the extent of mixing of individuals across the Tasman Sea and in the Indian Ocean, possibly involving collaborative input of tags in the eastern Tasman Sea and on either side of the Indian Ocean. Such programs will also serve to provide clarity on the timing of spawning migrations and the definition of reproductive schedules within this species.

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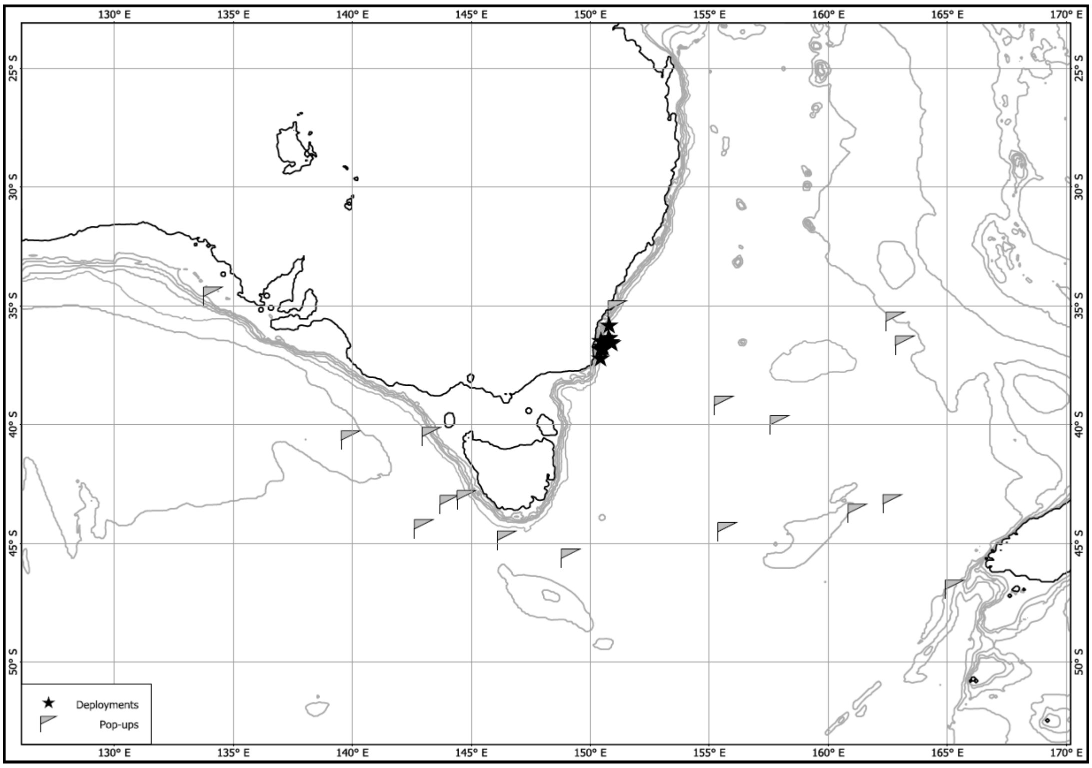
List of figures

A.



