CCSBT-ESC/0709/19

Analyses of tag return data from the CCSBT SRP tagging program - 2007

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Prepared for the CCSBT 8th Meeting of the Stock Assessment Group and the 12th Meeting of the Extended Scientific Committee
4-8 September, and 10-14 September 2007, Hobart, Australia

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Abstract

Analyses of the release and recapture data from the CCSBT SRP tagging program are presented. A tag attrition model was used to estimate cohort and age-specific fishing mortality rates for different groups of tag releases conditional on estimates of natural mortality, tag shedding and reporting rates (the latter three derived from separate analyses). The estimated fishing mortality rates are independent of the catch and catch-at-age data. There appear to be substantial tagger and age of release effects in the return data. The estimates of reporting rates from the surface fishery based on tag seeding results fell to a level of 0.21 in 2005/2006. Using this point estimate results in “unrealistically” high estimates of fishing mortality rates for some ages. Possible reasons for this are discussed. The issues associated confound quantitative interpretation of the tag return data, although quantitative lower bounds as well as a reasonable range of fishing mortality rate estimates can be evaluated under different assumptions about the reporting rates. If the tagging data are to provide useful estimates of fishing mortality rates, there is an urgent need to both increase the actual reporting rate and refine approaches for estimating reporting rates.

In spite of the problems with estimating reporting rates, the tag return results demonstrate high and possibly increasing fishing mortality rates in 2003, 2004, 2005 and 2006 for ages 2 and 3 for those fish tagged at ages 2 and above. However, rates based on age 1 releases, which primarily occurred in Western Australia, tend to be lower. High rates of recovery were obtained from age 3 fish released in December in the Great Australian Bight (GAB) during the same season they were released. Overall the results suggest high fishing mortality rates for fish in the GAB, but it is not clear to what extent this represents the overall juvenile population.

The number of returns from age 1 releases from the 2000, 2001, 2002 and 2003 cohorts were disproportionately low relative to returns from releases from other age classes and also relative to returns from the 1990s tagging experiments. This suggests either higher tagging mortality or natural mortality or changes in the spatial dynamics for age 1 fish. The spatial distribution of longline returns also suggests a possible change in spatial dynamics with few tagged fish moving into the Tasman Sea (but this may be confounded by reporting rate issues). Estimates of fishing mortality rates at age 2 were very low and appear inconsistent with the catch data from the surface fishery. Estimates of the number of tags returned per 1000 fish caught in the surface and longline fisheries also suggest possible inconsistencies with the catch data. In particular, not enough older fish appear to have been caught in the surface fishery relative to the number of tags returned from fish at older ages.

Introduction

As part of the Scientific Research Program (SRP), the CCSBT initiated a large scale tagging program to estimate juvenile fishing mortality rates beginning in 2000/2001 fishing season. The basic design of the tagging program was similar to that conducted in the 1990s as part of the CSIRO/NRIFSF Recruitment Monitoring Program with the aim to tag multiple cohorts at different ages in several years. This paper provides some analyses of the data collected to date in the SRP tagging program, including some initial estimates of fishing mortality rates obtained from a tag attrition model using similar approaches to those used in Polacheck and Eveson (2005, 2006).

Methods

Data

Tagging in the first year was only done off Western Australia (WA) with 1 and 2 year old fish being tagged. In all subsequent years, tagging was conducted in both WA and South Australia (SA) with almost all of the fish tagged being between ages 1 and 3 (i.e. less than 2% of the fish tagged are estimated to be older than age 3).

Some of the release and return data are considered unreliable for estimating mortality rates; therefore we applied the following screening process to the data prior to analysis.

For the release data:

- Only fish released into the wild were included (i.e., we excluded data from fish that were released into farms as part of a tag seeding program).
- Only releases where the fish was caught by pole and line were included. This method of catching fish is least likely to cause lasting injury to the fish.
- Only releases for which both tags were recorded as being inserted correctly were included to reduce the chance of tag shedding biasing our analyses.
- Only fish for which the injury due to tagging was regarded as slight were included to reduce the chance of fish mortality due to tagging biasing our analyses.
- Only fish whose length was recorded at the time of tagging were included because our analysis uses age of release, which is estimated based on length.

For the recapture data:

- Only recaptures corresponding to releases that met the above release criteria were included.
- Only recapture records from fish caught in the wild were included. For tagged fish that are harvested from the farms, the database has two records: one corresponding to the original capture from the wild and one corresponding to the harvest from the farm. For the purposes of estimating fishing mortality we are only interested in the information (date and location) for the capture from the wild.

A fish’s age at tagging was estimated from its length using cohort slicing and the growth curve currently adopted by the CCSBT (Anon. 2001b). SBT grow rapidly as juveniles so there is good separation between length distributions at the ages being tagged, and therefore the number of aging errors should be small. All tagging was done between December and April, so the release ages were adjusted in order that fish tagged in December from a given year-class/cohort were assigned the same age as those tagged after December. The recapture age was calculated using the age of release and the time between release and recapture. Recapture ages were also adjusted so that fish from a given cohort caught in November or December were given the same age as those caught after December.

As discussed below, results from separate analyses of tag shedding rates preformed by Dr. W.S. Hearn (CSIRO Marine and Atmospheric Research) are used in the estimation of mortality rates. In addition to the above data screening, Dr. Hearn excluded tag returns if the recapture year or month within year was uncertain, or if the day within month was uncertain for recaptures at liberty less than 270 days. Also, data sets associated with a tagger were only analysed if there were 30 or more acceptable recaptures in the set. Data associated with the remaining taggers were pooled into a set we call "tagger" Z and comprised returns from 25 tagged fish.

In the current paper, we have included none of the releases from the 2006/2007 fishing season, nor any of the recaptures from tags returned in 2006/2007. This is because the data for this year are still very incomplete because only a small fraction of fish had been harvested from the farms at the time the data were compiled for analysis.

Estimation Model

A basic tag attrition model was used to estimate cohort and age-specific fishing mortality rates for different groups of tag releases. This model was chosen because it provides a direct estimate of the fishing mortality rate for those fish tagged independent of any assumptions about mixing. This is seen as a first step to evaluate the consistency of estimates from different releases prior to developing a more integrated estimation model (e.g. a Brownie model).

We define two seasons: season 1 runs from January 1 to June 30 and corresponds to the Australian surface fishery; season 2 runs from July 1 to December 31 and corresponds to the longline fishery. For convenience, the model assumes all releases occurred in season 1 on January 1. In addition, the model follows the convention used in the CCSBT Management Procedure operating model in which all fishing is assumed to occur either on January 1 (season 1) or July 1 (season 2). All returns from the Australian surface fishery were assumed to occur in season 1 and all longline returns were assumed to occur in season 2. Natural mortality is assumed to occur at a constant rate throughout the year (i.e., it is evenly split between the two seasons since they are of equal length).

Because there are two seasons per year, it is convenient to work in terms of time periods taking values $t = 1, 2, 3, \ldots$, where season 1 corresponds to odd time periods, season 2 corresponds to even time periods, and a year consists of a consecutive odd and even time period.

Let

$$N_{c,a,g,t+1} = (N_{c,a,g,t} - \widehat{R}_{c,a,g,t})e^{-0.5m_{a*}} \quad (1)$$

where

$N_{c,a,g,t}$ = the number of tagged fish alive at the start of time period t from fish tagged from cohort c at age a by tagger group g;

$\widehat{R}_{c,a,g,t}$ = the estimated number of tagged fish caught in time period t from fish tagged from cohort c at age a by tagger group g;

m_{a*} = natural mortality for fish of age $a* = y - c$, where y denotes the year corresponding to time period t.

For reasons discussed below, it was important to examine results for different groups of taggers. In some cases this was all taggers pooled, in other cases it was a group of a few taggers, and in still others it was a single tagger – thus, the subscript g in the above equation.

The number of recaptured tagged fish, $\widehat{R}_{c,a,g,t}$, in equation 1 is not simply the number of tags actually returned but is estimated to take into account both tag shedding and non-reported tags. Specifically, $\widehat{R}_{c,a,g,t}$ is estimated by

$$\widehat{R}_{c,a,g,t} = \frac{\sum_{k \in g} \left(R_{c,a,k,t} / \gamma_{c,a,k,t} \right)}{\lambda_t}$$

where

$R_{c,a,k,t}$ = the actual number of reported tag returns in time period *t* from fish tagged from cohort *c* at age *a* by a tagger in sub-group *k* of tagger group *g*;

$\gamma_{c,a,k,t}$ = the probability that a fish tagged from cohort *c* at age *a* by a tagger in sub-group *k* has at least one tag still attached at the beginning of time period *t*;

λ_t = the tag reporting rate in time period *t*.

Recall that all fish have been double-tagged. The probability of a tagged fish still having at least one tag attached at the time of capture, $\gamma_{c,a,k,t}$, is given by

$$\gamma_{c,a,k,t} = 1 - \left[1 - Q_{a,k}(\tau)\right]^2$$

where

$Q_{a,k}(\tau)$ = the probability of a tag still being attached to a fish tagged at age *a* by a tagger in sub-group *k* after the fish has been at liberty for time τ. Note that τ is a function of *c* and *a* (which together define the time period of release) and *t* (the time period of recapture).

Finally, an estimate of the annual fishing mortality rate in year *y*, corresponding to time periods *t* and *t*+1 (where *t* is odd), for fish from cohort *c* (i.e. age $a^* = y - c$) can be calculated from the ratio of the estimated number of tagged fish alive at the start of year *y*+1 (time period *t*+2) to the estimated number of tagged fish alive at the start of year *y* (time period *t*). A separate value can be calculated corresponding to fish tagged at age *a* by a tagger in tagger group *g*. Thus,

$$f_{c,a,g,y} = -\left[m_{a^*} + \log\left(N_{c,a,g,t+2} / N_{c,a,g,t} \right) \right]$$

Bootstrap confidence intervals for $f_{c,a,g,y}$ were calculated by sampling the releases at age *a* from cohort *c* by tagger group *g* along with the associated recapture data with replacement and calculating the estimates of $f_{c,a,g,y}$ for each bootstrap sample. The confidence intervals presented are based on 1000 bootstrap replicates and treat each tag release as independent. This may underestimate the actual uncertainty if releases from the same school tend to stay together. The bootstrap estimates are also conditional on the estimates of reporting rates, shedding rates and natural mortality rates.

Reporting Rates

Estimates of the reporting rate in the Australian surface fishery are available for the 2003, 2004, 2005 and 2006 fishing seasons from tag seeding experiments conducted in these years (Polacheck and Stanley 2004, 2005; Polacheck et al. 2006; Hearn et al. 2007). Hearn et al. (2007) provides estimates for the mean reporting rate for each year[1] (reproduced in Table 1). There has been a decreasing trend overall and the difference in the reporting rates between 2003 and 2006 is clearly significant (Table 1). Consequently, in the analyses presented here we have used the season-specific rates. As discussed below, the low reporting rate estimates in recent years from the tag seeding yields in some cases unrealistically high values for the fishing mortality rates. Thus, in addition to the reporting rate estimates from the seeding experiments for the surface fishery, we have considered some alternative *ad hoc* values and estimates. These include assuming a 100% reporting rate in order to provide minimum estimates as well as some values examining the effects of possible non-independence in the shedding of tags in the tag seeded (see below).

Insufficient information was available to estimate reporting rates from the longline fisheries. Estimates of reporting rates from longliners were substantially below those in the surface fishery in the 1990s. Reporting rates for Japanese longliners in the 1990s ranged from 0.07 to 0.49 (Eveson and Polacheck 2005). There were no data to directly estimate reporting rates for Taiwanese vessels. In the absence of any direct data, a range of values was explored. Results were explored for two values, namely 0.65 (the same as the surface fishery in 2003) and 0.30, to provide an indication of the sensitivity of the results to the value assumed. The same value was used for all ages and years. Note, however, that unless the reporting rates were the same in the different longline fleets, the reporting rate would in fact vary with age and year even if the reporting rate was constant over time within a fleet; this is because the proportion of the total longline catch of a given age class by a given fleet varies among years (Pollock et al. 2001).

Tag Shedding

Tag shedding rates provided by Dr. Hearn were based on an analysis of the tag shedding data (number of recaptures with one tag versus two tags still attached) for taggers who participated in the SRP tagging program. Dr. Hearn applied the method of Kirkwood and Walker (1984) to estimate shedding parameters. The retention function (i.e., the probability of a tag still being attached after being at liberty for time τ) was assumed to have the form

$$Q_{a,k}\left(\tau\right) = \xi_{a,k} \exp\left(-\Omega_{a,k}\tau\right)$$

where $\xi_{a,k}$ is the fraction of tags immediately retained (i.e. $1 - \xi_{a,k}$ are immediately shed) for fish tagged at age a by a tagger in sub-group k, and $\Omega_{a,k}$ is the continuous shedding rate. Thus, the model allows for tag shedding to vary between tagger groups (which may be individual taggers) and between fish released at different ages. The retention function was assumed to be the same for both tags on a given fish. Table 2 provides the estimates of the

[1] The rates quoted here are for the weighted mean estimates in Hearn et al. (2007) as these are statistically more appropriate.

parameters for this retention function when fitted to the SRP tag return data. This table provides estimates for individual taggers as well as for groups of taggers with statistically insignificant differences in their tag shedding parameters. Only the estimates for the groups of taggers are used in the estimates of fishing mortality rates presented here, but the results are very similar if individual tagger estimates are used. In the notation above, each set of taggers constitutes a potential sub-group *k*.

