# Update on the global spatial dynamics archival tagging project - 2010

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## Abstract

As part of the CCSBT Scientific Research Program (SRP), Australia initiated a Global Spatial Dynamics project in 2003. This project involved the archival tagging of juvenile (2–4 year old) SBT throughout their range (i.e. from South Africa to New Zealand) with the objective of estimating movement and mixing rates, and periods of residency in different parts of this range. The results of this program to date are described. The tag deployment phase of the project has been completed, and the analysis phase is being completed over the coming 12 months. We previously noted that the movement patterns of the archival tags released in the 2000s differs from those seen from the archival tagged fish released during the 1990s in the extent of their eastward and westward movements. This analysis is currently being updated. The development of approaches to combine archival and conventional tagging data in a spatial mark-recapture model are near completion. We briefly outline the analyses and main outcomes. Modelling of movement dynamics and seasonal residence times has also commenced. The approach is based on the integration of position, temperature and depth data from the tags with oceanographic data.


## Introduction

As part of the CCSBT SRP, Australia initiated a Global Spatial Dynamics project involving the archival tagging of juvenile (2–4 year old) SBT throughout their range (i.e. from South Africa to New Zealand). The primary objective of the project is the estimation of movement and mixing rates, and periods of residency in different parts of this range. The project has been implemented as a collaborative project between New Zealand (NZ), Taiwan and Australia. This paper presents a summary on activities undertaken in the archival tagging project and planned activities in 2010-2011.

## 1. Global Spatial Dynamics Project - Overview

This project is a multi-year, large-scale project that CSIRO initiated to improve our understanding of the global spatial dynamics of juvenile southern bluefin tuna (SBT). Over the first 3 years of the project, the goal was to archival-tag 150 to 200 juvenile SBT per year throughout the range of habitats in which they are exploited. Using information from these archival tags, the project aims to improve our knowledge of the spatial dynamics and habitat utilization of juvenile SBT, and to provide an understanding of the implications of incorporating spatial dynamics directly into the analyses of conventional tag return data, CPUE standardizations using habitat-based approaches, SBT stock assessments, and management advice.

One major objective of the project is to develop approaches for incorporating archival and conventional (which could also be gene-tagging or pit-tagging, for example) tag data in mark-recapture models, and potentially stock assessment models. Archival data can be particularly useful in estimating mixing or movement rates between areas. The data collected in this spatial dynamics project have been used, together with a simulation study, to develop such approaches. The archival tag data provide information on mixing rates in a spatial mark-recapture model. This should help to provide a robust basis for interpreting conventional tagging results (e.g. estimates of natural and fishing mortality), particularly when it is impractical (or impossible) to release tags over a wide geographic area, as is the case for SBT. At the outset, the project was designed to be complementary to the SRP conventional tagging program, and to build upon previous and concurrently running archival tagging projects. Although the conventional tagging program has been suspended for the moment, the data collected and approaches developed under this project should provide valuable information for the design of any future tagging program for SBT. This work is close to completion and more detail is given below.

The second major objective was originally formulated in terms of the interpretation and standardisation of CPUE data. The potential impact of unreported catches on longline CPUE, together with concerns about spatial coverage of longline fleets, and changes in fleet behaviour has led to the objectives being modified to focus more directly on the modelling of habitat use and residency of SBT rather than the standardisation of CPUE. This work is currently underway and only briefly mentioned below.

## 2. Update on archival tag releases and recaptures

The tag deployment component of the project has now been completed. Although the number of release years was extended from the original goal of 3 years (2004-2006) to 6 years (2004-2009), the project has exceeded its minimum goal in terms of number of archival tag releases, with 568 releases as of May 2009 (*last release 28 May 2009*). Archival tags have been released in 5 locations in collaboration with this project:

1. in high seas in the central Indian Ocean
2. off the south west of West Australia (WA)
3. in the Great Australian Bight (GAB)
4. off New Zealand
5. off South Africa

A summary of the archival tag releases by year and area is shown in Table 1a below, together with recaptures (of those releases) to date. A summary of the number of returned tags by recapture area is given in Table 1b. Note that a few recaptures may have occurred that were not in the CCSBT tag database at time of data extraction (5 August 2010).

