Comparison of East-West Movements of Archival Tagged Southern Bluefin Tuna in the 1990s and early 2000s

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Abstract

Preliminary results on the east-west movements of juvenile southern bluefin tuna (SBT) from recaptured archival tags released in 2004-2005 suggests marked differences when compared to the results from archival tags released in the 1990s. For the tags released in 2004-2005, not a single fish has shown movements into the Tasman Sea (i.e. waters east of 140°E) during the winter period. This contrasts with the results from the 1990s, in which ~20% of the recovered tags moved into the Tasman Sea. While additional returns are needed to confirm these results, they are consistent with tag return data from conventional tagging and with reported juvenile catch rates in commercial longline fisheries. Possible reasons for the apparent disappearance of eastward migrants in the recent archival tag returns are discussed.

Introduction

The spatial dynamics and habit use of juvenile southern bluefin tuna (SBT) is complex and perhaps unique among large pelagic predators. Juvenile SBT (age 1 to 4) are currently found in large numbers during the Austral summer (December to April) in near shore waters in Western Australia (WA) and South Australia (SA) (e.g. see Caton 1991). Conventional tagging of fish in these areas indicated that some individuals move large distances (e.g. as far as South Africa or New Zealand) within 3 to 6 months (e.g Polacheck et al. 1995). Nevertheless, the vast majority of the tag returns from very extensive conventional tagging were recaptured in the surface fisheries in WA or SA, often within a hundred miles or less of where they were released (e.g. Polacheck et al, 1995; Stanley, 1998). This was true not only for short term recaptures but also for recaptures with time of liberty extending beyond the summer fishing season when the fish were tagged. It is only when the age of the recaptured tagged fish begins to exceed 5-6 that a high proportion of the returns do not come the Australian surface fishery but instead are caught in high seas longline fisheries (often at great distances from their release location). These results suggested that a large proportion of juvenile SBT spend their time in the waters around southern Australia and gradually disperse as they age into high seas areas where they subsequently become vulnerable to longline fisheries. These results were also consistent with the catches in the longline fisheries, in which some juveniles were persistently caught over wide areas but in which their frequency within the catch increased with age.

Results from archival tagging experiments conducted in the 1990's radically altered this picture. These tags provided daily estimates of the location of a fish between the time of release and recapture. The position estimates from archival tagged recaptured fish demonstrated that many juvenile SBT undertook extensive annual cyclic migrations. These cyclic migrations entailed spending periods of 2-5 months in the near-shore, shelf waters of southern Australia (SA) during the Austral summer. Following their austral summer residency in the shelf, the tagged fish showed rapid, directed movements south and then east or west into the high seas where animal would spend the Austral winter. This was then followed by rapid return to the shelf waters of SA for the following Austral summer. The winter migrations into the high seas were of three types: (1) extensive movements into the waters to the south of Australia (e.g. between Tasmania and Cape Leeuwin). In addition to these archival tag results, increasing number of conventional tags were returned from Japanese longline vessels from releases in the 1990s as a result of improved promotional and liaison activities. The return data in the 1990 indicated substantial and rapid interactions between the surface and longline fisheries, particularly when the generally low reporting rates from longline vessels (based on observer data) are taken into account. Thus, the previously very low proportion of juvenile conventional tag returns from longline fisheries in relation to the surface fishery now appears to have been due, at least in part, to low reporting rates from the high seas rather than a lack of availability of tagged fish in these areas (Polacheck et al 1995, Eveson and Polacheck, 2005).

To further clarify the spatial dynamics of juvenile SBT, an extensive archival tagging program was initiated in 2002; this project aimed to release archival tags in all areas where juvenile SBT are commonly found (Polacheck et al 2003). A better understanding of spatial movements is important for the analysis of the large scale conventional juvenile tagging that is being conducted during this same period by the Commission for the Conservation of Southern Bluefin Tuna (CCSBT) as part of its collaborative scientific research program (SRP). The returns to date from these latter archival tags further confirm the annual cyclic migration found in the 1990 releases. However, the preliminary results suggest that movement patterns during the Austral winter may have changed with possible implications for the interpretation of recent recruitment trends. The purpose of the present paper is to present an initial comparison of the movements patterns from archival tags released during the 1990s and 2000s. We also discuss hypotheses for the apparent changes that have been observed. It should be emphasized that the results are preliminary at this stage of the project and because more tags are expected to be recovered.

Material and Methods

Tagging methods

Electronic tagging was initiated by CSIRO in 1993. Sixteen major releases of juvenile SBT with implantable archival tags took place between 1993 and 2006 (Gunn et al 1994, Gunn and Block 2001, Polacheck et al 2006). Prior to 2003, all of the SBT were tagged and released in the Great Australian Bight off SA. Subsequently, archival tags have also been released from shelf waters off WA and on the high seas in the Indian Ocean and New Zealand. The high seas releases were conducted by trained observers from either Taiwan or New Zealand operating aboard longline vessels. All of the other fish tagged were caught by pole-and-line using barb-less hooks. The tags surgically implanted into the peritoneal cavity ventral to the stomach. The SBT targeted were 1-4 year olds with caudal fork lengths ranging between 50 and 120 cm Fish were tagged with either Zelcon Technic P/L SBT100, SBT150, SBT200 or Wildlife Computers Mk7 or Mk9 archival tags. All tags types have a pressure sensor, photodiode light sensor and two thermistors: one thermistor external to the body to record water temperature; as well as an internal thermistor to collect data on visceral temperature (the latter excepting the Zelcon SBT100 tags). The Zelcon tags were programmed to record data from each sensor every four minutes for the first three months at liberty. Thereafter, these tags recorded for two consecutive days each week and then turned off for the remaining five days allowing data to be collected over a full year. The Wildlife Computers Mk7 tags were programmed to sample every four minutes and Mk9 every 20 seconds or 1 minute until their memory was filled (estimated to be five years after release).

A reward of $AUD250 or equivalent merchandise was offered for tag return. Only tags recovered prior to July 2006 have been included in the current paper. We have subsequently received an additional 7 tags but time did not permit the processing of the data from these tags.

Position estimation

The tag-based light data allow the estimation of the times of sunrise and sunset for a given day (or night) and the mid-point between sunrise and sunset allows estimation of noon, or midnight. By relating either of these times to the respective times at Greenwich, longitude can be calculated using standard nautical formulae (Hill, 1994; Musyl, M. K. et al. 2001; Welch, and Eveson,1999). Light readings were corrected for depth attenuation prior to the estimation of sunrise and sunset. The light data combined with the water temperature measurements can be used to also estimate latitude. This is a more complex and time-demanding then the estimation of longitude. Time and resources have not permitted latitude estimation from the more recent returns to be included at this stage. As such, we have only used the longitude estimates in the current paper. The lack of latitude estimates, does not affect the results presented here since the analyses in this paper are focused on changes in the east-west (longitude) migratory behaviour and habitat use among the main winter resident locations.