In Polacheck and Eveson (2005), we also considered the potential effect of age-specific shedding. There were only sufficient data to meaningfully perform these calculations for two taggers. Only for one of these was the difference significant and the differences had only a minimal effect on the overall results. As such, we have not updated these estimates for this year's paper.

Natural Mortality Rates

Two age-specific natural mortality rate vectors were used in the calculation of the fishing mortality rates (Table 3) to provide a measure of the sensitivity of the estimates to assumptions about natural mortality. These two vectors are two of the vectors being used in the conditioning and projections being undertaken with the SBT Management Procedure operating model.

Results and Discussion

Table 4 provides a summary of the number of releases and recaptures by cohort. The low number of recaptures from the 2004 cohort and beyond reflect the fact that it is still too early to expect any substantial numbers of returns from these releases. Given the current fisheries, only significant numbers of recaptures are expected from fish ages 3 and older. Since most of the returns from this year's Australian surface fishery are not yet available, even for releases from the 2004 cohort the tagging data are not yet informative. As such, the focus of the results presented are for the 1999-2003 cohorts (the number of releases for the 1998 cohort are too small to provide meaningful results).

Table 5 provides a breakdown of the release and recapture data by cohort, age at release and age at recapture. Evident in this table is the very low percent of returns from fish released at age 1 compared to the percent of returns from fish released at ages 2 and 3 from the same cohort. While the number of returns at a given age from age 1 releases would be expected to be less because of natural mortality rates, the differences are quite extreme and contrast markedly with the returns from the 1990s tagging (Figure 1). This has been a persistent feature of the SRP tag returns (Polacheck and Eveson 2005, 2006) and is explored and discussed further below.

Location of Longline Returns

The interpretation of results from tagging experiments depends upon the extent to which the tagged fish can be considered representative of the population. Lack of complete mixing is one factor that can bias results – particularly if it is systematic. Plots of release and recapture locations can provide one indication of this. Figures 2-5 show maps of the release and return locations for all longline returns from the SRP tagging experiments. Figure 6 provides a comparison with the 1990s tagging experiments. What is evident is the rapid spread of tagged fish from the surface fishery into all areas where longline fisheries occur, and there is no evident differential pattern for the tags released in Western Australia compared to South Australia.

Nevertheless, evident in these plots is the very different spatial distribution of longline recoveries in the 2000s compared to the 1990s in terms of the low proportion of recoveries that come from the Tasman Sea. This is also evident when comparing the percentage of longline returns by age which came from the Tasman area in the 2000s (Table 6). This in part reflects differences in the spatial distribution of fishing effort within the Tasman Sea. Thus, in the 1990s, a substantial fraction of the longline effort was within the Australian Fishing Zone (AFZ) as a result of joint venture operations and bi-lateral access arrangements that allowed vessels to fish within the AFZ (i.e. smaller fish may be more concentrated in near shore waters) (Table 7). These arrangements ceased in 1998 and thus there has been little recent fishing effort in the areas where substantial numbers of the 1990s returns came from. In addition, there were more tag recovery opportunities for Japanese vessels in the AFZ than in some other areas due to a combination of observers and port visits by tag liaison officers. However, it is not clear whether these factors are sufficient to explain the large differences in the spatial distribution of longline returns in the 1990s compared to the 2000s. For example, there were still substantial numbers of longline returns outside of the AFZ in the 1990s (Table 7). Moreover, in the 2000-2002 period, a substantial percentage (28-42%) of the reported Japanese longline catch of juveniles aged 3-4 came from the Tasman area (Figure 7), and all of this was outside of the AFZ. However, in 2004, these percentages decreased dramatically (~10% in 2004) without a decline of similar magnitude in the proportion of fishing effort in the Tasman area (Figure 7). There was some increase in 2005 to ~20%. Overall, the Japanese longline catch and effort data would also tend to suggest a shift in the spatial distribution of juveniles. It should be emphasized that the reliability of these percentage estimates and their interpretation is uncertain because of the large longline overcatches of SBT (Anon, 2006a, b, c, d).

Fishing Mortality Rate Estimates Based on Tag Seeding Reporting Rate Estimates

Sufficient release and return data (e.g. at least ~400 releases at a particular age and at least one year of full recoveries) exist to derive age-specific fishing mortality rate estimates for five cohorts, namely cohorts 1999, 2000, 2001, 2002 and 2003 (e.g. Table 8). It should be noted that estimates of fishing mortality rates based on returns from the same year of release (e.g. the F estimates for age 2 based on age 2 releases) can be highly misleading in terms of being representative of the fishing mortality experienced by a cohort because the releases may have occurred before, during or after the main period of fishing, and the distribution of releases would also affect the number of returns. However, they do provide a measure of the fishing mortality rate experienced by the set of tagged fish and in this sense can still be informative.

Tables 8-10 provide comparisons of estimates of fishing mortality rates for the two different mortality rate vectors in Table 3 and of estimates based on releases for all taggers versus releases from only tagger 1. Similar comparisons have been provided previously to provide an indication of the sensitivity of the estimates to these two factors. Evident in the estimates in these tables are the very high estimates of fishing mortality rates for the 2006 fishing year (e.g. the age 3 estimates for the 2003 cohort) for ages 3, 4 and 5 for tags fished at age 2 and older. The estimates in a number of cases seem unrealistically high (e.g. greater then 1.5 or greater than ~80% of the remaining fish represented by that batch of tags were caught in 2006). In a few instances, the estimates are infinite, indicating that the estimator is predicting that more tags were captured then were actually released. The very high and seemingly “unrealistic” fishing mortality rate estimates occur independent of which natural mortality vector is used or whether releases from all taggers are used or only those from tagger 1. As would be expected, the estimates are somewhat higher with higher natural mortality rates. Similarly, they are also higher for releases only from tagger 1. This is not unexpected as previous analyses of these tagging data suggest there may be a consistent tagger effect in the fishing mortality rate estimates (see Polacheck et al. 2005, 2006).

Issues in the Estimation of Reporting Rates from the Tag Seeding Data

The primary source of the very high fishing mortality rates seen for some releases in 2006 results from the low reporting rate estimate for this year from the surface fishery from the tag seeding analyses (Hearn et al. 2007), combined with the high actual number of tags recovered. There is also potential confounding with the reporting rate estimates from previous years (e.g. an underestimate of the reporting rate in the previous year would result in an underestimate of the number of tagged fish surviving to the beginning of 2006). Thus, it would seem that if the fishing mortality rate estimates for 2006 are unrealistically high, the most likely source of the bias would be that, for some unknown reason, the tag seeding results are providing too low estimates of the actual reporting rates. In this section, we explore possible reasons that could lead to biases in the reporting rates from the tag seeding experiments and alternative sources of information that can provide insights into whether the tag shedding reporting rate estimates are reasonable.

Possible Biasing Factors

We have identified four potential factors that could introduce biases into the tag seeding reporting rate estimates:

1. Lack of independence in shedding among the two tags within individual seeded fish (i.e. a violation of the underlying independence assumption for estimating shedding rates from double tagging). In particular, the possibility that there is a high initial shedding of both tags after seeding due to tags rubbing against the cage nets, etc.
2. Seeded tags can be distinguished from tags put into wild fish at the time fish are harvested from the farms and industry differentially returns tags from these two different sources.
3. Tags recaptured from fish which are harvested for the fresh auction market may be more likely to be recovered than those harvested for the freezer boat market, combined with possible size differential in the fish which are harvested in these two cases (i.e. larger fish being harvested for the fresh fish market). This would lead to reporting rates being size/age dependent. In particular, estimates of reporting rates for the older age range of fish (e.g. ages 3 and 4) may be too low if this were the case. It is within the fishing mortality rate estimates for the older ages caught in the surface fishery that unrealistically high values occur.
4. The use of an inexperienced tagger in the tag seeding in 2005/2006 may have lead to a high rate of dependent initial shedding of both tags due to poor tag placement, etc.

With respect to potential factor 1, there is no direct evidence which would indicate that there is a high initial shedding of both tags. Farmers report they have not observed this, nor has there been any reports of seeded tags having been detected around the foreshore areas of Port Lincoln (the tags are positively buoyant and tags from wild released fish have been reported after having been detected in foreshore areas in the southern areas of Australia). Nevertheless, we do know that reasonable numbers of seeded tags are shed based on the single returns from the double tagging. Thus, only a single tag was returned from 296 of the double tagged seeded fish that have been recovered between 2004-2006. Given that there were 893 releases of double tagged fish during this same period, this would suggest that ~359 seeded tags would have been shed if the independence assumption was correct. However, there have been no beach recoveries of seeded tags found on the foreshore. As such, the fact that farmers have not noted any substantial number of shed tags in their farm cages, nor have large numbers been detected in the foreshore areas, can be taken as evidence that high initial shedding of both tags was not occurring. At this point, there appears to be no available information to directly assess whether lack of independence in the shedding of seeding tags has been occurring.

With respect to potential factor 2, the seeded tags are identical to those used in the tagging of wild fish – the only difference being the unique identification number on each tag. The tag numbers of the seeded tags are not available to the farm operators when the fish are tagged. In essence the experiment has been designed to ensure that there is nothing that would allow tags from seeded and wild tagged fish to be distinguishable. Even if farm operators were able to distinguish seeded and wild tagged fish at the time of harvest, there is no obvious motivation why they would preferentially return wild tags. If anything, the expectation might be the opposite.

With respect to potential factor 3, differential in size of fish harvested for the fresh and frozen markets has been reported to occur. Additionally, farm operators have stated that when processing fish for the freezer boats, the large numbers being processed in a day and the speed of processing means that recovery and return of tags is less likely than when fish are processed for the fresh market. Examination of the size distribution of the release length for tag-seeded fish compared to the release length for those tag-seeded fish that were recovered suggests that there may be some differential in the return rates for different size fish (Figure 8). For example, 21% of the tag-seeded fish between 2003/2004 to 2005/2006 were over 100cm while 28% percent of returns were greater than 100cm (based on a chi-square test the difference is not quite significant; $p = 0.070$). This suggests that if there is a size/age differential due to differential tag reporting for fresh and frozen fish that it is likely to be small. However, if there are size biases in the 40 fish sampling, this could tend to mask any differential size related to reporting rates. In this regard, one known size-related bias in the seeding of the 40 fish sampling is that fish under 10kg are used in the determination of the average weight of fish in a cage and these fish of less than 10kg have also not been sampled. This means that the reporting rates from the seeded tagging would be biased towards the rate for larger/older fish if size/age biases in reporting rates exist. As such, this would not contribute to an underestimation of reporting rates for those age ranges in which “unrealisitic” high fishing mortality rate estimates are being observed.

With respect to potential factor 4, an inexperienced tagger with little or no tag training was used to tag a substantial number of tow cages in 2005/2006 (16 out of 32 cages in which seeding took place). A detailed look at the tag seeding results for this season revealed that for

9 out of the 16 cages in which this individual did the seeding, no seeded tags were recovered, and the overall recovery rate for seeded tags from this individual was 10%. In contrast, for the remaining 16 cages in which more experienced taggers did the seeding, only in 2 cages were there no returns of seeded tags and the overall return rate of seeded tags was 28%. In addition, comparison of the by-cage return rates for wild releases per 1000 fish with the by-cage return rates of seeded tags results in a negative correlation between these for 2005/2006 if all cages are included and a positive correlation if the cages in which this inexperienced tagged did the seeding are excluded. The cages in which the inexperienced tagger did seeding were spread across a range of different tuna farm operations and it appears that the low return rate for this tagger is unlikely to be related to the cages in which he tag seeded. All of this suggests that there was likely to have been high levels of dependent tag shedding for the seeded fish that were tagged by this inexperienced tagger (e.g. the tags were inserted poorly because of lack of experience and were shed rapidly after release).

Non Tag Seeding Information Related to Surface Fishery Reporting Rates

There are two sources of information that can provide some independent insight into whether the tag seeding estimates of reporting rates may be biased:

1. Data collected in 2005/2006 by a tag recovery agent that the CCSBT Executive Secretary arranged to attend 20 days of processing on freezer vessels to recover all tags present on fish being processed and record the number of fish where there was evidence of the recent removal of tags earlier in the processing chain.
2. Recovery rate of wild tagged fish captured during the 40 fish sampling and re-released into the farm cages.