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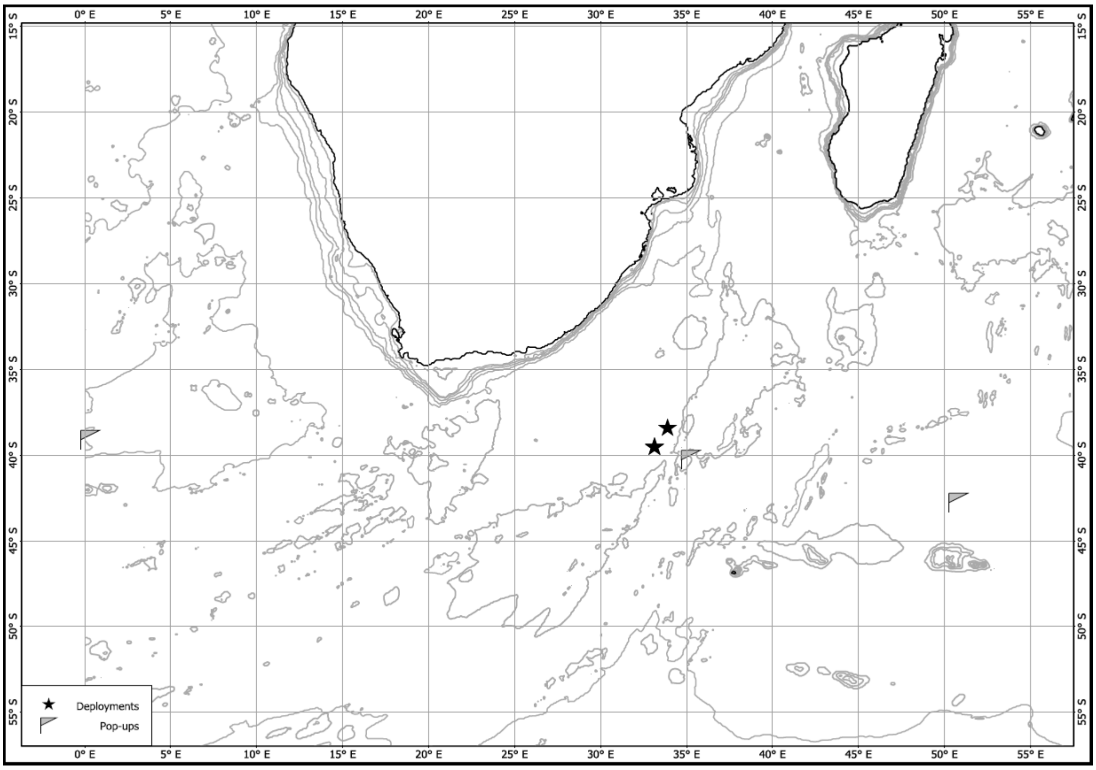


Figure 1. Release and pop-up positions of PSATs deployed in the (a) western Tasman Sea and the (b) south-western Indian Ocean in 2006.