Only fish which for which at least one migration from summer residencies to winter grounds could be determined are included in the analyses here. This meant that not all recoveries from longline releases have been included since to date none of these have provided information on such migrations[1]. We have also not included tags which were released in the GAB during the summer and recaptured during the following winter by high-seas longline vessels. Although these tags do provide information on the east-west movements, differential in reporting rates among fisheries and areas, as well as changes over time, confounded the interpretation of the results from these tags.

Results and Discussion

East-West Movement

Figures 1-3 show the light-based longitude estimates for recovered archival tags released in three different periods (i.e. 1993-1995, 1998-2000 and 2002-2005). In each figure the positions are plotted in relationship to January 1 of the release year for each tag. Positions are shown up to day 450, until the day of recapture, or to the day the electronics failed. Three different patterns are evident in movements during the winter months in these figures:

(1) movement into, and substantial time spent in, the Indian Ocean (i.e. west of ~110°E);

[1] The longline releases have occurred during the winter months and all recaptures to date have either been during the same winter or the next summer. Thus, movements have been for a period less than 1 year.

(2) movement restricted primarily to the waters south of the Australian continent (i.e. ~115-145°E) and

(3) movement into, and substantial time spent in, the Tasman Sea (i.e. ~145-175°E).

Within those fish that moved into the Indian Ocean, there is a large amount of variability in the extent of westward movement. Some animals moved into the far western Indian Ocean approaching South Africa, others moved only as far as the central Indian Ocean and other still restricted their movements to the more eastern parts of the Indian Ocean.

Comparison of the tracks in Figures 1 to 3 suggest that east-west movements have substantially contracted for tags released in 2002 or later compared to the early releases – in their eastward and perhaps in their westward extent. Thus, not a single one of the 13 recoveries from the 2002-2005 releases moved into the Tasman Sea. This compares to 18 out of 57 (or 32%) of the earlier releases (Table 1). The difference in the percentage is significant based on a chi-square test (p=0.046). It should be noted that two of the 2000's recaptures were from fish tagged off Western Australia, while all of the 1990 recaptures were from releases in the GAB. Excluding these two tags, the chi-square for the differences in the percentage yields a p-value of 0.072. However, one of the WA recaptures provided data for two years and after spending its second summer in the GAB, it spent the following winter in the Indian Ocean before being recaptured in the GAB. As such, the second year of movement data for this tag is comparable to a SA release, and its inclusion yields a p-value of 0.057. The more recent archival tags also had a tendency not to move to the more western portions of the Indian Ocean. Thus, not a single tag moved farther west than 65°E compared to 11 from the earlier releases (Table 2). However, in this case the differences are not significant (p=0.19). It is also worth noting that altogether three of the archival tags released in the 2002-2005 period have provided data for two winter seasons. In all three cases, the animals returned to the Indian Ocean for their second winter at liberty before being recaptured in the GAB during their second summer at liberty.

The changes evident in the movement patterns from the archival tags with respect to the Tasman Sea are consistent with conventional tag return data and juvenile catch rates (e.g. Polacheck and Eveson 2005, 2006, Hartog et al 2006). Very low numbers of conventional tags have been recovered from longline operations in the Tasman Sea for releases since 2001compared to the 1990s (Figures 4 and 5). As discussed in Polacheck and Eveson (2006), the lack of longline returns from the Tasman Sea can not be attributed to a lack of longline effort. Catch rates of juvenile SBT in the Tasman Sea have also been very low – both on an absolute level relative to those in the Indian Ocean and relative to those in the 1990s (Hartog et al, 2006). Furthermore, since around 2002 juvenile SBT have been almost completely absent in the New Zealand SBT fisheries. This suggests that those juvenile SBT which do enter the Tasman Sea are not moving as far east as previously observed.

Environmental Changes

Major changes in the ocean environment can result in changes in migration patterns and habitat use. We undertook some preliminary, comparative analyses of sea surface temperature (SST) in the 1990s and 2000s to see if there was any indication of major changes over this period. While change in a range of environmental variables may potentially affect the east-west movements of juvenile southern SBT, in this preliminary investigation we have focused only SST because of time constraints and because SST often provides an informative indicator/predicator of major environmental changes in oceanic ecosystems. We first considered the SST in a restricted portion of the Tasman Sea [140-155°E, 45-35°S], which encloses the eastern portion of the Tasman Sea area used by SBT in the 1990's, using the CSIRO 10-day average SST data (Figure 6).We combined all images for the months May-August for each year to create a winter composite SST dataset. We then compared the SST over two periods; an early period (1993-1998) and a late period (2003-2006). We also calculated the difference between them. To investigate changes in other parts of the migration pathway, we considered two other regions where juvenile SBT occur using the same approach;

(1) south of the Great Australia Bight [125-140°E, 45-35°S],
(2) eastern Indian Ocean [100-125°E, 45-35°S]

We note that the Tasman Sea (south-east Australia) has shown a warming trend over the past 30 years (Hobday and Matear 2005; Cai 2006). Our analysis of satellite SST data during the Austral winter over a shorter time-series also shows this warming (Figure 7**).** In the region of the Tasman Sea considered, the surface ocean has warmed during winter by approximately 0.5°C (Table 3**)** with warming of up to 2°C off eastern Tasmania. The spatial pattern of warming (Figure 8**)** shows that the warming has been most dramatic in the far south-east, in the suspected path of tuna migration, around southern Tasmania, and north into the Tasman Sea. This warming may potentially be acting to restrict the movements of juvenile SBT to areas previously visited in the 1990s. With regard to the other two areas considered, there has been considerably less warming (if any) in the southern Great Australia Bight and the eastern Indian Ocean (Figures 9 and 10**,** Table 3).

The warming in the Tasman Sea is related to a greater southward extension of the East Australia Current (Cai, 2006). Changes in additional variables, such as forage distribution, remain difficult to estimate, and so SST remains as a proxy for environmental change. The link from environment to changes in tuna distribution remains speculative, however, as we have not investigated potential changes in all other parts of the tuna range, although we showed there was virtually no similar change in one other region (the eastern Indian Ocean) and a change of substantially lower magnitude in another region (the GAB). We do not know in what way or how increases in SST might act to deter juvenile SBT movements to the east coast. The temperature in the Tasman Sea during the winter in the 2000 certainly is not a physiological barrier to juvenile SBT (e.g. juvenile SBT are found in warmer waters during the summer in the GAB). In addition, archival tagged SBT tagged in the 2000s did not move east of 145°E which westward of the areas experiencing the warming (Figure 8). Thus, it is not clear what information these fish would have used to know that conditions in the Tasman Sea had changed. Finally, sub-adult and adult SBT are still found on the east coast and off New Zealand during these more recent high-SST winters. At this point, the most that we can say is that the changes in the observed eastward movement of fish as measured with archival tags have occurred at the same time as the oceanographic conditions in Tasman Sea have changed. Changes of similar magnitude have not been observed in other parts of the species range that we explored.