The data collected by the tag recovery agent on the freezer boat can provide insight into reporting rates by comparing the return of tags that he observer per 1000 fish compared with the tag return rates from fish he not observe. Also, the number of seeded tags he recovered per 1000 fish sample can be compared with the number of seeded tags released and the total number of fish in cages. However, the interpretation of the data collected by this tag recovery agent is confounded by a number of factors. These factors and the data collected by the tag recovery agent are discussed in detail in Appendix 1. The conclusion from the analyses presented there is that the data collected by the freezer boat tag recovery agent are not necessarily inconsistent with the tag seeding results given the issues and problems in interpreting the results from this experiment. Nevertheless, the results from the data collected by the agent on the freezer boat do raise concerns about possible shedding rates and lack of independence in shedding for double tagged seeded fish released directly into farm cages.

During the course of the 40 fish sampling, wild tagged fish are sometime caught. When this occurs these fish are re-released into the farm cage. The subsequent reporting rate of these fish provides an independent estimate of the actual reporting rate in the surface fishery. These re-releases provide estimates that are independent of any of the issues associated with shedding or tagging experience in the seeding experiments. These wild tagged, re-released fish would have the same probability of recapture as other wild tagged fish (although any size biasing factors discussed above would still apply). Unfortunately, as would be expected the number of wild tagged fish caught during the 40 fish sampling is relatively small. Nevertheless, over the past 4 years a total of 30 wild tagged fish with their tag numbers have been recorded in the 40 fish sampling (Table 11). Of these, 47% were subsequently returned during the harvesting from farms. The results also suggest that the return rates may have declined over the 4 year period. The trend is not statistically significant (e.g. chi-square test of the proportion returned during the first two years compared with the last two years results in a p-value of 0.16), but yearly sample sizes are too small to be very informative in this regard. Nevertheless, the overall reporting rate from these re-released tagged fish provide a robust indicative estimate of the overall reporting rate from the surface fishery over these four years. The 47% recovery rate for these re-releases compares with a raw recovery rate of 35% from the tag seeding results.

Some Alternative Reporting Rates

In order to get an indication of the sensitivity of estimates of fishing mortality to the factors identified above that may possibly be biasing the tag seeding reporting rate estimates, some alternative reporting rate vectors were developed (Table 12):

A1- assumes reporting rate equals 1.0. This provides an upper bound for the reporting bound and thus a lower bound for the fishing mortality rates.

A2 - assumes that the reporting rate in 2002/2003 was 1.0 and that the difference between the estimate of 0.65 from the tag seeding was due to high initial shedding of both tags (i.e. a lack of independence in shedding) associated with tagged fish being in cages. Further assumes that the rate of high initial shedding is constant across years and re-adjusts the other reporting rates accordingly.

A3 - eliminates the data from the inexperienced tagger from the 2005/2006 tag seeding experiment and re-estimates the reporting rate for this year.

A4 - eliminates the data from the inexperienced tagger from the 2005/2006 tag seeding experiment and adjusts the report rates as in A2.

A5 - assumes reporting rates have been constant and uses the rate of return from the re-release of wild tagged fish from the 40 fish samples as an estimate of the reporting rate (Table 11).

A6 - assumes reporting rates were the same in 2002/2003 to 2003/2004 and 2004/2005 to 2005/2006 and uses the rate of return from the re-release of wild tagged fish from the 40 fish samples for these two periods to estimate the reporting rates (Table 11).

These vectors are *ad hoc* but provide some basis for assessing the extent to which various factors may be affecting tag seeding estimates of reporting rates affect the estimates of fishing mortality rates.

Estimates of Fishing Mortality Rates Based on Alternative Reporting Rates for the Surface Fishery

Tables 13-18 provide estimates of age-specific fishing mortality rates by cohort and age of release for the six alternative reporting rate vectors in Table 12. Results are only provided for mortality rate vector 1 in Table 3 and for releases from all taggers. The estimates show the same general pattern but are somewhat higher if mortality rate vector 2 is used or if only the releases from tagger 1 are used. For all of the alternative reporting rate vectors considered, the very high, "unrealistic" estimates are eliminated (e.g. all estimates are less than 1.2) except in the case of A3 (which eliminates the data from the inexperienced tagger from the 2005/2006 tag seeding experiment). The reporting rate estimates for A1, A2 and A4 all contain the assumption that the reporting rate in one or more years was 100%, which is unrealistic as the re-releases of wild fish from the 40 fish sampling show clearly this is not the case. As such, the fishing mortality rates in these cases are lower bounds for the factors being explored. Overall, the results based on the re-releases of wild fish from the 40 fish sampling are perhaps the most indicative of the actual fishing mortality rates as they are independent of any problems of dependent, high initial shedding in the seeded tag results. Nevertheless, as there is no direct information indicating dependent shedding among the seeded tags, the possibility that fishing mortality rates may be extremely high for some cohorts and age classes of fish found in the GAB cannot be completely discounted.

General Summary of Fishing Mortality Rate Estimates

As discussed in previous years (Polacheck et al. 2005, 2006), there are some apparent anomalous features in the fishing mortality rates from the SRP tagging program. The results suggest that there may be a consistent tagger effects, with tagger 1 consistently yielding somewhat higher results. Another anomaly is the lack of returns at age 3 from the releases of the 1999 cohort at age 2. Only 11 out of the 750 age 2 releases were recovered at age 3 while 50 were recovered at age 4. This results in a very low estimate of the fishing mortality rate at age 3 for this cohort (0-0.08) and a relatively high rate at age 4 (0.25-0.45). It should be pointed out that all of these fish were tagged in WA. Given that most of the surface fishery catch in 2002 (i.e. the year when these fish were age 3) is estimated to be comprised of 3 year old fish, this would suggest that either reporting rates in 2002 were very low or that very few of these fish went to the GAB at age 3 but that a large fraction came back at age 4. There is no direct information on reporting rates in 2002 (i.e. there were no tag seeding experiments). This was also the first year that any substantial numbers of SRP tags would have been expected to have been recaptured and promotional activities were minimal.

The estimates of fishing mortality rates for age 2 are always low relative to those for older ages. Note that when considering these estimates, only estimates based on age 1 releases provide meaningful estimates because the estimates based on age 2 releases are confounded by the time of release relative to the fishery (releases may have occurred before, during or after the main period of fishing). Nevertheless, the estimates of fishing mortality rates for age 2 based on age 1 releases indicate an increasing trend between 2002/2003 and 2004/2005 with some decrease in 2005/2006. The increases are roughly consistent with the trend in estimated numbers of 2 year old fish in the catches by the Australian surface fishery (e.g. 4 fold increase between 2002/2003 and 2004/2005 followed by a 20% decrease in 2005/2006). The increases could reflect increased targeting on or availability of smaller fish in the surface fishery, declining recruitments, or a change in movement patterns (i.e. a higher fraction of 1 year olds are beginning to return to the GAB). If the latter is the case, then the differences in the mortality rates at older ages for age 1 releases versus older releases should diminish. The factors discussed above relative to the overall lack of returns in the SRP tagging from smaller fish need to be kept in mind when interpreting the absolute magnitude of the fishing mortality rate estimates for age 2, as these are all based on age 1 releases.

Overall, taking into account the various alternative reporting rates, the results suggest relatively high to extremely high fishing mortality rates for ages 3 and 4 in 2003 to 2006 for fish tagged at age 2 and similarly for age 4 for fish tagged at age 3 (Table 19). However, it is not clear to what extent this represents the overall juvenile population given the differences in the returns and estimated fishing mortality rates between the age 1 releases and older age releases.

Lack of Returns from 1 Year Old Tagged Fish

As noted above, there has been a comparatively marked lack of returns from fish tagged at smaller sizes and this contrasts markedly from the tag returns in the 1990s (Figure 1). Three possible reasons for the lack of returns from smaller tagged fish are: (1) high tagging mortality of small fish, (2) incomplete mixing and (3) high natural mortality rates on smaller/younger fish. In considering the likelihood of any of these, there must have been a substantial change in at least one of these factors for it to be the primary reason given the contrast in the results for the 1990s and 2000s tagging experiments. In this regard it seems unlikely that high tagging-associated mortality rates are a significant factor. The tagging techniques and a number of the taggers are the same in both cases. Also the acoustic tagging of juvenile fish in WA indicates high rates of survival over the subsequent few months (Hobday et al., 2007) and acoustic tagging constitutes a much greater risk as it involves a surgical operation as well as the placement of conventional tags.

The fact that most small fish are tagged in WA while most of the larger fish are tagged in the GAB is a potential source of non-mixing and difference in the return rates between smaller/younger tagged fish and larger/older fish. This is particularly the case given that most of the tag returns are from the GAB. Thus, it may be that a large fraction of the smaller fish tagged in WA never go to the GAB at older ages during the summer months and that the fraction not going to the GAB has substantially increased since the 1990s. Incomplete mixing is indicated by the much higher return rates from 1 year olds tagged in the GAB than from those tagged in WA (Table 20). Similarly, 6.5% of the 1 year old releases are from the GAB, but 25% of the returns from 1 year old releases are from the 1 year old releases in the GAB. However, a similar bias in the returns from 1 year olds towards GAB tagged fish is seen in both the returns from the Australian surface fishery in the GAB and the returns from the high seas longline fishery. Thus, 26% (N=514) of the returns by purse seiners of 1 year old tagged fish were from fish tagged in the GAB and 19% (N= 89) of the returns by longliners. If mixing is incomplete, there is no obvious reason why 1 year olds found in the GAB, as compared to those found in WA, would preferentially be found at older ages in the high seas winter feeding grounds where longlining occurs. The size distribution at release for tags subsequently recaptured by the longline and purse seine fisheries are also similar (Figure 9). If, in fact, the lack of returns from small or 1 year old fish is due to these fish not being vulnerable to the Australian surface fishery as a result of not going to the GAB, then the expectation would have been for a much higher proportion of the returns of the small and 1 year old fish to have been caught in the longline fishery. It should be noted that no differential is seen in the return rates for 2 year old fish tagged in the WA or the GAB (Table 20). Thus, if the lack of returns from small/younger fish from the SRP tag releases compared to the 1990s tagging is the result of increased non-mixing then it would appear that these fish are not only not going to the GAB, but are also not going to areas where the longline fishery is operating.

Finally, there is the possibility that the lack of returns from small/younger fish is due to high natural mortality rates. There is no direct evidence for this. If this were the case, there must have been a marked increase in the natural mortality rates of 1 year old fish between the 1990s and the 2000s. Moreover, the actual rate must be quite high given the range of estimates for age 1 fish from the 1990s experiments (e.g. Polacheck et al. 1998; 2002) and the very large differential in the return rates from 1 and 2 year old tagged fish when there is virtually no fishing mortality on age 1 fish. Thus, a rough estimate based on Table 20 would be that 80% of the 1 year olds tagged in WA would have to have died in order to yield the same return rate as the 1 year olds tagged in the GAB.

Resolving the reason for the lack of returns from 1 year old tagged fish in the recent SRP tagging experiments is critical both for the interpretation of the results from these tagging experiments and the broader implications for the status of the stock and fisheries. On the one hand, if the lack of returns rates from 1 year old is due to non-mixing, then the implications of the high mortality rates seen for fish tagged at ages 2 and 3 would not represent the rate on the population as a whole. The main concerns would be for the implications for localized depletion and possible long term effects on the spatial dynamics/sub-stock structure, particularly given the collapse of the NSW surface fishery when fishing mortality rates were apparently locally quite high. On the other hand, if non-mixing is not the primary reason for the lack of returns from 1 year old releases, it would suggest that there has been very high natural mortality rates on 1 year old fish as a result of some unknown change, that juvenile fishing mortality rates on the stock as a whole are high and that potential for recent recruitments to contribute significantly to the spawning stock in the future would be low.

Resolving these issues will not be simple. It would most likely require improved experimental tagging designs including:

1. Release of juvenile tagged fish over the entire geographic range to be able to understand and estimate mixing and movement rates;
2. Reliable estimates of reporting rates from all fisheries and areas;
3. Reliable estimates of the size/age composition of the various fisheries by area;
4. Application of an integrated analytical framework for the tag return and catch data.