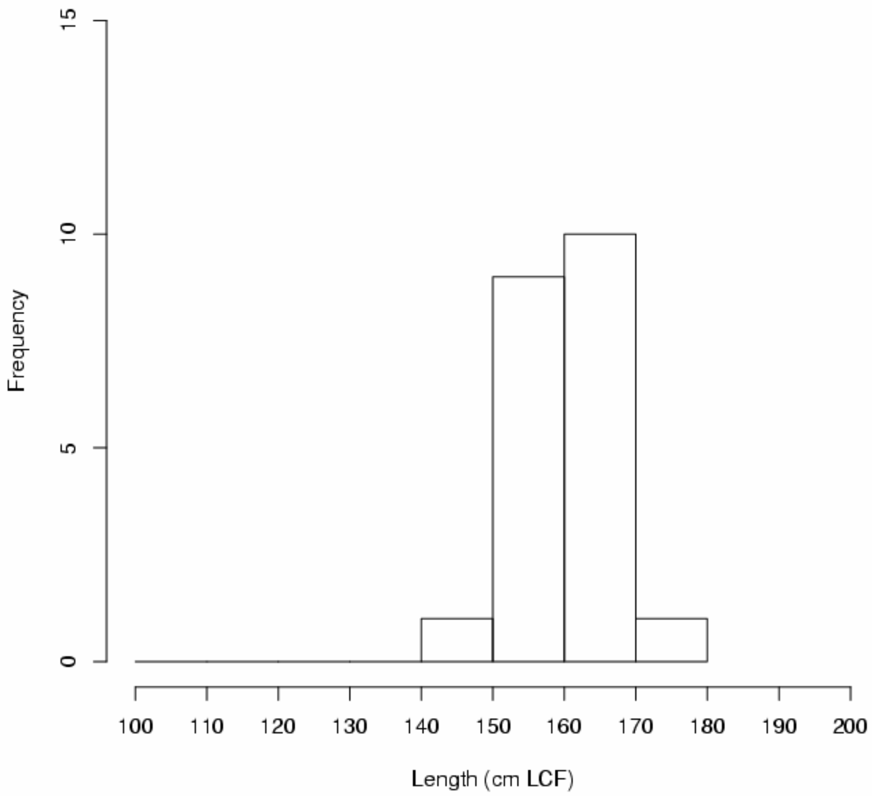


Figure 2. Distribution of lengths of SBT tagged with PSATs in the western Tasman Sea and the south-western Indian Ocean.

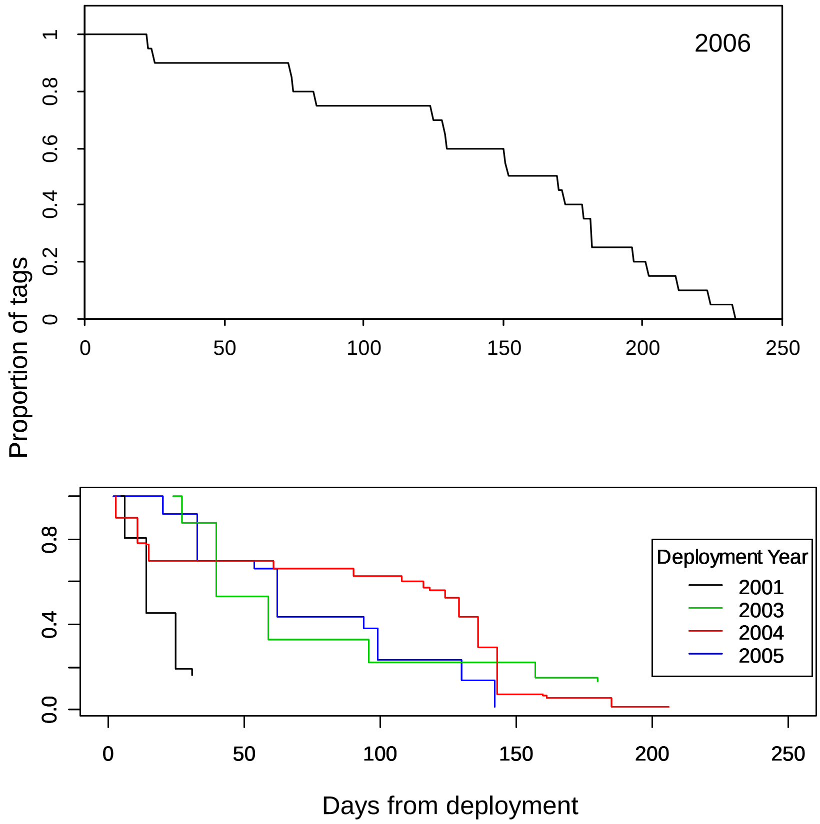
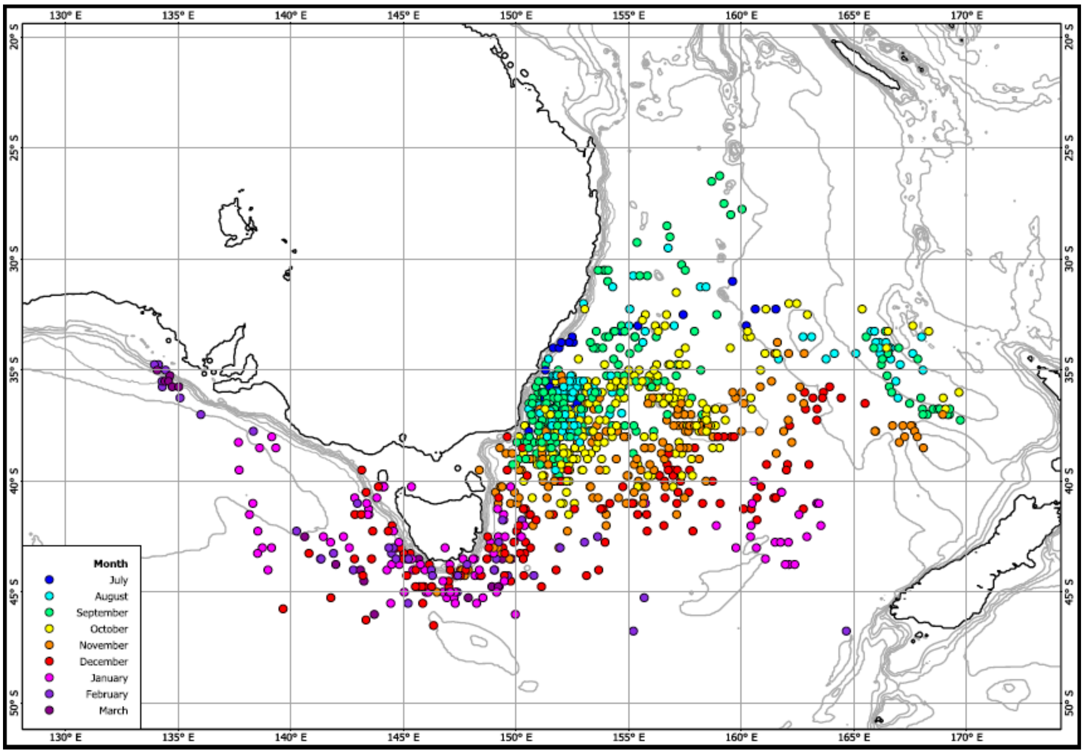