A scarcity of suitable fish in New Zealand severely restricted the tagging of juvenile SBT from this area in the first two years of this project. Greater success was achieved during the 2006-2008 period, resulting in a total of 77 fish released from waters around New Zealand (although some of the recent success was achieved by tagging fish larger than the target range for this project).

As noted previously, the project was unsuccessful in its early attempts to have fish tagged off South Africa (Polacheck et al. 2007). However, during the latter part of 2007 and the early part of 2008, the program was successful in having 27 SBT archival-tagged by observers on Taiwan vessels. In the central Indian Ocean, a total of 159 SBT were archival-tagged between 2004 and 2007.

The total SRP/RMA mortalities in 2005/2006 attributable to the release activities associated with this project were 7 fish or 477kg (CCSBT-ESC/0709/20). No additional SRP/RMA mortalities were attributable to the project since then and no additional ones are anticipated.

Table 1a. Numbers of archival tagged SBT by release area and fishing year (1 November year *y* —1 to 31 October year *y*), together with corresponding numbers of recaptures. Data were extracted from the CSIRO tag database as at 5 August 2010.

| Year | Data | Indian Ocean | WA | GAB | Tasman Sea | South Africa | Total |
|---|---|---|---|---|---|---|---|
| 2004 | No. released | 37 | 22[a] | 23 | 6 | | 88 |
| | No. recaptured | 6 | 6 | 9 | 1 | | 22 |
| 2005 | No. released | 48 | 15 | 40 | | | 103 |
| | No. recaptured | 7 | 3 | 11 | | | 21[b] |
| 2006 | No. released | 25 | 39 | 35 | 30 | | 129 |
| | No. recaptured | 2 | 4 | 12 | 3 | | 21 |
| 2007 | No. released | 49 | 50 | 24 | 19 | 2 | 144 |
| | No. recaptured | 2 | 2 | 1 | 0 | 0 | 5[c] |
| 2008 | No. released | | 49 | | 22 | 25 | 96 |
| | No. recaptured | | 3 | | 1 | 0 | 4[d] |
| 2009 | No. released | | | | 8 | | 8 |
| | No. recaptured | | | | 0 | | 0 |
| Total | No. released | 159 | 175 | 122 | 85 | 27 | 568 |
| | No. recaptured | 17 | 18 | 33 | 5 | 0 | 73[e] |

a) Deployed in conjunction with CSIRO/NRIFSF Recruitment Monitoring Program (RMP).
b) 2 tags recaptured but not returned, so actual number returned to us is 19
c) 1 tag recaptured but not returned, so actual number returned to us is 4
d) 1 fish recaptured but archival tag not recovered, so actual number returned to us is 3
e) actual number returned to us is 69

A total of 73 tags had been recaptured and entered into the CSIRO tag database as of 5 August 2010, 69 of which have been returned to CSIRO (Table 1). We anticipate that additional archival tags have been recaptured and are in the farms in South Australia and look forward to these being returned during the harvesting operations. As expected, the largest percentage of returns is from the releases in 2004, followed by the 2005 and 2006 releases. It is too early to have had significant numbers of returns from the 2007, 2008 and 2009 releases, in particular the latter since fish in the farms from the 2009/10 fishing season in South Australia are still being harvested. From the 88 releases in 2004, 22 or ~25% have been recovered to date. These include 6 from releases in the central Indian Ocean, 6 from releases in Western Australia, 9 from releases in the GAB and 1 from releases in the Tasman Sea (New Zealand). The recoveries from the releases in the Indian Ocean and New Zealand are the first recoveries ever of archival tags from releases in these two areas. For the 2005 and 2006 releases, 20% and 16%, respectively, have been recovered to date. Most of the recoveries have been from the Australian surface fishery, and there has been a paucity of returns from the Japanese (2) and Korean (0) longline fleets. These recovery rates suggest that reporting rates may have declined and that reporting rates may be low in some of the longline fisheries.