Returns from the First Season for December Releases

Tag returns from releases near the beginning of the fishing season in the GAB can provide an indication of localized exploitation, particularly if tagging does not take place in the immediate vicinity of fishing operations. In 2003, 2004, 2005 and 2006, some of the SRP tagging operations took place in December in the GAB in inshore areas. Fishing operations are concentrated near the shelf edge. Over the next four months, tags were recovered from 10%-38% of the age 3, 4 or 5 year old fish (Table 21). These recapture rates suggest very high exploitation rates for fish found in the GAB in December – particularly in 2004, where over 50% of the tagged age 3 and 4 fish are estimated to have been caught within the fishing season, taking into account the estimates of reporting rates from tagging seeding experiments given in Table 1. The estimated rates decline for 2005, but nevertheless are high (i.e. 29% and 23% for age 3 and 4 respectively). In 2005, 68 age 5 fish were tagged in December and an estimated 49% were caught within the season, taking into account the estimated reporting rate for 2005. This is almost twice as high as the rate for either age 3 or 4 fish and would suggest that the surface fishery may be quite successful at capturing those larger/older fish that happen to enter into the GAB during a year.

It should be noted that the times of recapture and locations of recapture relative to where the tags were released indicate that these high recapture estimates are not the result of tagging in very close temporal or spatial proximity to where fishing operations were occurring (Figures 10-11). Overall, the return rates during the first season suggest high rates of exploitation of fish within the GAB, particularly in 2004. The extent to which these may represent global rates depends in part on the proportion of the age 3 and 4 fish that are in the GAB during the summer months.

Perhaps somewhat surprising in these data are the low levels of returns from age 2 fish tagged in the same location and time period (Table 21). Less than 5% of the fish tagged at age 2 were estimated to have been recovered during the fishing season in spite of the fact that there were sizable catches of 2 year olds in all four years (particularly since 2003/2004, where the catch of 2 year olds was estimated to comprise 31% to 53% of the catch and to be 7 to 25 times greater than the catch of 4 year olds).

Returns Per 1000 fish

The returns by age from releases of a cohort at a given age can provide an estimate of the catch at age for that cohort for a commercial fleet. There are only sufficient returns from the purse seine fleet to undertake such estimates. Comparison of the percent by age of a cohort's catch for the surface fishery based on catch data from the commercial fishery and on tag returns for different ages at release indicates substantive and consistent differences (Table 22 – note that the figures exclude recaptures from the first year of recovery). The comparisons in Table 22 indicate that relative to the tag return data the estimated number of age 2 fish in the commercial fishery is consistently too high and the number of age 4 and 5 fish is too low. It should be emphasized that the estimates for the tag return data have not been corrected for tag shedding and tag reporting rates. As the effect of tag shedding increases over time and since reporting rates appear to have also declined over time, the results in Table 22 are an underestimation of the actual differences between the commercial fishery and tagging results. If the commercial estimates are in fact representative of the actual catch at age, this would mean that tagged fish, as they age, become differentially and increasingly more vulnerable to the surface fishery than those fish not tagged. This seems unlikely given the location of where the fish were tagged.

In previous papers (Polacheck et al. 2005, 2006) we have compared estimates of the number of tag returns per 1000 fish caught by age and year in the surface fishery and longline fishery. We have not included such comparisons this year because the large longline overcatches (Anon. 2006a,b,c,d) mean that such estimates for the longline fish have little reliability.

For the surface fishery, the sharply increasing estimates of the fraction of individuals with tags at older ages (Table 23) would tend to suggest that not enough older fish have been caught in the surface fishery relative to the number of tags returned from fish at these older ages. For example, for the 2002 cohort at age 4, 5.5% of the estimated surface catch is estimated to have had tags when recaptured based on releases at age 2 (i.e. the recapture of 55.3 tags per 1000 fish for age 4 in 2006 in Table 23). Given that the number of tags released from this cohort at age 2 was 6256 (Table 5), this would suggest that the size of this cohort at the time of tagging (at least the portion that mixed with the tagged fish) was very small (i.e. ~20 times the number of releases or ~ 113,000 fish). It should be emphasized that this 5.5% figure does not take into account unreported tags. If the reporting rates were 50%, then the estimated size of these cohorts at the time of tagging would be approximately half. Since 123,000 fish were estimated to have been captured from this cohort at age 3 in the GAB by the purse seine fishery, the results indicate large inconsistencies between the tag return data and the estimated catch at size/age data from the surface fishery based on the 40 fish sample.

Acknowledgements

We wish to acknowledge the large number of individuals that have contributed to the CCSBT SRP tagging program, including the taggers, the crews of the tagging vessels, those involved in promotion and tag recovery activities, and those responsible for the data processing and management aspects. A special thanks to Bill Hearn for his analyses and provision of the tag retention parameters used in this paper and useful discussion on the reporting rates.

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Table 1: Estimates of reporting rates, their variances and standard errors for the Australian surface fishery for years 2002/2003 to 2005/2006 from Hearn et al. (2007).

Year	Weighted $\hat{\lambda}$	$Var(\hat{\lambda})$	$SE(\hat{\lambda})$	CV
2002/2003	0.652	0.00498	0.071	10.9
2003/2004	0.550	0.00268	0.052	9.5
2004/2005	0.417	0.00082	0.028	6.7
2005/2006	0.218	0.00059	0.024	11.0

Table 2: Shedding rate estimates by individual taggers and by tagger groups (results provided by Dr. Hearn, CSIRO Marine and Atmospheric Research).

	Tagger ID	Initial retention fraction (ξ)	Continuous shedding rate (Ω)	Recaptures with 2 tags	Recaptures with 1 tag	Total number recaptures
	2	0.976	0.105	1842	768	2610
	4	0.909	0.204	817	803	1620
	418	1.000	0.173	47	47	94
	419	1.000	0.284	75	103	178
	444	1.000	0.198	52	45	97
	570	0.850	0.143	87	76	163
	1439	0.778	0.070	258	222	480
	1525	0.887	0.000	169	43	212
	1646	0.884	0.144	228	178	406
	ZZ	0.438	0.000	7	18	25
Tagger Group						
1	2	0.976	0.105	1842	768	2610
2	418+444+570+ 1439+1646	0.821	0.099	672	568	1240
3	4+419	0.914	0.211	892	906	1798
4	ZZ	0.438	0.000	7	18	25
5	1525	0.887	0.000	169	43	212

Table 3: Age-specific natural mortality rates used in the estimation of fishing mortality rates.

	Age				
Vector	1	2	3	4	5
1	0.3401	0.3028	0.2700	0.2420	0.2153
2	0.4202	0.3703	0.3278	0.2894	0.2538

Table 4: Total number of tag releases and reported recaptures by cohort (includes returns to date from the 2007 fishing season).

Cohort	Number releases	Number recaptures	Percent
1998	50	7	14.0
1999	1190	138	11.6
2000	5789	885	15.3
2001	9899	2048	20.7
2002	10307	1390	13.5
2003	14481	1727	11.9
2004	15154	104	0.7
2005	17877	15	0.1
2006	3952	7	0.2

Table 5: The number of releases by age and recaptures by age for the 1998-2005 cohorts. Note that the incomplete recoveries from the 2007 fishing season have not been included nor have releases involving less then 20 fish.

Cohort	Age at release	Number released	Number recaptured by age							Total	Percent recaptured
			1	2	3	4	5	6	7		
1998	5	44					3	1	1	5	11.4
1999	2	750		0	11	51	10	3	1	76	10.1
	3	23			0	1	0	2	0	3	13.0
	4	414				34	16	8	1	59	14.3
2000	1	1921	0	4	88	19	4	1		116	6.0
	2	492		1	50	37	14	1		103	20.9
	3	3276			294	255	66	19		634	19.4
	4	32				7	4	1		12	37.5
	5	68					12	6		18	26.5
2001	1	2748	0	9	127	18	5			159	5.8
	2	5869		29	1092	281	72			1474	25.1
	3	1146			253	100	40			393	34.3
	4	135				12	10			22	16.3
2002	1	3316	1	26	68	25				120	3.6
	2	6256		88	694	344				1126	18.0
	3	720			53	88				141	19.6
2003	1	2662	0	32	152					184	6.9
	2	8692		102	1200					1302	15.0
	3	3127			236					236	7.5
2004	1	7084	1	28						29	0.4
	2	7591		66						66	0.9
2005	1	9177	3							3	0.0

Table 6: Percent of longline returns that occurred in the Tasman Sea (defined as east of 142°E). Note that the RMP results have not been updated for returns in 2005/2006 and beyond.

		Age at recapture						
		2	3	4	5	6	7	8
1990s RMP	All longline returns	39.6	46.7	53.8	58.6	60.3	64.1	45.7
	Japanese returns	39.1	48.3	51.7	56.3	58.9	63.3	48.4
2000s SRP	All longline returns	11.5	5.0	4.7	0.0	-	-	-
	Japanese returns	32.1	17.9	15.9	0.0	-	-	-

Table 7: Percent of longline returns from the Tasman Sea (defined as east of 142°E) that occurred in the Australian Fishing Zone (AFZ) for the 1990s RMP tag releases. Note that the results have not been updated for returns in 2005/2006 and beyond.

	Age at recapture						
	2	3	4	5	6	7	8
% in AFZ	90.7	77.5	67.8	51.4	42.2	34.7	21.6

Table 8: Estimates of age-specific fishing mortality rates for different cohort derived from tags released in the waters around southern Australia. Results are presented separately for tags released at different ages. Lower and upper 5% refer to the lower and upper 5th percentiles from the bootstrap estimates (i.e. the 90% confidence interval). The results shown are for releases from all taggers using the tagging group shedding rates in Table 2 and natural mortality vector 1 of Table 3. A reporting rate of 0.65 was assumed for the longline fisheries.

Cohort	Age at release	Number of releases	Age	F	Lower 5%	Upper 5%
1999	2	750	2	0.000	0.000	0.000
			3	0.036	0.020	0.055
			4	0.258	0.191	0.329
			5	0.103	0.052	0.163
			6	0.070	0.018	0.146
			7	0.025	0.000	0.073
	4	414	4	0.138	0.099	0.179
			5	0.128	0.079	0.182
			6	0.118	0.055	0.198
			7	0.035	0.000	0.100
2000	1	1921	1	0.000	0.000	0.000
			2	0.006	0.001	0.011
			3	0.173	0.138	0.205
			4	0.075	0.044	0.109
			5	0.022	0.004	0.039
			6	0.017	0.000	0.050
	2	492	2	0.004	0.000	0.011
			3	0.270	0.206	0.342
			4	0.501	0.350	0.700
			5	0.513	0.288	0.998
			6	0.042	0.000	0.151
	3	3276	3	0.151	0.138	0.165
			4	0.293	0.261	0.328
			5	0.169	0.136	0.206
			6	0.107	0.063	0.157
2001	1	2748	1	0.000	0.000	0.000
			2	0.008	0.004	0.013
			3	0.222	0.190	0.257
			4	0.059	0.037	0.086
			5	0.031	0.008	0.059
	2	5869	2	0.008	0.006	0.011
			3	0.791	0.737	0.847
			4	0.821	0.700	0.965
			5	0.961	0.621	1.568
	3	1146	3	0.615	0.539	0.694
			4	0.909	0.692	1.189
			5	∞	1.897	∞
2002	1	3316	1	0.001	0.000	0.002
			2	0.023	0.015	0.031
			3	0.124	0.100	0.151
			4	0.104	0.069	0.147
	2	6256	2	0.029	0.025	0.035
			3	0.569	0.523	0.616
			4	1.581	1.283	2.015
	3	720	3	0.220	0.172	0.274
			4	2.874	1.555	∞
2003	1	2662	1	0.000	0.000	0.000
			2	0.046	0.033	0.061
			3	0.769	0.622	0.925
	2	8692	2	0.030	0.026	0.035
			3	2.235	1.898	2.683
2004	1	7084	1	0.000	0.000	0.001
			2	0.022	0.014	0.029

Table 9: Estimates of age-specific fishing mortality rates for different cohort derived from tags released in the waters around southern Australia. Results are presented separately for tags released at different ages. Lower and upper 5% refer to the lower and upper 5th percentiles from the bootstrap estimates (i.e. the 90% confidence interval). The results shown are for releases from all taggers and *natural mortality vector 2* of Table 3. A reporting rate of 0.65 was assumed for the longline fisheries.