Figure 3. Tag survival rates for PSATs deployed on SBT in 2006 (upper panel) compared to 2001-2005 (lower panel).

A.



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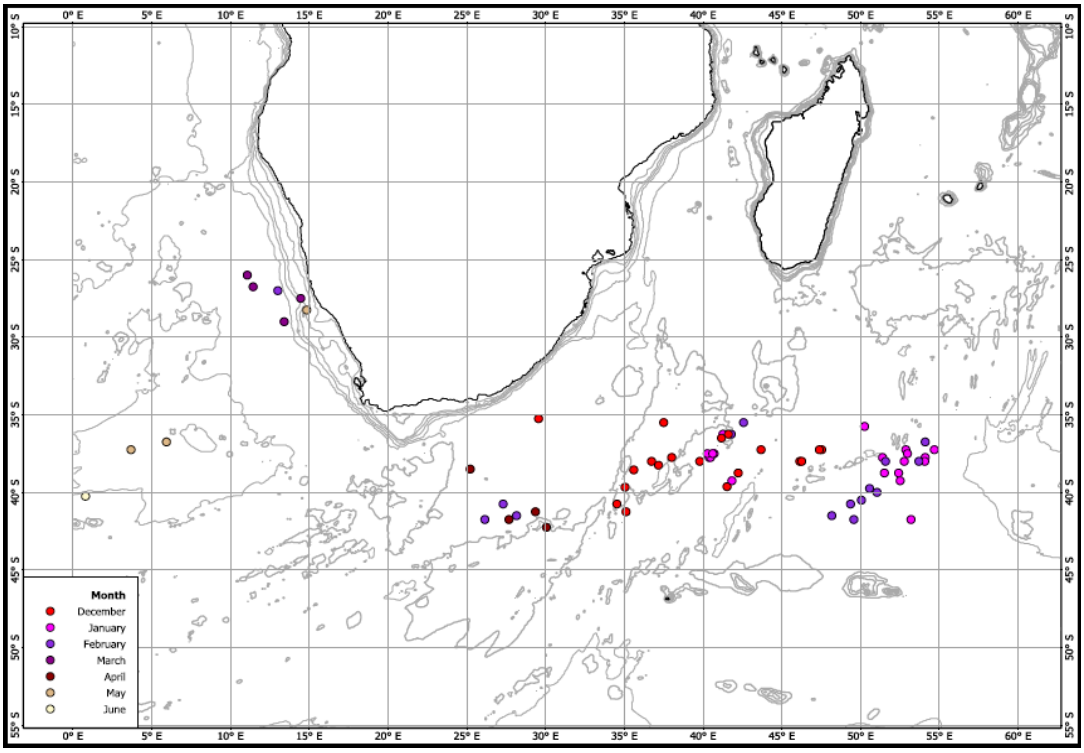