Altogether 17 recaptures have been made from the 159 fish tagged by Taiwanese observers in the central Indian Ocean in June-August of 2004-2007 (Table 1). These results, combined with the recapture of 1 out of 6 releases by observers in New Zealand in 2004, demonstrate the feasibility and viability of conducting archival tagging from longline vessels and using trained observers to do the tagging.

As expected, the majority of the (reported) recaptures have come from the GAB (63 of the 73 tags, 86%). Of the remaining recaptures, 6 have come from the central Indian Ocean, 2 from South Africa, 1 from SW-West Australia and 1 from the Tasman Sea (Table 1b).

Table 1b. Numbers of archival tagged SBT by recapture area and recapture year. Data were extracted from the CSIRO tag database as at 5 August 2010.

| Year | Data | Indian Ocean | WA | GAB | Tasman Sea | South Africa | Total |
|---|---|---|---|---|---|---|---|
| 2004 | No. recaptured | 1 | | 1 | | | 2 |
| 2005 | No. recaptured | | | 13 | | | 13 |
| 2006 | No. recaptured | | | 23 | | 1 | 24 |
| 2007 | No. recaptured | 2 | 1 | 15 | | | 18 |
| 2008 | No. recaptured | 2 | | 4 | | 1 | 7 |
| 2009 | No. recaptured | 1 | | 7 | | | 8 |
| 2010 | No. recaptured | | | | 1 | | 1 |
| Total | No. recaptured | 6 | 1 | 63 | 1 | 2 | 73 |

## 3. Geolocation estimates

Geolocation estimates for archival tags are based on light data – essentially, on the length of day and characteristics of the light curve (over time) at dawn and dusk. We previously commented on the difficulties involved in light-based geolocation and the availability of estimates for the SBT archival tag dataset based on existing methods. We have now completed development of an in-house likelihood-based method, and are in the final stages of testing and refining the software (mostly ensuring the software is fast and robust).
We are currently in the process of incorporating these robust likelihoods into a Hidden Markov Model framework. This works builds on initial models (Pedersen et al. submitted) being jointly developed with colleagues from the Danish Technical University / Institute for Aquatic resources, Copenhagen.

## 4. Change in east-west movement

In previous reports on this project, we noted that the movement patterns of the archival tags released in the 2000s seemed to differ from those released during the 1990s in the extent of their eastward movements (Polacheck et al. 2006a). This analysis is currently being updated and results will be presented in a future paper to the CCSBT.

## 5. Approaches for combining archival and conventional tag data

One of the main objectives of this project is to use the information provided by archival tags on the mixing rates of juvenile SBT between the major SBT fishing areas to inform the analyses of the conventional tagging data.

A fundamental assumption in estimation of mortality rates and abundance from tag data is that tagged and untagged animals are fully mixed throughout the range of the population. For

SBT, this can be difficult to achieve since they are distributed over such a large geographic area. If complete mixing is not achieved, then spatial heterogeneity in survival and capture probabilities can lead to biased estimates of mortality rates and abundance if not accounted for. This is potentially relevant in the case of SBT since conventional tagging primarily occurred off western and southern Australia, rather than over the full distributional range of juveniles. We know that capture rates differ significantly between major fisheries/fishing regions for juvenile SBT, so it is important to consider a tagging model that takes spatial heterogeneity into account.

As part of a previous FRDC project, Polacheck et al. (2006b) developed a discrete-space, discrete-time spatial model for estimating mortality rates (both fishing and natural), abundance and movement probabilities from conventional tag-return data. The model was initially developed under a general framework, but was subsequently modified to accommodate spatial and temporal dynamics resembling those of juvenile SBT (see Appendices 11 and 16 of Polacheck et al. 2006b for details). We will refer to this as the spatial SBT model.