General Discussion

Changes in habitat use by a population can arise as a response to (1) changes in the environment, (2) changes in population abundance (e.g. density-dependent responses – MacCall, 1990) or (3) reduction/elimination of a sub-stock/component of the population. Given the available information, any of these causes or a combination of them could be contributing to the observed change in juvenile movements and spatial patterns. Thus, the examination of SST indicates a substantive difference in the Tasman Sea. However, stock assessment and fishery indicators indicated several years of low recruitment around 2000 (corresponding to the year classes of fish tagged with archival tags since 2000). This could be indicative of a density dependent response. In addition conventional tagging results indicate very high exploitation rates on fish from these year classes found within the GAB and apparently differentially so from those found at age 1 off WA (see Polacheck et al 2006). This might indicate differential reduction in different sub-components of the stock. Within this context, it is worth noting that the surface fishery off NSW in the late 1970's and early 1980's also operated on locally aggregated schools of juvenile tuna in that area and that exploitations rates were very high at this time. The NSW fishery continued to operate until juvenile schools essentially disappeared from this area in the early 1980's and there have been no signs of any appreciable recovery since then. The results from NSW indicate that geographic components of the juvenile SBT population are vulnerable to extirpations. Finally, the preliminary nature and relatively small sample sizes currently available for the 2000 releases should be kept in mind when interpreting the results presented here.

Acknowledgements

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Table 1: The number of recovered archival tags by release year which had a maximum longitude less than or exceeding 145°E.

	Maximum Longitude	
Year	<145	>145
1993	2	0
1994	6	2
1995	12	4
1998	9	7
1999	4	3
2000	6	2
2002	1	0
2003	1	0
2004	10	0
2005	1	0
Total	52	18

Table 2: The number of recovered archival tags by release year which had a minimum longitude less than or exceeding 65°E.

	Minimum Longitude	
Year	>65	<65
1993	2	0
1994	5	3
1995	15	1
1998	14	2
1999	4	3
2000	6	2
2002	1	0
2003	1	0
2004	10	0
2005	1	0
Total	59	11

Table 3: Summary of mean SST (°C) for the three regions considered.

	East Coast	GAB	Indian Ocean
Early average (1993-1998)	13.58	12.51	12.39
Late average (2003-2006)	14.13	12.70	12.42
Difference (late-early)	0.57	0.19	0.03

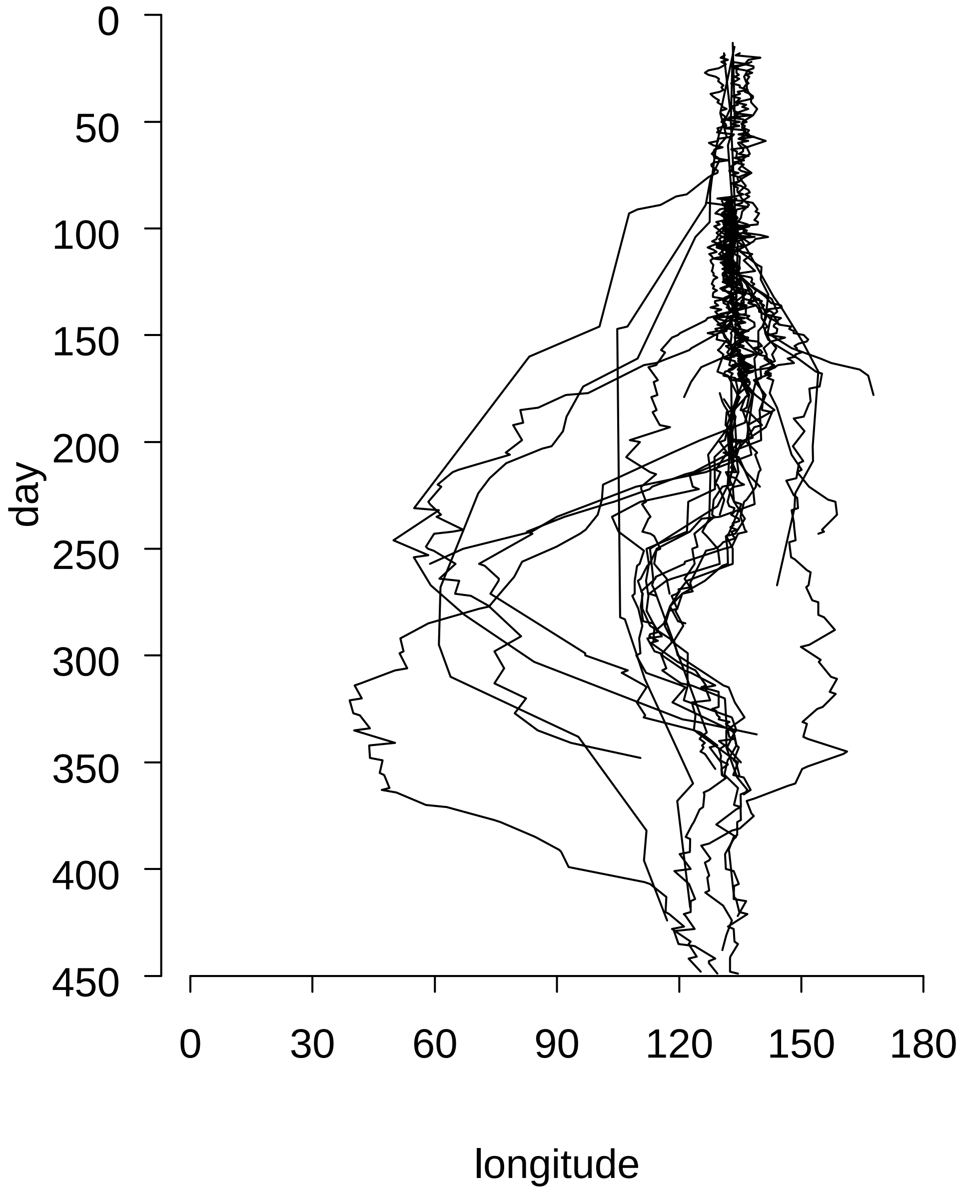

Figure 1: Estimated longitude of archival tags released in 1993-1995 over time relative to January 1 in the year of release for each tag (N=26).