Figure 4. Position estimates of SBT tagged in the (a) Tasman Sea Region and (b) Indian Ocean at liberty July 2006 – June 2007.

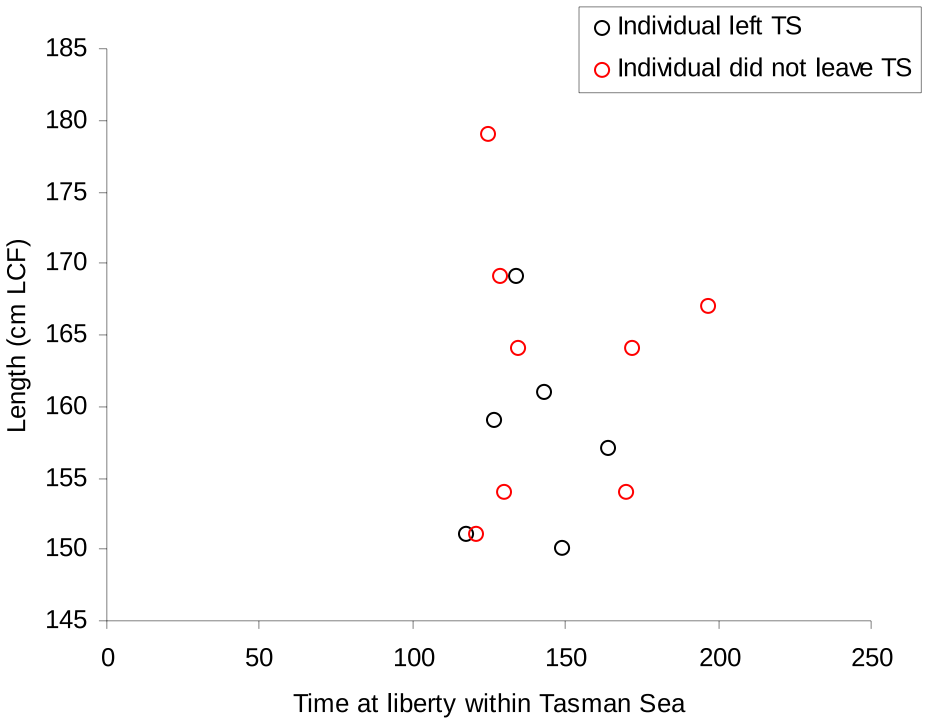

Figure 5. Relationship between the length of individuals tagged and the time spent within the Tasman Sea. Black circles represent those individuals recorded to leave the Tasman Sea, red circles represent those individuals still in the Tasman Sea on tag detachment.