Cohort	Age at release	Number of releases	Age	F	Lower 5%	Upper 5%
1999	2	750	2	0.000	0.000	0.000
			3	0.039	0.021	0.060
			4	0.300	0.230	0.385
			5	0.131	0.062	0.204
			6	0.094	0.025	0.197
			7	0.035	0.000	0.115
	4	414	4	0.138	0.104	0.176
			5	0.135	0.082	0.203
			6	0.130	0.056	0.209
			7	0.040	0.000	0.125
2000	1	1921	1	0.000	0.000	0.000
			2	0.006	0.001	0.012
			3	0.204	0.168	0.247
			4	0.097	0.060	0.138
			5	0.030	0.009	0.055
			6	0.024	0.000	0.074
	2	492	2	0.004	0.000	0.011
			3	0.293	0.220	0.377
			4	0.613	0.414	0.896
			5	0.792	0.384	2.239
			6	0.081	0.000	0.777
	3	3276	3	0.151	0.136	0.167
			4	0.314	0.280	0.349
			5	0.194	0.149	0.234
			6	0.131	0.081	0.192
2001	1	2748	1	0.000	0.000	0.000
			2	0.009	0.004	0.014
			3	0.263	0.220	0.309
			4	0.077	0.049	0.110
			5	0.043	0.011	0.084
	2	5869	2	0.009	0.006	0.011
			3	0.882	0.823	0.947
			4	1.189	0.968	1.485
			5	∞	1.821	∞
	3	1146	3	0.617	0.542	0.702
			4	1.003	0.761	1.318
			5	∞	∞	∞
2002	1	3316	1	0.001	0.000	0.002
			2	0.025	0.017	0.034
			3	0.146	0.117	0.176
			4	0.132	0.086	0.182
	2	6256	2	0.030	0.025	0.035
			3	0.625	0.570	0.681
			4	3.070	1.974	∞
	3	720	3	0.220	0.171	0.275
			4	8.568	1.807	∞
2003	1	2662	1	0.000	0.000	0.000
			2	0.051	0.036	0.067
			3	0.983	0.796	1.238
	2	8692	2	0.030	0.026	0.036
			3	3.138	2.469	7.051
2004	1	7084	1	0.000	0.000	0.001
			2	0.024	0.016	0.032

Table 10: Estimates of age-specific fishing mortality rates for different cohort derived from tags released in the waters around southern Australia. Results are presented separately for tags released at different ages. Lower and upper 5% refer to the lower and upper 5th percentiles from the bootstrap estimates (i.e. the 90% confidence interval). The results shown are for releases from *tagger 1* and natural mortality vector 1 of Table 3. A reporting rate of 0.65 was assumed for the longline fisheries.

Cohort	Age at release	Number of Releases	Age	F	Lower 5%	Upper 5%
1999	2	58	2	0.000	0.000	0.000
			3	0.000	0.000	0.000
			4	0.285	0.104	0.591
			5	0.105	0.000	0.384
			6	0.000	0.000	0.000
			7	0.000	0.000	0.000
	4	215	4	0.157	0.099	0.219
			5	0.124	0.058	0.214
			6	0.218	0.087	0.393
			7	0.077	0.000	0.240
2000	1	401	1	0.000	0.000	0.000
			2	0.018	0.006	0.037
			3	0.211	0.144	0.292
			4	0.124	0.051	0.208
			5	0.023	0.000	0.072
			6	0.000	0.000	0.000
	2	242	2	0.007	0.000	0.023
			3	0.289	0.198	0.385
			4	0.899	0.557	1.520
			5	1.964	0.552	∞
			6	0.788	0.000	∞
	3	1654	3	0.178	0.154	0.203
			4	0.299	0.251	0.345
			5	0.191	0.140	0.256
			6	0.106	0.048	0.171
2001	1	1015	1	0.000	0.000	0.000
			2	0.014	0.005	0.024
			3	0.469	0.376	0.566
			4	0.206	0.123	0.302
			5	0.134	0.034	0.253
	2	2301	2	0.009	0.004	0.013
			3	0.988	0.881	1.109
			4	1.496	1.089	2.502
			5	∞	1.769	∞
	3	636	3	0.658	0.553	0.781
			4	0.984	0.705	1.499
			5	∞	1.231	∞
2002	1	1029	1	0.000	0.000	0.000
			2	0.043	0.023	0.063
			3	0.218	0.155	0.283
			4	0.208	0.109	0.324
	2	2987	2	0.034	0.026	0.043
			3	0.679	0.612	0.763
			4	3.039	1.754	∞
	3	114	3	0.413	0.245	0.661
			4	2.716	0.712	∞
2003	1	1127	1	0.000	0.000	0.000
			2	0.061	0.040	0.086
			3	0.927	0.664	1.265
	2	1819	2	0.037	0.025	0.050
			3	2.211	1.656	4.035
2004	1	2858	1	0.000	0.000	0.000
			2	0.027	0.016	0.040

Table 11: Summary of the number of wild tagged fish captured and released into farm cages during the 40 fish sampling from the Australian surface fishery and the number and percentage of these that were subsequently returned.

Fishing Season	Number re-released	Number returned	Percentage Returned
2002/2003	7	4	57.1
2003/2004[1]	5[2]	4	80.0
2004/2005	5	1	20.0
2005/2006	13[3]	5	38.5
Total	30	14	46.7

1) The re-release data for 2003/2004 was not included in the CCSBT tag database provided by the CCSBT secretariat and was obtained directly from the CCSBT data manager.
2) In 2003/2004, there was an error in recording the tag number of one of the re-released fish. The fish was recorded as having two consecutive tag numbers but the wild release data indicates that these were tags from two different fish. This fish was included in the total number of re-released fish and it assumed that the tag from this fish was not recovered.
3) In 2004/2005, there was an error in the recording of tag number for one of the re-released fish (i.e. the tag number recorded had not yet been released). This re-released fish has been excluded from the results presented here.

Table 12: The set of alternative *ad hoc* reporting rate estimates considered for the surface fishery. See text for detail.

Reporting Rate Vector	2002/2003	2003/2004	2004/2005	2005/2006
A1	1.00	1.00	1.00	1.00
A2[1]	1.00	0.79	0.62	0.34
A3	0.65	0.55	0.42	0.30
A4[2]	1.00	0.79	0.62	0.47
A5	0.47	0.47	0.47	0.47
A6	0.67	0.67	0.33	0.33

1) These are calculated by assuming that the reporting in 2002/2003 is 100% and that seeded tags not reported after release are due to shedding of both tags shortly after seeding. This yields a scaling factor of 1.563 for the reporting rate in that year which is used to scale up the weighted reporting rates in the other years.
2) Calculated as for A2 and with the inexperienced tagger in 2005/2006 excluded

Table 13: "Lower bound" estimates of age-specific fishing mortality rates for different cohorts derived from tags released in the waters around southern Australia assuming 100% reporting rates from the surface fishery (vector A1 in Table 12) and from the longline fishery. Results are presented separately for tags released at different ages. Lower and upper 5% refer to the lower and upper 5% percentiles from the bootstrap estimates (i.e. the 90% confidence interval). The results shown are for releases from all taggers using the tagging group shedding rates in Table 2 and natural mortality vector 1 of Table 3.

Cohort	Age at release	Number of Releases	Age	F	Lower 5%	Upper 5%
1999	2	58	2	0.000	0.000	0.000
			3	0.030	0.015	0.046
			4	0.173	0.132	0.224
			5	0.067	0.035	0.109
			6	0.022	0.006	0.047
			7	0.021	0.000	0.065
	4	215	4	0.090	0.063	0.116
			5	0.064	0.039	0.094
			6	0.043	0.023	0.072
			7	0.006	0.000	0.019
2000	1	401	1	0.000	0.000	0.000
			2	0.005	0.001	0.009
			3	0.115	0.094	0.136
			4	0.044	0.026	0.063
			5	0.020	0.004	0.039
			6	0.003	0.000	0.010
	2	242	2	0.004	0.000	0.011
			3	0.177	0.134	0.223
			4	0.213	0.150	0.283
			5	0.146	0.080	0.230
			6	0.020	0.000	0.062
	3	1654	3	0.097	0.088	0.107
			4	0.133	0.120	0.149
			5	0.051	0.040	0.061
			6	0.025	0.016	0.035
2001	1	1015	1	0.000	0.000	0.000
			2	0.006	0.003	0.010
			3	0.108	0.092	0.126
			4	0.024	0.015	0.034
			5	0.010	0.003	0.019
	2	2301	2	0.007	0.005	0.010
			3	0.328	0.312	0.345
			4	0.156	0.140	0.174
			5	0.076	0.061	0.092
	3	636	3	0.270	0.243	0.301
			4	0.175	0.146	0.207
			5	0.118	0.089	0.153
2002	1	1029	1	0.001	0.000	0.002
			2	0.014	0.010	0.019
			3	0.049	0.039	0.058
			4	0.029	0.019	0.042
	2	2987	2	0.016	0.013	0.019
			3	0.182	0.170	0.193
			4	0.163	0.148	0.179
	3	114	3	0.085	0.066	0.106
			4	0.209	0.170	0.243
2003	1	1127	1	0.000	0.000	0.000
			2	0.021	0.015	0.027
			3	0.146	0.124	0.167
	2	1819	2	0.015	0.012	0.017
			3	0.240	0.229	0.252
2004	1	7084	1	0.000	0.000	0.001
			2	0.007	0.005	0.009

Table 14: Estimates of age-specific fishing mortality rates for different cohort derived from tags released in the waters around southern Australia using reporting rates for the surface fishery which assume high initial shedding rates for seeded tags (see vector A2 in Table 12); a reporting rate of 0.65 was assumed for the longline fishery. Results are presented separately for tags released at different ages. Lower and upper 5% refer to the lower and upper 5% percentiles from the bootstrap estimates (i.e. the 90% confidence interval). The results shown are for releases from all taggers using the tagging group shedding rates in Table 2 and natural mortality vector 1 of Table 3.

Cohort	Age at release	Number of releases	Age	F	Lower 5%	Upper 5%
1999	2	750	2	0.000	0.000	0.000
			3	0.030	0.015	0.046
			4	0.173	0.130	0.215
			5	0.074	0.038	0.118
			6	0.036	0.009	0.070
			7	0.021	0.000	0.066
	4	414	4	0.090	0.066	0.118
			5	0.078	0.046	0.116
			6	0.065	0.032	0.103
			7	0.019	0.000	0.058
2000	1	1921	1	0.000	0.000	0.000
			2	0.005	0.001	0.010
			3	0.115	0.094	0.137
			4	0.050	0.031	0.070
			5	0.020	0.004	0.038
			6	0.010	0.000	0.030
	2	492	2	0.004	0.000	0.011
			3	0.177	0.136	0.218
			4	0.267	0.188	0.354
			5	0.216	0.125	0.338
			6	0.022	0.000	0.069
	3	3276	3	0.097	0.089	0.107
			4	0.168	0.151	0.185
			5	0.082	0.065	0.100
			6	0.055	0.035	0.077
2001	1	2748	1	0.000	0.000	0.000
			2	0.006	0.003	0.010
			3	0.136	0.115	0.156
			4	0.035	0.021	0.049
			5	0.020	0.006	0.036
	2	5869	2	0.007	0.005	0.010
			3	0.426	0.401	0.449
			4	0.274	0.247	0.303
			5	0.193	0.153	0.237
	3	1146	3	0.347	0.308	0.387
			4	0.318	0.262	0.383
			5	0.415	0.294	0.569
2002	1	3316	1	0.001	0.000	0.002
			2	0.016	0.011	0.022
			3	0.074	0.060	0.089
			4	0.066	0.044	0.090
	2	6256	2	0.019	0.016	0.023
			3	0.300	0.278	0.321
			4	0.516	0.464	0.580
	3	720	3	0.130	0.099	0.158
			4	0.815	0.631	1.033
2003	1	2662	1	0.000	0.000	0.000
			2	0.030	0.022	0.039
			3	0.428	0.366	0.501
	2	8692	2	0.020	0.017	0.023
			3	0.860	0.803	0.925
2004	1	7084	1	0.000	0.000	0.001
			2	0.015	0.010	0.020

Table 15: Estimates of age-specific fishing mortality rates for different cohort derived from tags released in the waters around southern Australia using reporting rates for the surface fishery with the inexperienced tagger in 2005/2006 excluded (vector A3 in Table 12)); a reporting rate of 0.65 was assumed for the longline fishery. Results are presented separately for tags released at different ages. Lower and upper 5% refer to the lower and upper 5% percentiles from the bootstrap estimates (i.e. the 90% confidence interval). The results shown are for releases from all taggers using the tagging group shedding rates in Table 2 and natural mortality vector 1 of Table 3.