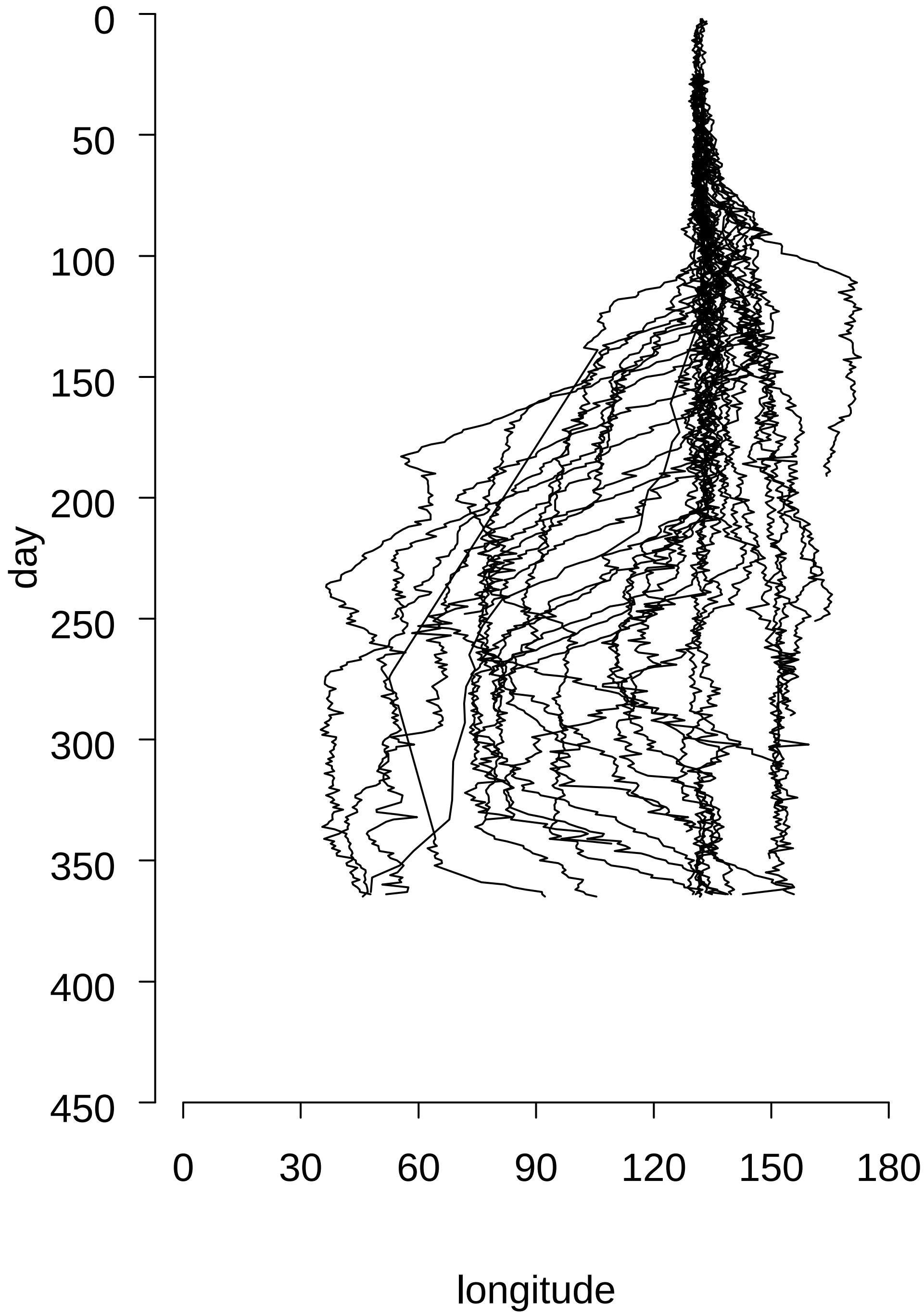

Figure 2: Estimated longitude of archival tags released in 1998-2000 over time relative to January 1 in the year of release for each tag (N=30).