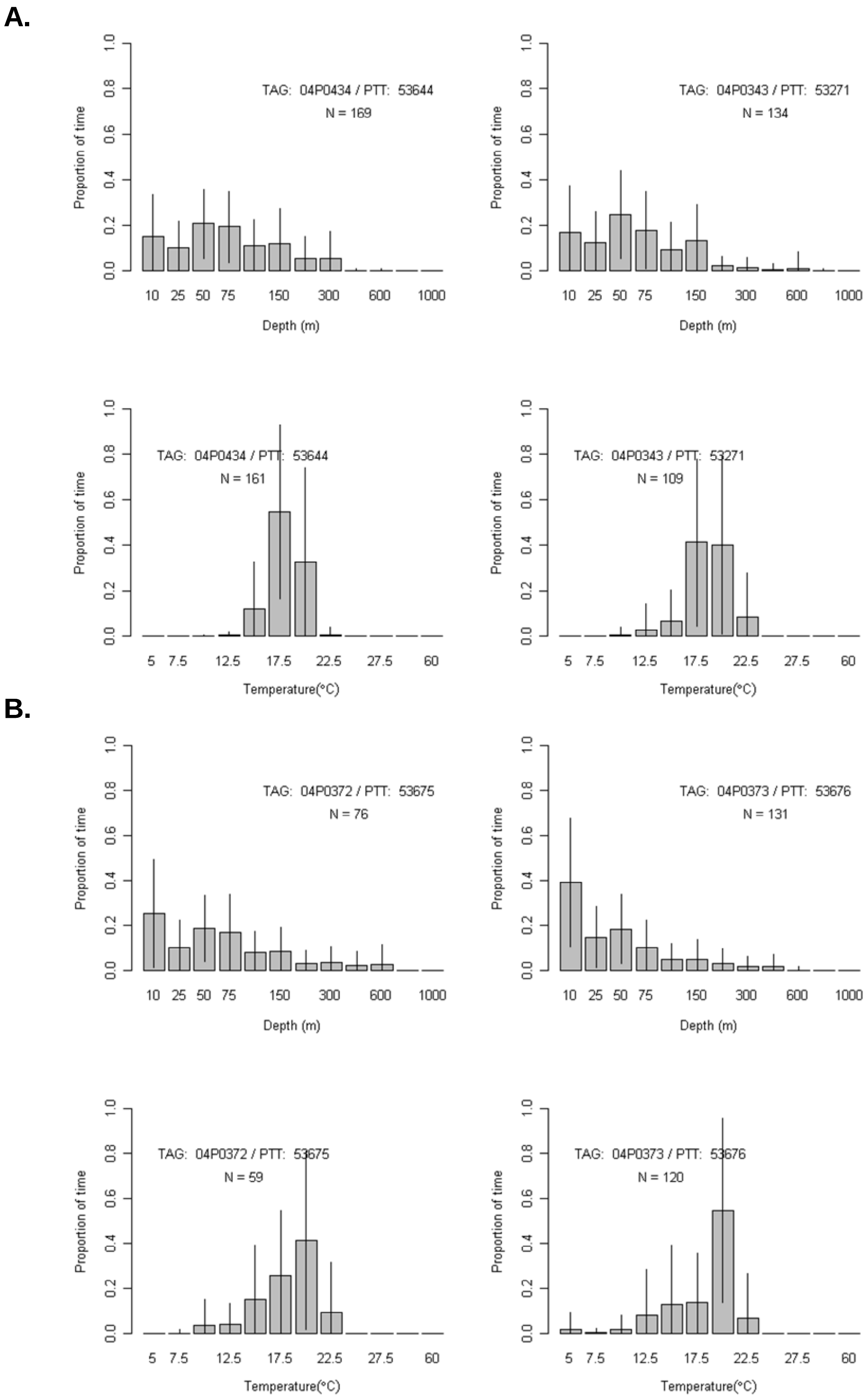

Figure 6. Time spent at depth and temperature for (a) two SBT tagged with the tags 53644 and 53271 in the Tasman Sea and (b) two SBT tagged with tags 53675 and 53676 in the Indian Ocean.