Having position estimates from archival tags that were released at the same time as conventional tags can improve the spatial SBT model in a number of ways. First, archival tag data can provide valuable information about the appropriateness of the spatial and temporal structure being assumed; e.g., are the area and season definitions reasonable? The archival tag data collected to date already suggest the need for some changes to the structure of the spatial SBT model developed in Polacheck et al. (2006b). In particular, the model has an area referred to as South Australia, where juvenile fish are present only in summer, after which they migrate to one of three longline regions. Originally we thought fish of ages 1 and 2 were found off of Western Australia predominantly in the summer, so this area was included with the GAB as part of the summer South Australia region. The archival tag tracks show that, in fact, quite a few fish spend their winter in waters around WA before going back into the GAB, so it would probably make better sense to have WA as a separate region that can have juvenile SBT present in both summer and winter.

Second, the spatial SBT model has difficulty separating fishing mortality from movement with conventional tagging data alone. The information provided by archival tag data on fish location/movement can be very useful in this regard. Two general approaches for including this information in the model are:

1) Two-stage approach: Use the position estimates from archival tags to estimate the parameters of the transition matrices, which can then be plugged into the model as known or as priors (i.e., with uncertainty).
2) Integrated approach: Directly incorporate archival tag data into the model through an additional likelihood component. For each archival tag return, the data to be included is the region that the fish was in during each time period between release and recapture.

**Two-stage approach**

Ideally the conventional and archival tag data should overlap in time. Unfortunately, for the 1990s the overlapping conventional and archival tag data are sparse. We therefore estimated transition probabilities from archival tags released between 1993 and 2000 (inclusive). Use of the single resulting transition matrix implies the assumption that the migration dynamics of SBT was essentially constant over that time period. Although the overlap between archival and conventional tags is good in the 2000's, there are a couple of other issues that make applying the spatial tag model to data from the 2000s complicated. First, there are no data for estimating reporting rates for the longline fisheries in the 2000s, so we need to make educated guesses. Second, from previous analyses of the conventional tag data from the 2000s, we know that *F* estimates derived from conventional tags released at age 1 off the south coast of Western Australia (WA) are much lower than those derived from tags released at ages 2 and 3 primarily in the GAB. This difference was not observed in the 1990s tag data. The spatial tag model integrates releases from all ages to produce estimates of *F* and *M*. Thus, the estimates obtained from applying the model to the 2000s data will have an unclear interpretation. Until we better understand the reason for the differences between WA and GAB releases, we opted to omit the WA releases (and corresponding recaptures).

We applied the spatial tag model to the 1990s data set and the reduced 2000s data set with: i) the transition matrices (movement probabilities) freely estimated, and ii) the transition matrices fixed at those estimated from the archival tag data. The results from i) are not very realistic for either data set —for instance, for the 2000s, the transition estimates suggest that at the end of winter essentially no fish return to the GAB from the South Africa and southeast Indian Ocean (SEIO) regions; the *M* estimates are implausibly low; and the *F* estimates for the GAB are implausibly high. By fixing the transition matrices at those estimated from the archival tags (which suggest all fish return to the GAB at the end of winter), the *M* and *F* estimates become much more realistic.[1]

## Integrated Approach

The second approach of directly integrating archival tag data into the spatial tag model has now been implemented as well. Although we initially discussed using 'hidden state' models, after further consideration we decided it was more practical to modify the already-developed spatial tag model to include a likelihood component for the archival tag data. For each archival tag recovery, the data to be included is the region that the fish was in during each time period (i.e. summer/winter season) it was at liberty. To calculate the probability that a fish released in a given region and time period is recaptured in a given region and time period is relatively simple compared to a conventional tag because all intermediate transitions between release and recapture are known. Although this approach does not overcome some issues (e.g., if a fish spends most of the winter in region 2, it is classified as a "region 2 fish" for that winter and the model only allows for the possibility of it being caught in this region, even though it may have spent some time in other regions), it seems to provide a reasonable balance between approximating reality and minimizing model complexity.