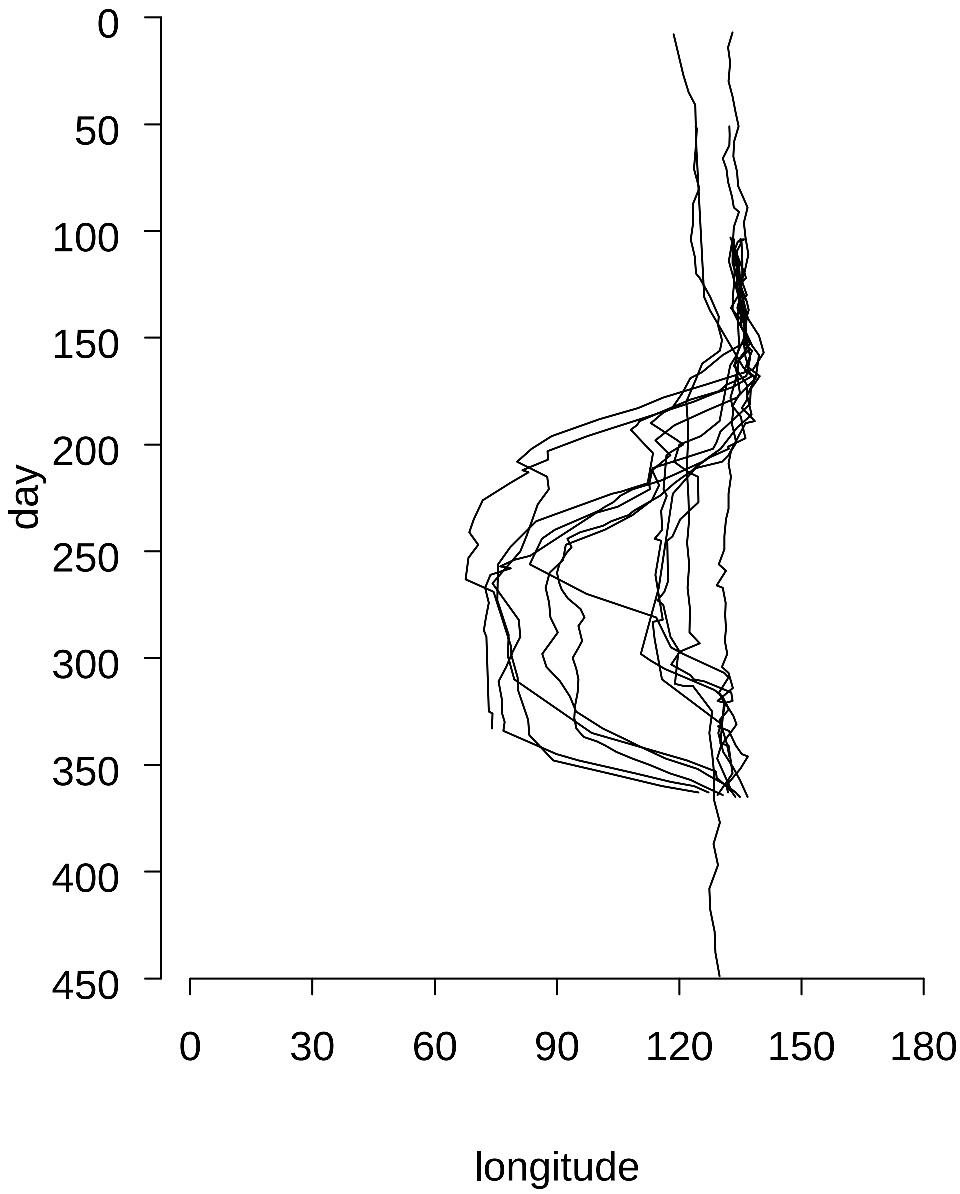

Figure 3: Estimated longitude of archival tags released in 2002-2005 over time relative to January 1 in the year of release for each tag (N=13).

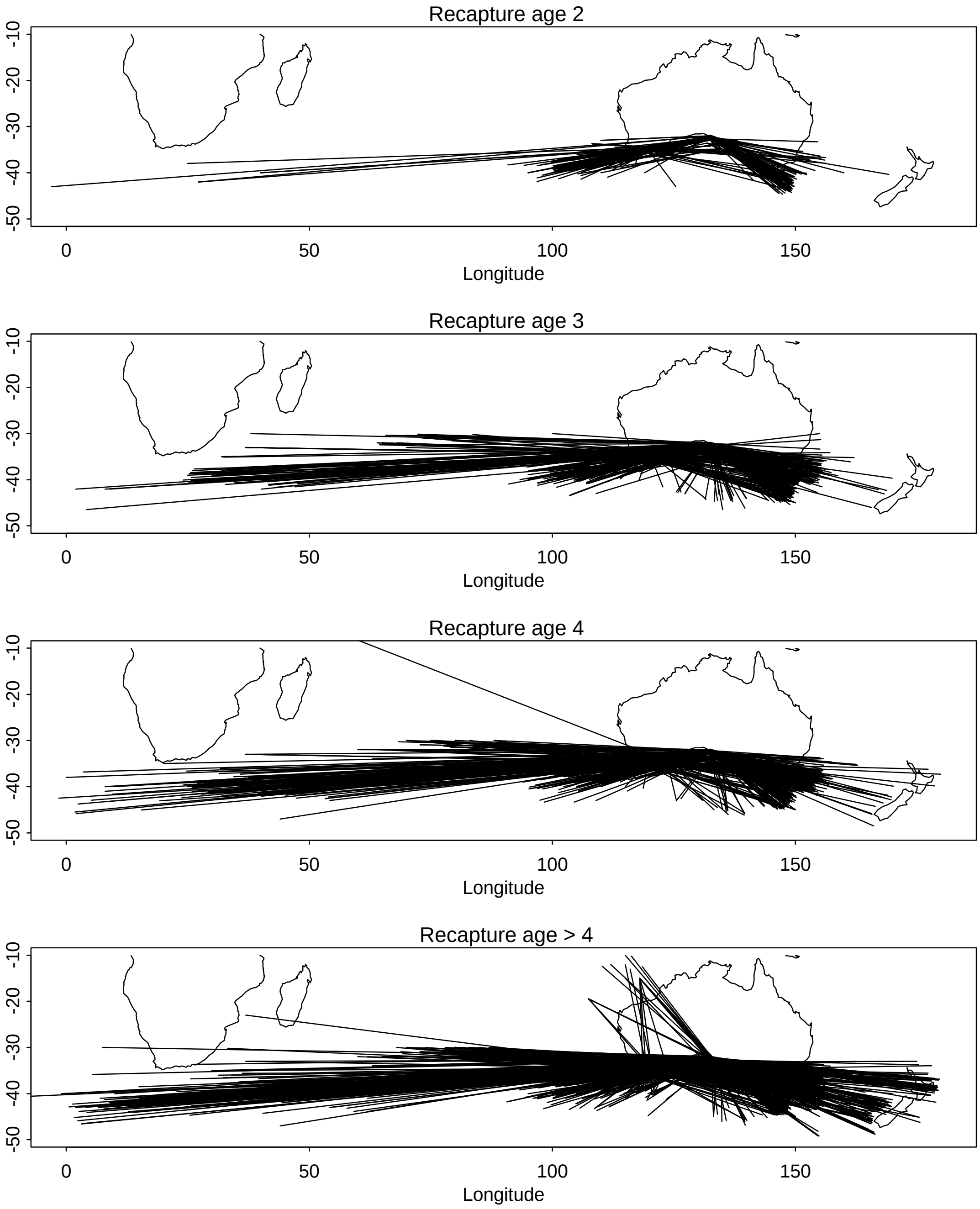

Figure 4: Release and recapture locations for longline tag returns for different ages at recapture from the RMP conventional tagging in WA and SA in the 1990s.