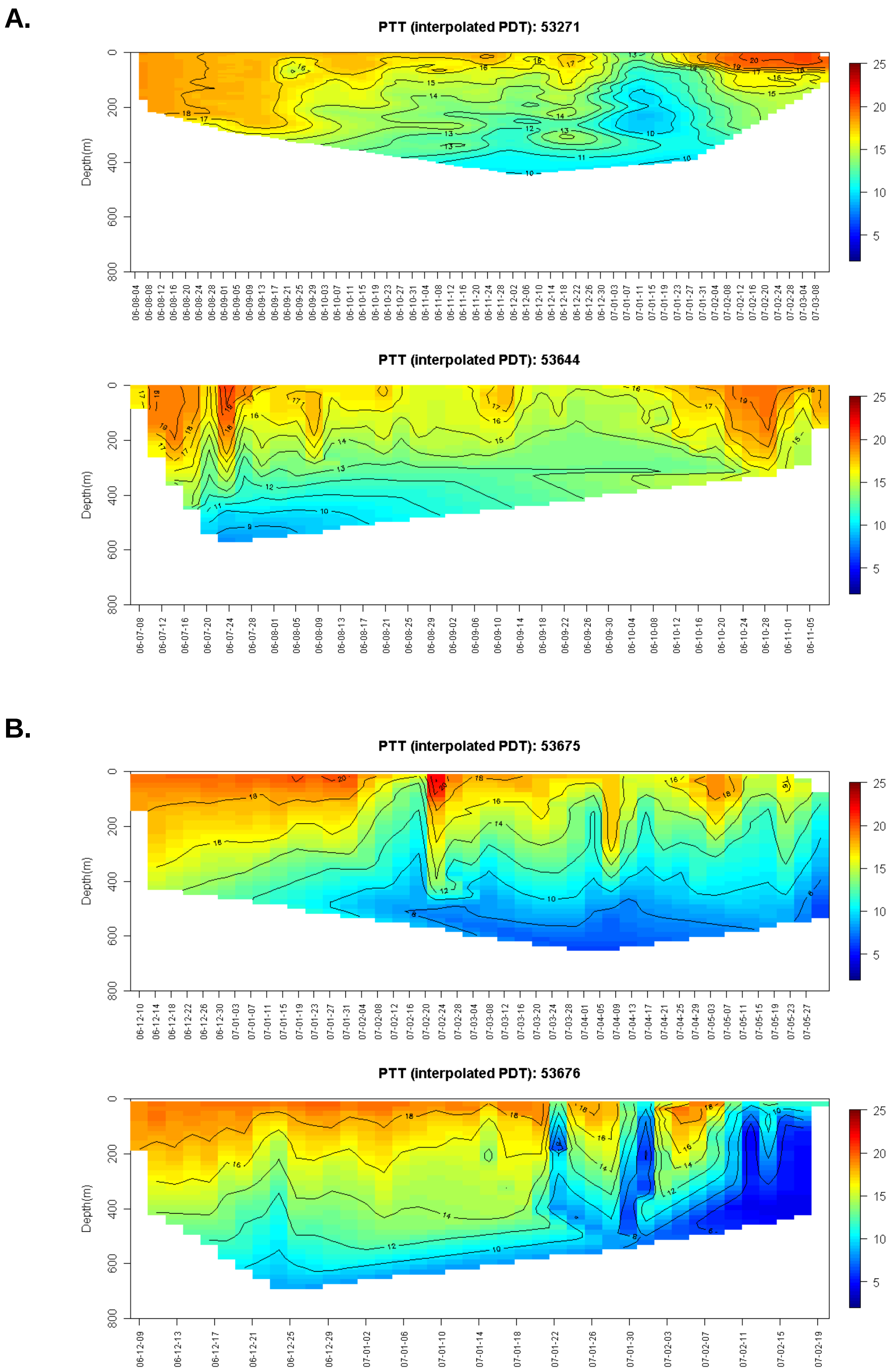

Figure 7. Interpolated temperature-depth profiles for (a) two SBT tagged with the tags 53644 and 53271 in the Tasman Sea and (b) two SBT tagged with tags 53675 and 53676 in the Indian Ocean.