Cohort	Age at release	Number of releases	Age	F	Lower 5%	Upper 5%
1999	2	750	2	0.000	0.000	0.000
			3	0.036	0.019	0.053
			4	0.258	0.194	0.325
			5	0.103	0.051	0.160
			6	0.070	0.019	0.151
			7	0.025	0.000	0.077
	4	414	4	0.138	0.100	0.178
			5	0.128	0.075	0.187
			6	0.118	0.055	0.190
			7	0.025	0.000	0.079
2000	1	1921	1	0.000	0.000	0.000
			2	0.006	0.001	0.011
			3	0.173	0.141	0.209
			4	0.075	0.048	0.104
			5	0.022	0.005	0.044
			6	0.012	0.000	0.037
	2	492	2	0.004	0.000	0.011
			3	0.270	0.199	0.342
			4	0.501	0.349	0.687
			5	0.513	0.257	0.902
			6	0.042	0.000	0.140
	3	3276	3	0.151	0.137	0.165
			4	0.293	0.260	0.327
			5	0.169	0.134	0.210
			6	0.079	0.048	0.115
2001	1	2748	1	0.000	0.000	0.000
			2	0.008	0.003	0.013
			3	0.222	0.188	0.258
			4	0.059	0.038	0.082
			5	0.024	0.007	0.044
	2	5869	2	0.008	0.006	0.011
			3	0.791	0.736	0.846
			4	0.821	0.706	0.948
			5	0.640	0.440	0.897
	3	1146	3	0.615	0.547	0.702
			4	0.909	0.688	1.234
			5	2.104	0.962	∞
2002	1	3316	1	0.001	0.000	0.002
			2	0.023	0.017	0.030
			3	0.124	0.099	0.152
			4	0.077	0.051	0.105
	2	6256	2	0.029	0.024	0.035
			3	0.569	0.526	0.615
			4	0.875	0.759	1.020
	3	720	3	0.220	0.168	0.280
			4	1.122	0.827	1.535
2003	1	2662	1	0.000	0.000	0.000
			2	0.046	0.032	0.061
			3	0.494	0.421	0.573
	2	8692	2	0.030	0.025	0.035
			3	1.029	0.949	1.114
2004	1	7084	1	0.000	0.000	0.001
			2	0.016	0.011	0.022

Table 16: Estimates of age-specific fishing mortality rates for different cohort derived from tags released in the waters around southern Australia using reporting rates for the surface fishery which assume high initial shedding rates for seeded tags and which exclude the inexperienced tagger in 2005/2006 (vector A4 in Table 12); a reporting rate of 0.65 was assumed for the longline fishery.. Results are presented separately for tags released at different ages. Lower and upper 5% refer to the lower and upper 5% percentiles from the bootstrap estimates (i.e. the 90% confidence interval). The results shown are for releases from all taggers using the tagging group shedding rates in Table 2 and natural mortality vector 1 of Table 3.

Cohort	Age at release	Number of Releases	Age	F	Lower 5%	Upper 5%
1999	2	58	2	0.000	0.000	0.000
			3	0.030	0.015	0.045
			4	0.173	0.133	0.223
			5	0.074	0.034	0.118
			6	0.036	0.000	0.074
			7	0.021	0.000	0.066
	4	215	4	0.090	0.067	0.116
			5	0.078	0.049	0.118
			6	0.065	0.030	0.108
			7	0.014	0.000	0.040
2000	1	401	1	0.000	0.000	0.000
			2	0.005	0.001	0.009
			3	0.115	0.095	0.135
			4	0.050	0.032	0.071
			5	0.020	0.004	0.037
			6	0.007	0.000	0.021
	2	242	2	0.004	0.000	0.011
			3	0.177	0.134	0.224
			4	0.267	0.196	0.347
			5	0.216	0.121	0.327
			6	0.022	0.000	0.071
	3	1654	3	0.097	0.089	0.107
			4	0.168	0.149	0.185
			5	0.082	0.065	0.099
			6	0.042	0.026	0.059
2001	1	1015	1	0.000	0.000	0.000
			2	0.006	0.003	0.010
			3	0.136	0.116	0.157
			4	0.035	0.021	0.047
			5	0.016	0.006	0.029
	2	2301	2	0.007	0.005	0.010
			3	0.426	0.404	0.451
			4	0.274	0.243	0.306
			5	0.149	0.119	0.180
	3	636	3	0.347	0.313	0.385
			4	0.318	0.256	0.384
			5	0.290	0.212	0.373
2002	1	1029	1	0.001	0.000	0.002
			2	0.016	0.011	0.022
			3	0.074	0.057	0.088
			4	0.050	0.034	0.069
	2	2987	2	0.019	0.016	0.023
			3	0.300	0.279	0.320
			4	0.358	0.323	0.393
	3	114	3	0.130	0.102	0.162
			4	0.512	0.420	0.623
2003	1	1127	1	0.000	0.000	0.000
			2	0.030	0.022	0.039
			3	0.296	0.255	0.346
	2	1819	2	0.020	0.017	0.023
			3	0.542	0.513	0.575
2004	1	7084	1	0.000	0.000	0.001
			2	0.012	0.008	0.016

Table 17: Estimates of age-specific fishing mortality rates for different cohort derived from tags released in the waters around southern Australia using a constant reporting rates for the surface fishery and based on the return rate of re-released wild tagged fish caught during the 40 fish sample (vector A5 in Table 12); a reporting rate of 0.65 was assumed for the longline fishery. Results are presented separately for tags released at different ages. Lower and upper 5% refer to the lower and upper 5% percentiles from the bootstrap estimates (i.e. the 90% confidence interval). The results shown are for releases from all taggers using the tagging group shedding rates in Table 2 and natural mortality vector 1 of Table 3.

Cohort	Age at release	Number of releases	Age	F	Lower 5%	Upper 5%
1999	2	750	2	0.000	0.000	0.000
			3	0.043	0.023	0.066
			4	0.359	0.269	0.460
			5	0.117	0.053	0.193
			6	0.061	0.015	0.133
			7	0.028	0.000	0.084
	4	414	4	0.192	0.138	0.250
			5	0.140	0.086	0.208
			6	0.100	0.047	0.163
			7	0.017	0.000	0.051
2000	1	1921	1	0.000	0.000	0.000
			2	0.006	0.002	0.013
			3	0.240	0.195	0.290
			4	0.082	0.051	0.119
			5	0.024	0.005	0.046
			6	0.008	0.000	0.026
	2	492	2	0.004	0.000	0.011
			3	0.381	0.286	0.490
			4	0.603	0.422	0.902
			5	0.526	0.290	1.113
			6	0.053	0.000	0.202
	3	3276	3	0.213	0.191	0.232
			4	0.326	0.289	0.367
			5	0.145	0.116	0.179
			6	0.061	0.039	0.085
2001	1	2748	1	0.000	0.000	0.000
			2	0.010	0.004	0.015
			3	0.230	0.195	0.268
			4	0.048	0.029	0.069
			5	0.018	0.007	0.034
	2	5869	2	0.010	0.007	0.013
			3	0.830	0.775	0.887
			4	0.621	0.535	0.717
			5	0.353	0.270	0.464
	3	1146	3	0.641	0.560	0.727
			4	0.653	0.524	0.836
			5	0.650	0.405	1.007
2002	1	3316	1	0.001	0.000	0.002
			2	0.024	0.016	0.031
			3	0.097	0.078	0.117
			4	0.052	0.037	0.072
	2	6256	2	0.030	0.025	0.036
			3	0.418	0.387	0.449
			4	0.425	0.380	0.480
	3	720	3	0.170	0.133	0.211
			4	0.548	0.447	0.678
2003	1	2662	1	0.000	0.000	0.000
			2	0.037	0.026	0.049
			3	0.302	0.254	0.350
	2	8692	2	0.025	0.020	0.029
			3	0.554	0.522	0.589
2004	1	7084	1	0.000	0.000	0.001
			2	0.012	0.009	0.016

Table 18: Estimates of age-specific fishing mortality rates for different cohort derived from tags released in the waters around southern Australia assuming two different reporting for the surface fishery (i.e. pre 2004/2005 and post) and based on the return rate of re-released wild tagged fish caught during the 40 fish sample (vector A6 in Table 12); a reporting rate of 0.65 was assumed for the longline fishery. Results are presented separately for tags released at different ages. Lower and upper 5% refer to the lower and upper 5th percentiles from the bootstrap estimates (i.e. the 90% confidence interval). The results shown are for releases from all taggers using the tagging group shedding rates in Table 2 and natural mortality vector 1 of Table 3.

Cohort	Age at release	Number of Releases	Age	F	Lower 5%	Upper 5%
1999	2	58	2	0.000	0.000	0.000
			3	0.036	0.019	0.057
			4	0.249	0.186	0.313
			5	0.086	0.045	0.137
			6	0.075	0.020	0.156
			7	0.024	0.000	0.077
	4	215	4	0.133	0.096	0.174
			5	0.094	0.054	0.134
			6	0.124	0.063	0.205
			7	0.024	0.000	0.071
2000	1	401	1	0.000	0.000	0.000
			2	0.005	0.001	0.010
			3	0.167	0.136	0.199
			4	0.059	0.038	0.083
			5	0.021	0.005	0.041
			6	0.012	0.000	0.036
	2	242	2	0.004	0.000	0.011
			3	0.260	0.206	0.327
			4	0.345	0.248	0.478
			5	0.456	0.237	0.819
			6	0.034	0.000	0.116
	3	1654	3	0.145	0.131	0.160
			4	0.207	0.187	0.228
			5	0.169	0.131	0.205
			6	0.073	0.047	0.101
2001	1	1015	1	0.000	0.000	0.000
			2	0.008	0.004	0.012
			3	0.159	0.135	0.182
			4	0.061	0.038	0.086
			5	0.023	0.006	0.042
	2	2301	2	0.008	0.006	0.011
			3	0.514	0.485	0.545
			4	0.623	0.541	0.700
			5	0.351	0.263	0.446
	3	636	3	0.414	0.363	0.459
			4	0.767	0.602	0.973
			5	0.991	0.587	1.839
2002	1	1029	1	0.001	0.000	0.002
			2	0.018	0.013	0.025
			3	0.136	0.110	0.165
			4	0.078	0.051	0.103
	2	2987	2	0.022	0.019	0.026
			3	0.639	0.586	0.695
			4	0.985	0.839	1.165
	3	114	3	0.242	0.185	0.308
			4	1.193	0.874	1.783
2003	1	1127	1	0.000	0.000	0.000
			2	0.051	0.035	0.067
			3	0.502	0.416	0.592
	2	1819	2	0.033	0.027	0.038
			3	1.051	0.977	1.139
2004	1	7084	1	0.000	0.000	0.001
			2	0.017	0.011	0.022

Table 19: Summary of fishing mortality rate estimates in years 2002 to 2006 from tags released at ages 1 to 4 and recaptured at ages 2 to 5. Shown are the F estimates and bootstrapped 90% confidence intervals obtained using reporting rate vector A5 in Table 12 for the surface fishery, a reporting rate of 0.65 for the longline fishery, and shedding rates given in Table 2.

Release Age	Recapture Age	Recapture Year	# Tagged	F	Lower 5%	Upper 5%
1	2	2002	1921	0.006	0.002	0.013
1	2	2003	2748	0.010	0.004	0.015
1	2	2004	3316	0.024	0.016	0.031
1	2	2005	2662	0.037	0.026	0.049
1	3	2003	1921	0.240	0.195	0.290
1	3	2004	2748	0.230	0.195	0.268
1	3	2005	3316	0.097	0.078	0.117
1	3	2006	2662	0.302	0.254	0.350
1	4	2004	1921	0.082	0.051	0.119
1	4	2005	2748	0.048	0.029	0.069
1	4	2006	3316	0.052	0.037	0.072
1	5	2005	1921	0.024	0.005	0.046
1	5	2006	2748	0.018	0.007	0.034
2	3	2002	750	0.043	0.023	0.066
2	3	2003	492	0.381	0.286	0.490
2	3	2004	5869	0.830	0.775	0.887
2	3	2005	6256	0.418	0.387	0.449
2	3	2006	8692	0.554	0.522	0.589
2	4	2003	750	0.359	0.269	0.460
2	4	2004	492	0.603	0.422	0.902
2	4	2005	5869	0.621	0.535	0.717
2	4	2006	6256	0.425	0.380	0.480
2	5	2004	750	0.117	0.053	0.193
2	5	2005	492	0.526	0.290	1.113
2	5	2006	5869	0.353	0.270	0.464
3	4	2004	3276	0.326	0.289	0.367
3	4	2005	1146	0.653	0.524	0.836
3	4	2006	720	0.548	0.447	0.678
3	5	2005	3276	0.145	0.116	0.179
3	5	2006	1146	0.650	0.405	1.007
4	5	2004	414	0.140	0.086	0.208

Table 20: Comparison of the number and percent of tags recovered by age and release location.

Age at Release	Release Location	Number Recovered	Number Released	Percent Recovered
1	GAB	153	1161	13.2%
	WA	460	16570	2.8%
2	GAB	2435	13745	17.7%
	WA	1432	8314	17.2%

Table 21: First year recaptures of fish released in December in the Great Australian Bight by age of release and fishing year. Estimated percent caught is based on reporting rate estimates in Table 1, with no allowance for tag shedding.