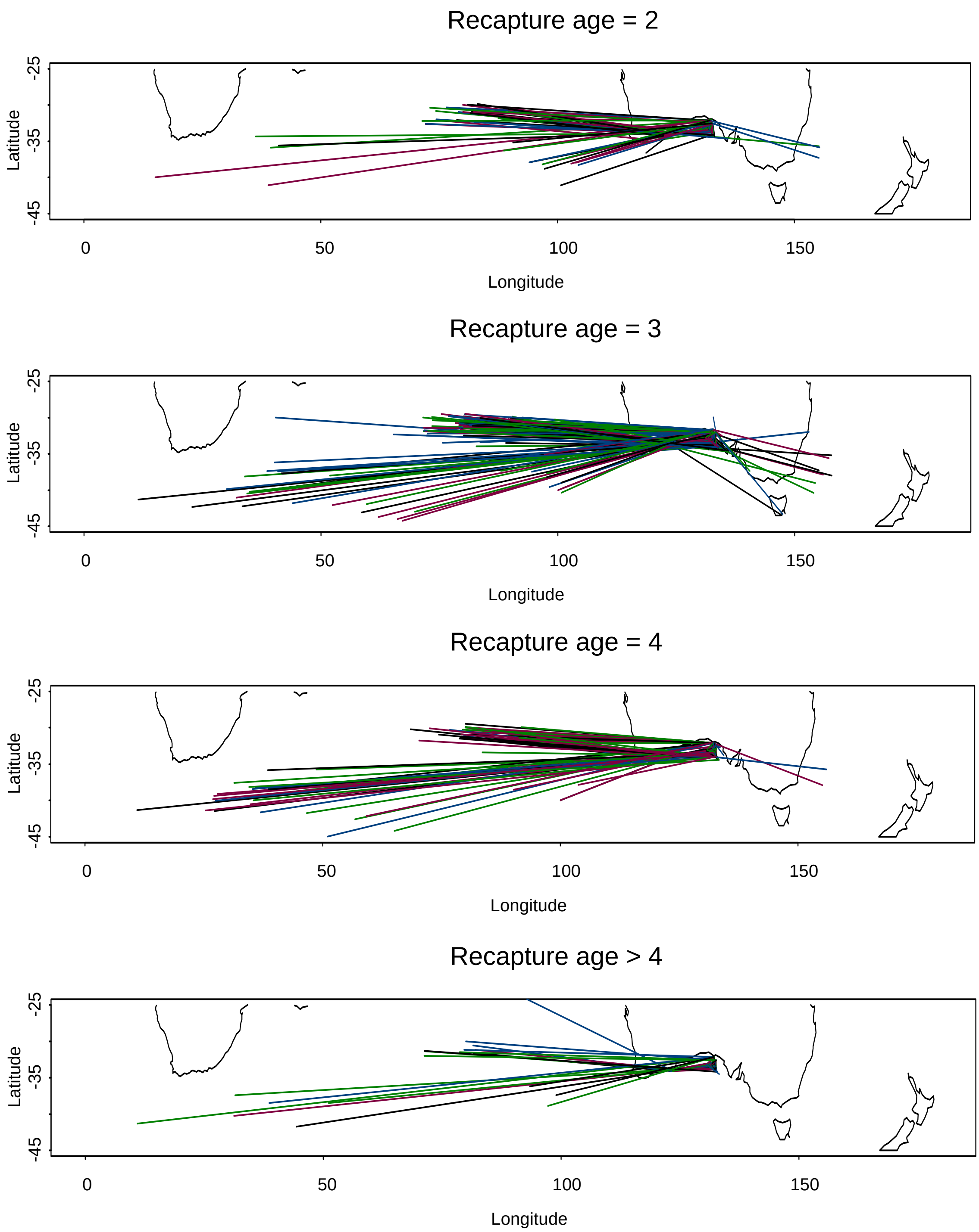

Figure 5: Release and recapture locations for longline tag returns for different ages at recapture from the SRP conventional tagging in WA and SA since 2001.

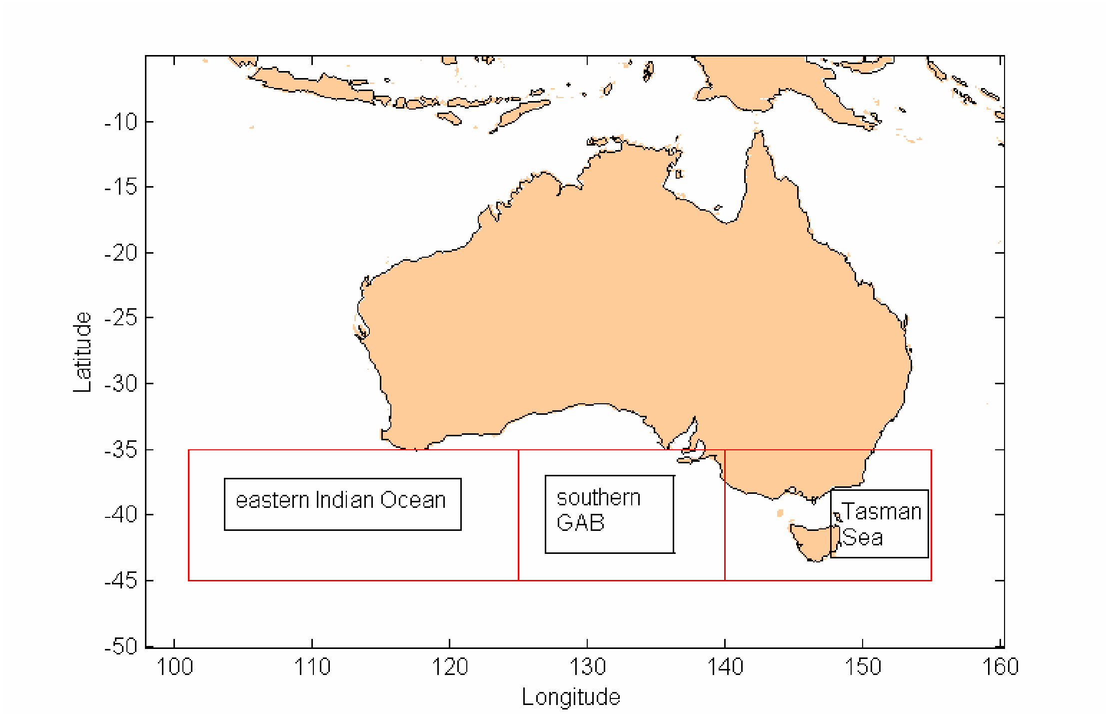

Figure 6: Map indicating the regions considered in the analysis of potential change in SST.

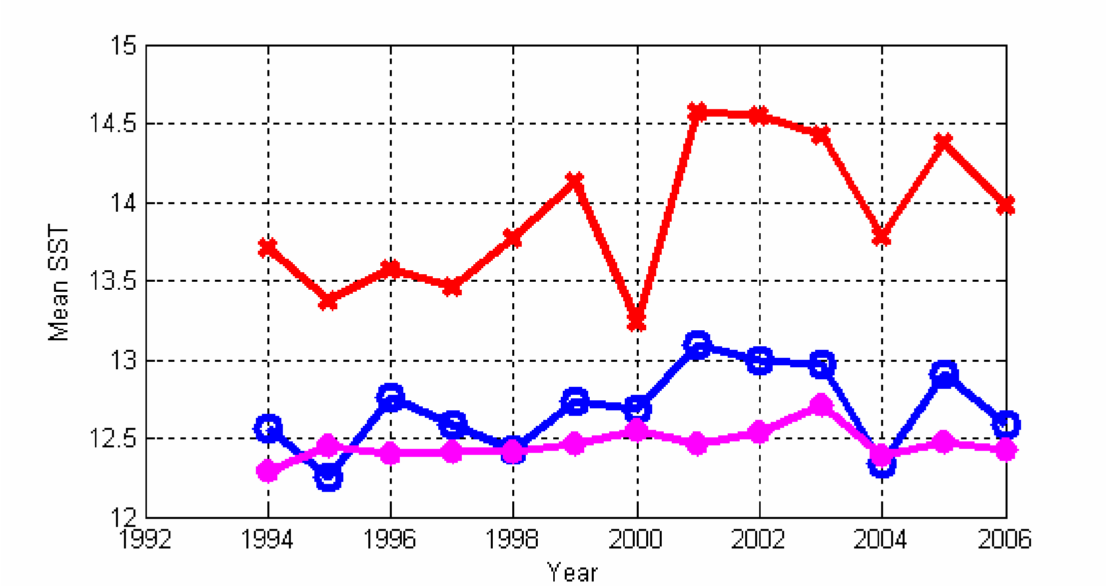

Figure 7: The average sea surface temperature for the winter months (May-August) for the three regions considered (red x's, Tasman Sea; blue open circles GAB; magenta closed circles, eastern Indian Ocean)