### *Simulation trials*

The integrated spatial tag model was first applied to simulated data to investigate how well it can perform in theory compared to the model with only conventional tag data (i.e., how much can incorporating archival tag data improve the parameter estimates). Two sets of simulations were conducted: one using the same spatial and temporal structure as the model for SBT (i.e., 4 regions, 2 seasons per year, and movement and fishing dynamics representative of SBT), and one using a more general structure (i.e., 3 regions, yearly time periods, and no restrictions on the end-of-year movement probabilities or location/timing of fishing operations).

[1] Catch data can be included in the spatial tag model, in which case estimates of abundance are obtained in addition to estimates of F and M. However, given the large uncertainties and biases that exist in the catch data for SBT, we chose to leave these data out of the model, at least for now.

For both sets of simulations two tagging scenarios were considered:

- one where fish were tagged in each region and period of fishing, and
- one where the tagging design was reduced—specifically, for the SBT model, fish were tagged only in region 1 in season 1 each year; for the generic model, fish were tagged in all regions in the first year then only in region 1 thereafter.

In each region and period of tagging, a certain percent of releases was assumed to be archival tags, and this percentage was varied from 0 to 75%. For both sets of simulations, when tags were released in all regions and time periods of fishing, increasing the proportion of archival tags led to significant improvements in the precision of the transition probability estimates (and also to small improvements in the $F$ estimates for the SBT model). In the simulations with a reduced tagging design, not all of the parameters were estimable *unless* archival tag data were included; this was true for the SBT model and for specific situations using the generic model. Increasing the proportion of archival tags led to significant improvements in the CVs of the transition probability estimates and many of the $F$ estimates (those for regions and ages where tagging did not occur). Interestingly, for the generic model, the relative improvements in CVs was actually greater for the $F$ estimates than the transition estimates.

*Application to SBT data*

We also applied the integrated spatial tag model to SBT data from the 1990s and 2000s[2]. A fairly manual approach was used to evaluate each archival tag track and determine the most appropriate region designation in each season. Many of the tracks stop before the fish was caught (due to a number of reasons such as the light sensor failing, the battery dying, etc), so the likelihood for the archival tag data was modified to accommodate incomplete tracks by treating each one the same as any archival tag up until the track stops, then treating it as a conventional tag that was released in the last observed region/time period (and recaptured in the region/time period where the fish was caught). The integrated spatial model requires that the archival tag data correspond to the same release years and ages as the conventional tag data. Unfortunately, for the 1990s the overlapping conventional and archival tag data are sparse, so incorporating archival tag data directly into the model has very little effect on the parameter estimates. For the 2000s, the amount of overlapping conventional and archival tag data is much greater, and incorporating archival tag data has a significant effect on many of the parameter estimates. For instance, the $M$ estimates are larger and more plausible (e.g., ~0.1 at ages 2-5, as opposed to zero without archival data). The transition probability estimates suggest:

i) most fish (92%) move from the GAB to the SEIO at the end of summer (as opposed to only 5% in the model without archival data);
ii) the proportion of fish returning to the GAB at the end of winter is greatest for the SEIO, followed by the Tasman and lastly South Africa (as opposed to no fish returning from the SEIO in the model without archival data); and
iii) the proportion of fish returning to the GAB at the end of winter diminishes with age.

The $F$ estimates are less affected by the inclusion of archival tag data than the M estimates and transition probabilities, and still show some very high estimates for the GAB at ages 3-5.

[2] We did not include catch data in the model, and for the 2000s, we again omitted conventional tag releases from WA.

## 6. Plans for 2010–2011

The archival tag releases intended for this project have now been completed. There are no plans for further releases, and only if additional tags were made available would additional releases be possible. The focus of the work in 2010-2011 includes: completion of the in-house geolocation method and track-filter (under a CSIRO funded project) to use with the archival tag data from the "Global Spatial" project; continued work on using archival tag data to improve the conventional tag model for estimating movement rates, mortality rates and abundance; and integrating position, temperature and depth data from the tags with oceanographic data to develop a seasonal model of residence times and habitat use for regions with consistent temporal patterns across years.

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