Fishing Year	Release Age	Number Released	Number Returned	Percent Returned	Est. Percent Caught
2003	1	17	0	0	0
	2	894	13	1.5	2.3
	3	3004	283	9.4	14.6
	4	242	32	13.2	20.5
	5	8	3	37.5	58.1
2004	1	622	0	0.0	0.0
	2	3187	75	2.4	4.9
	3	978	234	23.9	49.6
	4	27	7	25.9	53.8
	5	3	0	0.0	0.0
2005	1	52	0	0.0	0.0
	2	2760	33	1.2	3.3
	3	308	32	10.4	28.6
	4	130	11	8.5	23.3
	5	68	12	17.6	48.6
2006	1	22	0	0.0	0.0
	2	1887	15	0.8	3.7
	3	2442	179	7.3	34.1
	4	14	1	7.1	33.2
	5	1	0	0.0	0.0

Table 22: Comparison of the percent by age of a cohort's catch for the surface fishery based on catch data from the commercial fishery and based on tag returns for different ages at release. Recaptures from the first year of recovery are not included. Percent of a commercial catch by age are based on the corresponding ages from which tag return data are available for a cohort and age at release.

Cohort	Release Age		Catch/Recapture Age 2	3	4	5	# Caught/ # Returned
2000	1	Catch	7.5	70.6	21.5	0.5	250152
		Tag	2.1	84.2	13.7	0.0	95
	2	Catch		76.3	23.2	0.5	231499
		Tag		51.1	37.5	11.4	88
	3	Catch		0.0	97.8	2.2	54950
		Tag		0.0	79.3	20.7	295
2001	1	Catch	16.5	74.3	8.8	0.4	258402
		Tag	4.3	83.6	10.0	2.1	140
	2	Catch		89.0	10.5	0.5	215740
		Tag		77.6	19.0	3.4	1316
	3	Catch			95.7	4.3	23669
		Tag			100.0	0	96
2002	1	Catch	41.3	56.3	2.4		220820
		Tag	19.4	62.2	18.4		98
	2	Catch		95.9	4.1		129562
		Tag		70.1	29.9		931
2003	1	Catch	45.8	54.2			367936
		Tag	16.5	83.5			158

Table 23: Estimates of the number of tags returned per 1000 fish caught by age, age of release and year for the SBT surface fisheries. No adjustment has been made to the number of tags recaptured to account for tag shedding and reporting rates. The estimates of the catch by age are based on those provided by the CCSBT secretariat and take no account of possible over-catches. Note that tags recaptured in the year of release have been excluded from the number of tags recaptured.

Year	Release Age	Recapture Age 2	3	4	5
2003	1	0.14	0.45	0.00	
	2		0.25	0.82	0.00
	3			0.02	0.00
2004	1	0.21	0.61	1.01	0.00
	2		5.32	2.57	17.21
	3			18.25	0.00
2005	1	0.15	0.49	0.62	0.00
	2		5.25	11.03	8.28
	3			4.24	50.50
2006	1	0.14	0.66	3.43	2.98
	2		5.51	52.96	44.69
	3			16.00	32.78

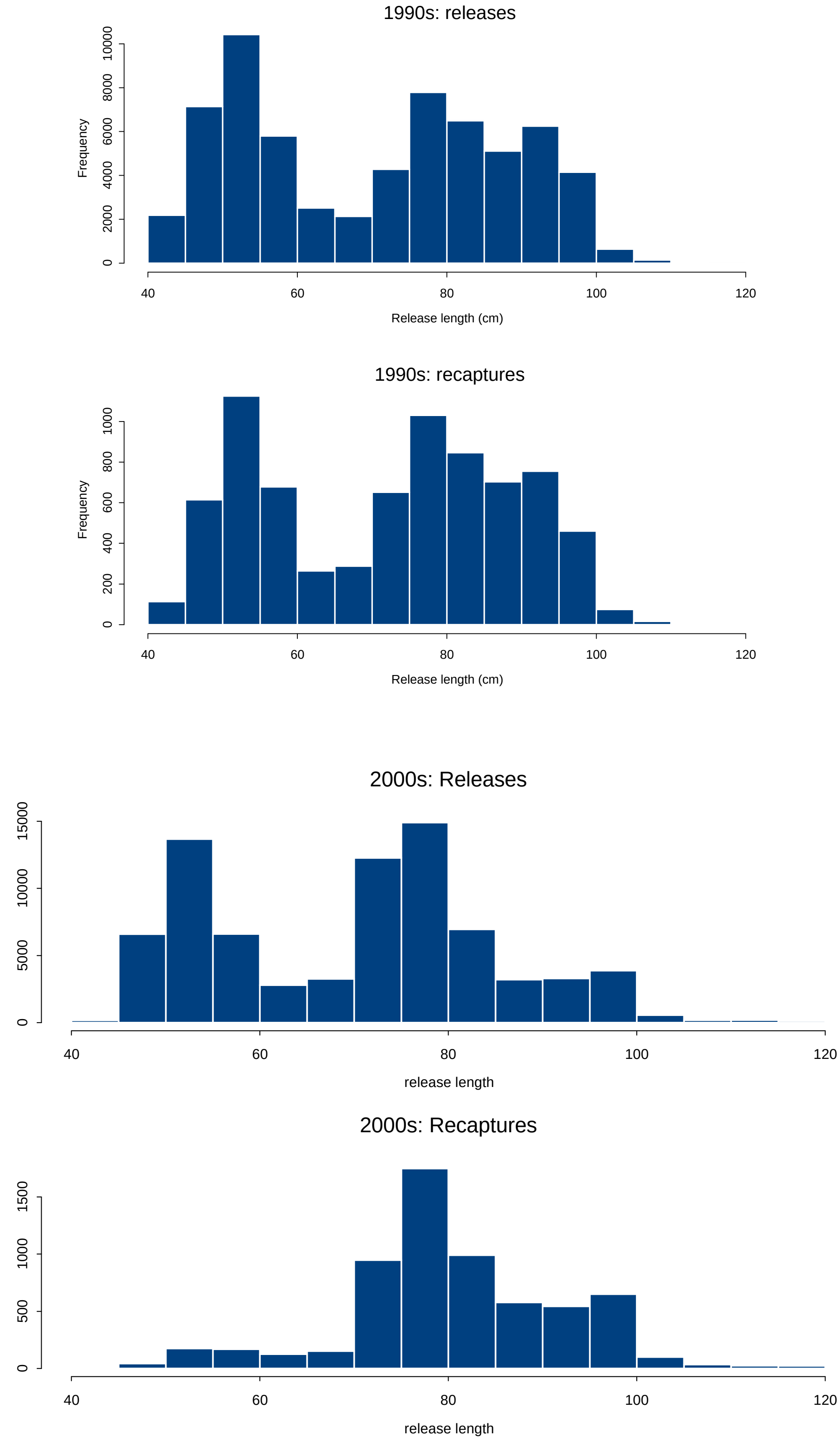


Figure 1: Comparison of the release length distribution for all fish released and for those fish that were recaptured. The upper two panels are for the 1990s releases and the lower two are for the 2000s releases.

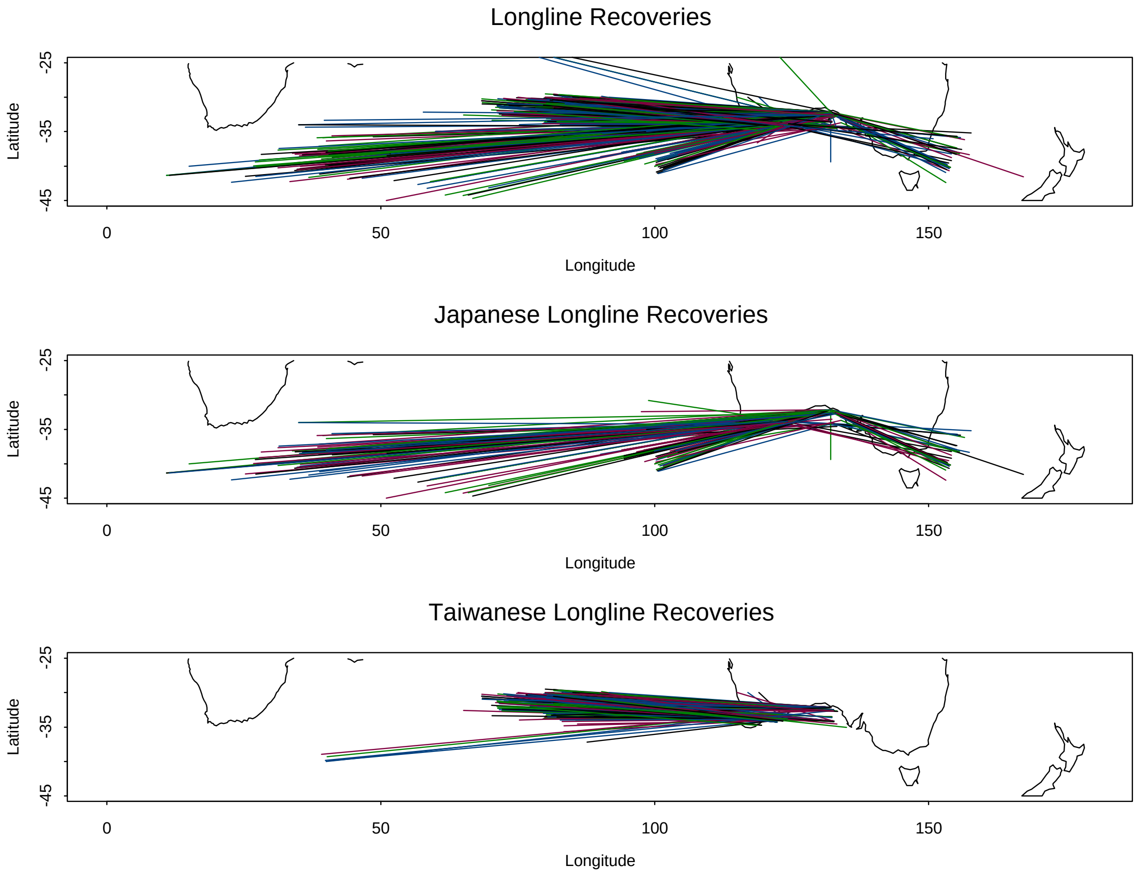


Figure 2: Release and recapture locations for longline returns from the SRP conventional tagging in WA and SA.

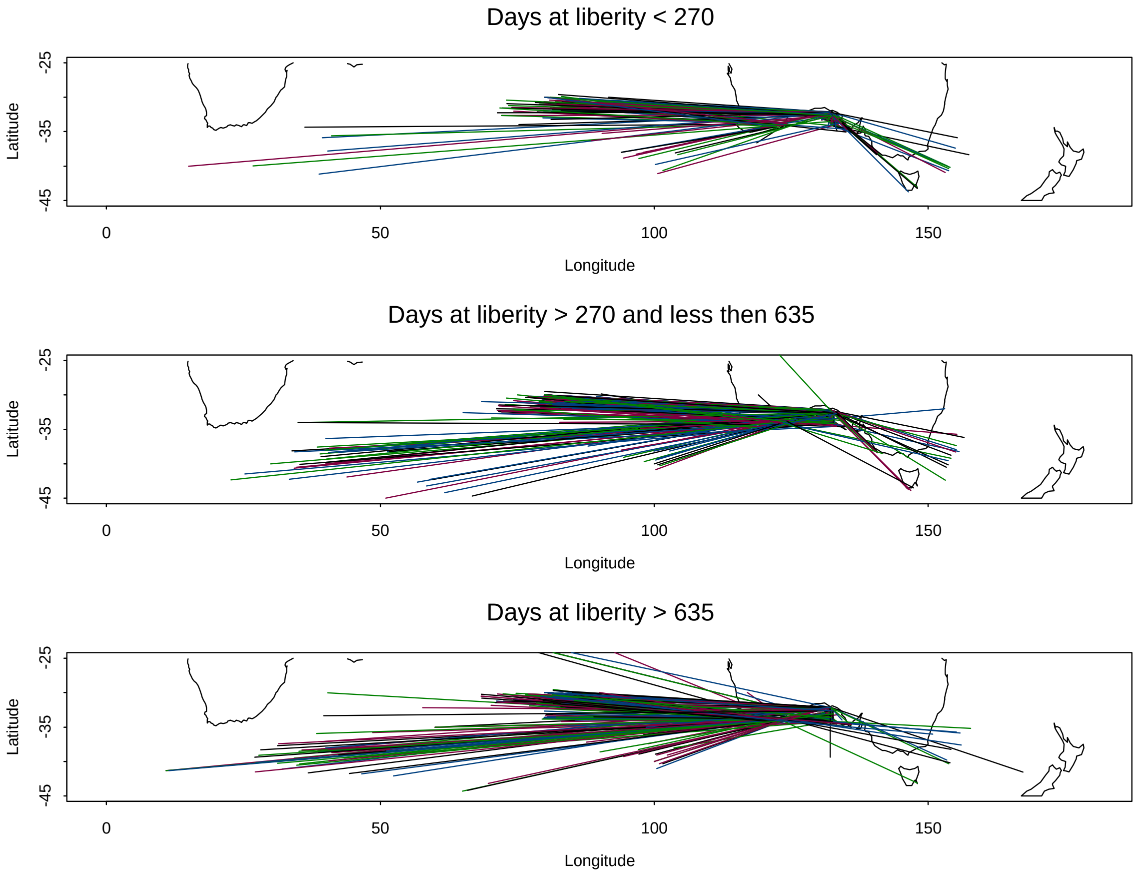


Figure 3: Release and recapture locations for longline tag returns for different times at liberty from the SRP conventional tagging in WA and SA.