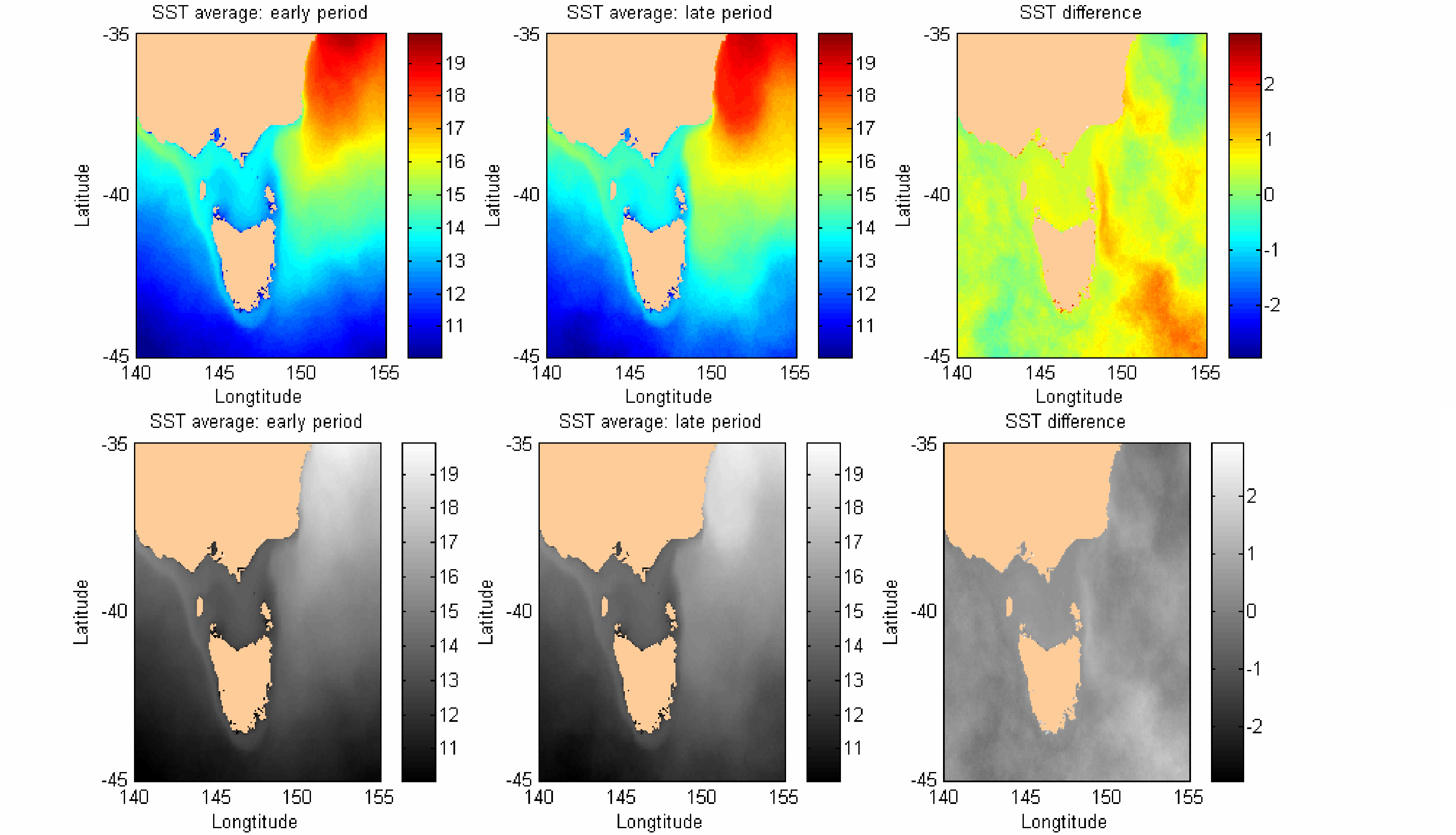

Figure 8: Mean SST for the winter months (May-August) on the east coast of Australia for the early period (1993-1998) of tag releases (left panel), the late period (2003-2006, center panel), and the difference between the two periods (right panel). Note that both color (upper panel) and grey scale versions have been provided to allow for black and white printing.

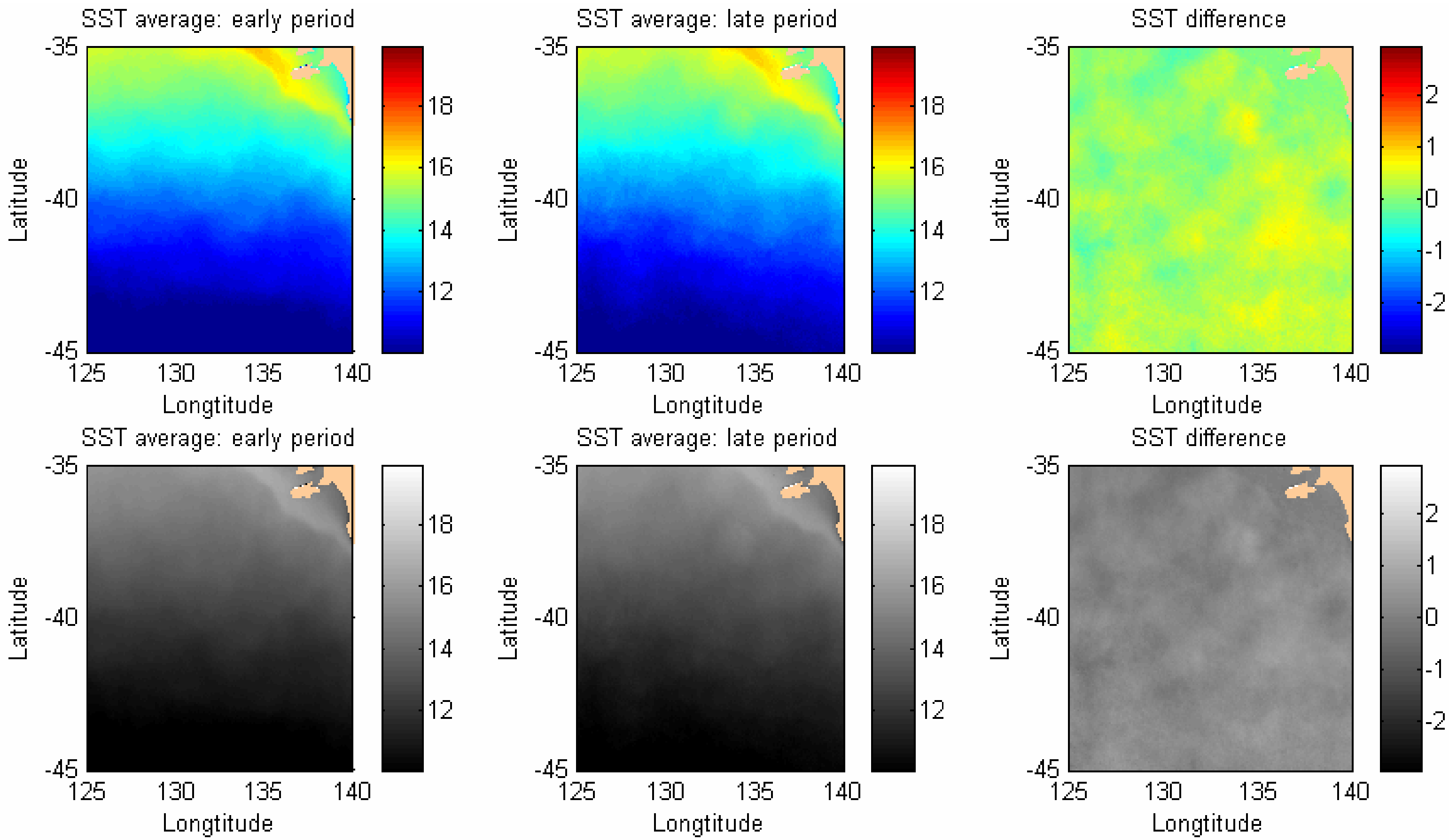

Figure 9: Mean SST for the winter months (May-August) below the Great Australia Bight for the early period (1993-1998) of tag releases (left panel), the late period (2003-2006, center panel), and the difference between the two periods (right panel). Note that both color (upper panel) and grey scale versions have been provided to allow for black and white printing.

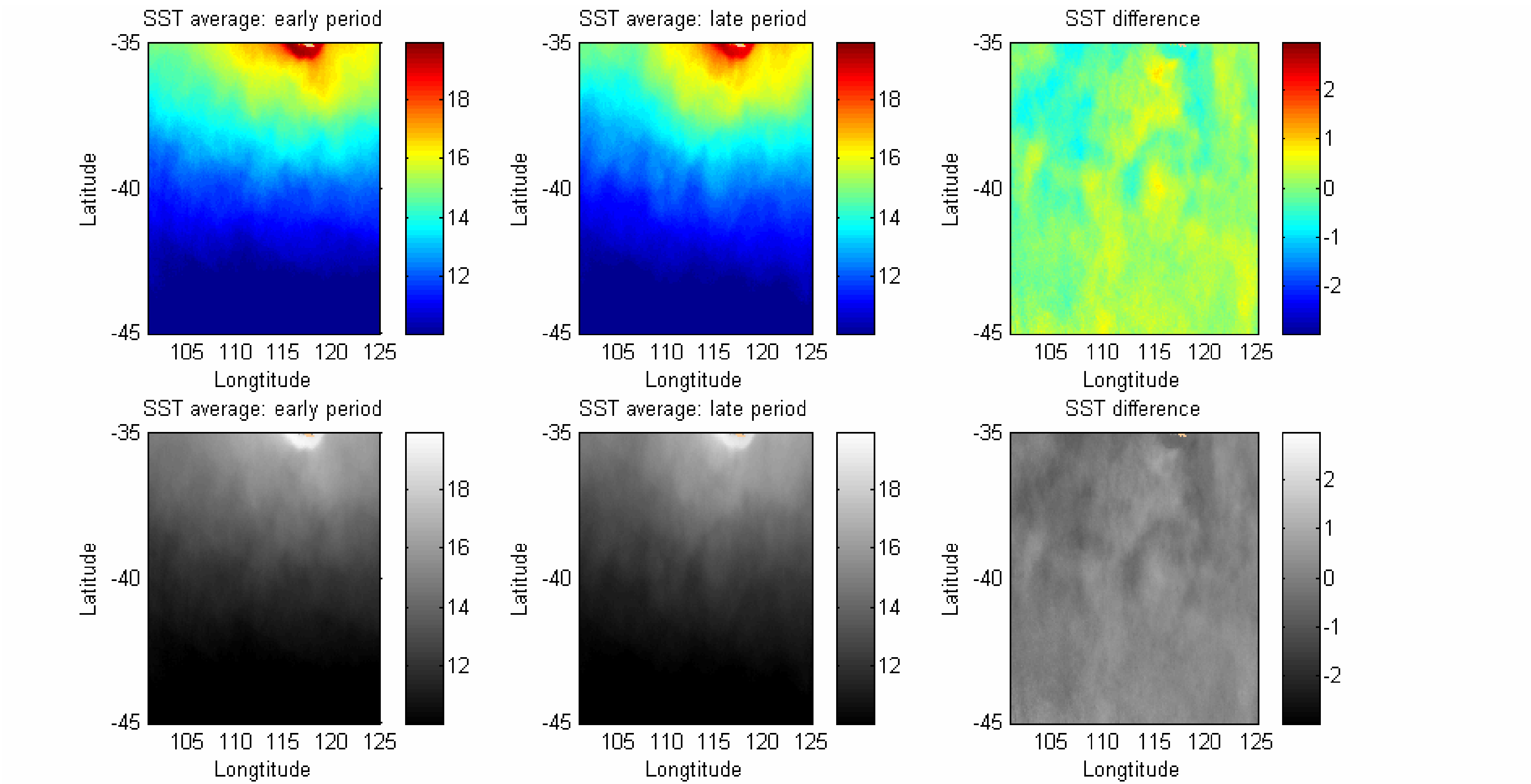

Figure 10: Mean SST for the winter months (May-August) for the eastern Indian Ocean for the early period (1993-1998) of tag releases (left panel), the late period (2003-2006, center panel), and the difference between the two periods (right panel). Note that both color (upper panel) and grey scale versions have been provided to allow for black and white printing.