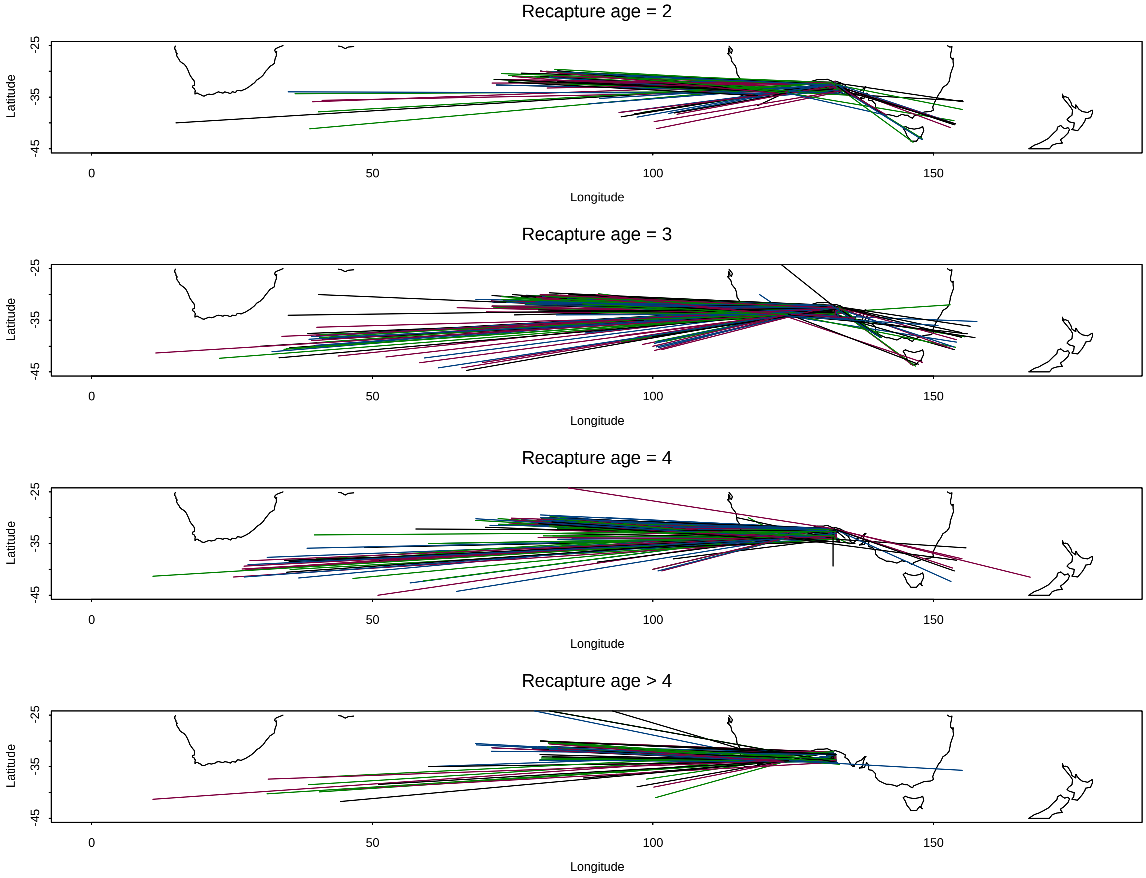


Figure 4: Release and recapture locations for longline tag returns for different ages at recapture from the SRP conventional tagging in WA and SA.

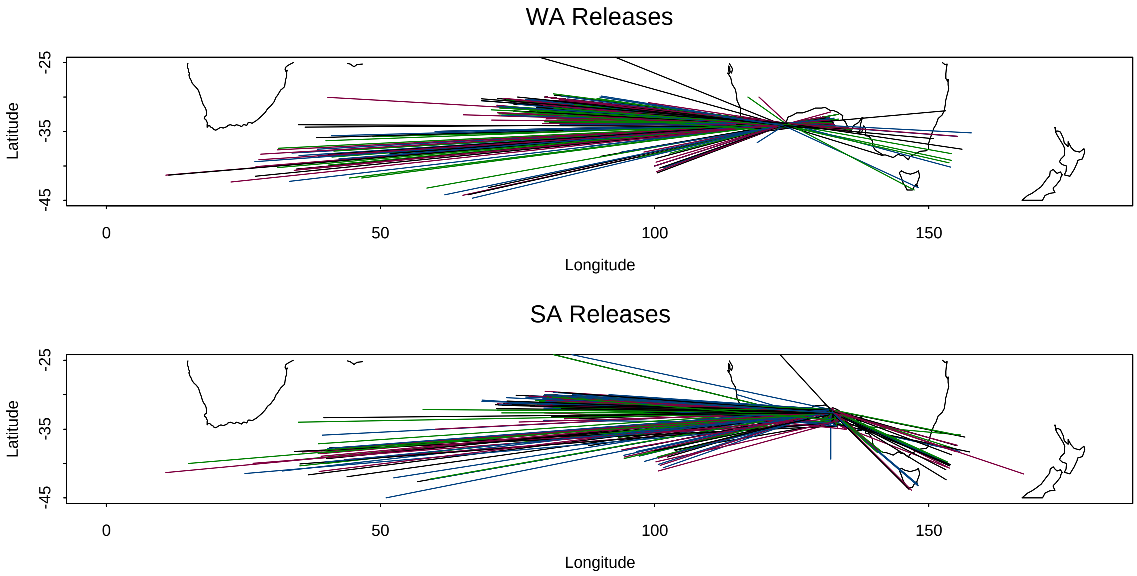


Figure 5: Comparison of release and recapture locations for longline tag returns released in Western Australia (WA) versus South Australia (SA) as part of the SRP conventional tagging.

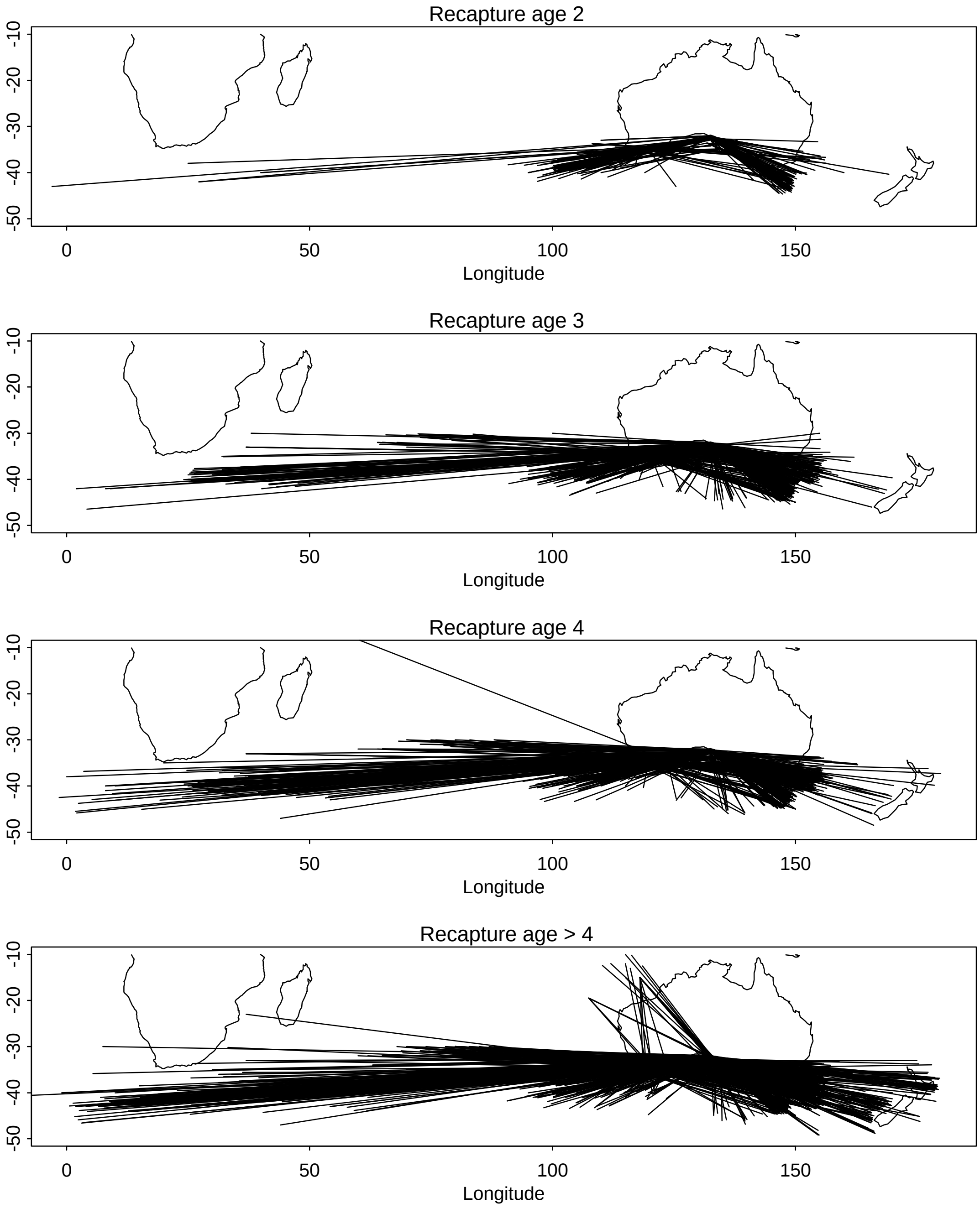
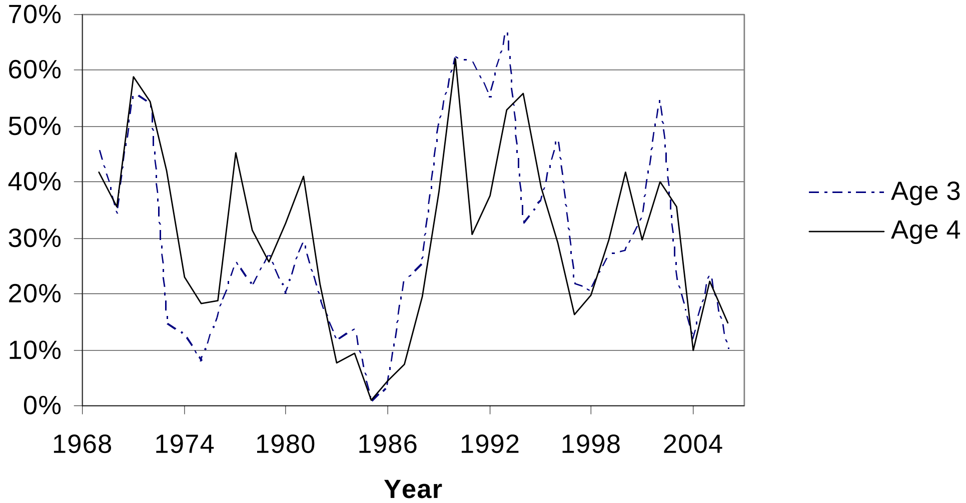


Figure 6: Release and recapture locations for longline tag returns for different ages at recapture from the RMP conventional tagging in WA and SA in the 1990s.



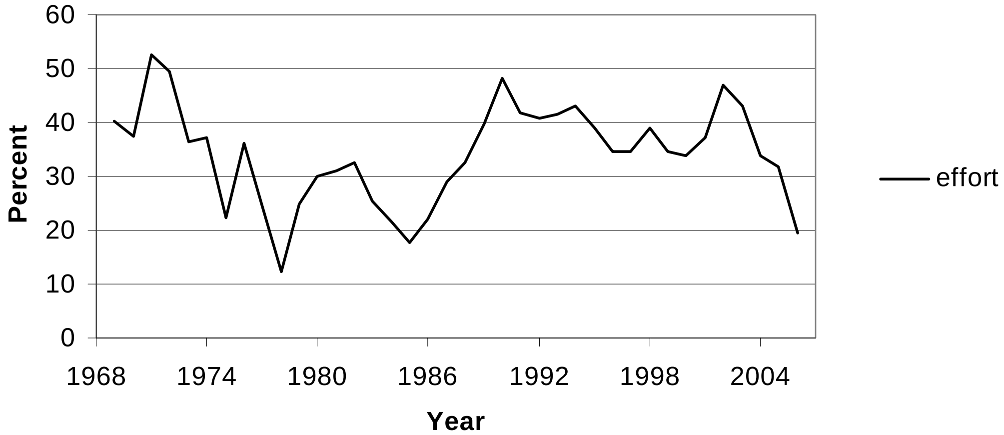
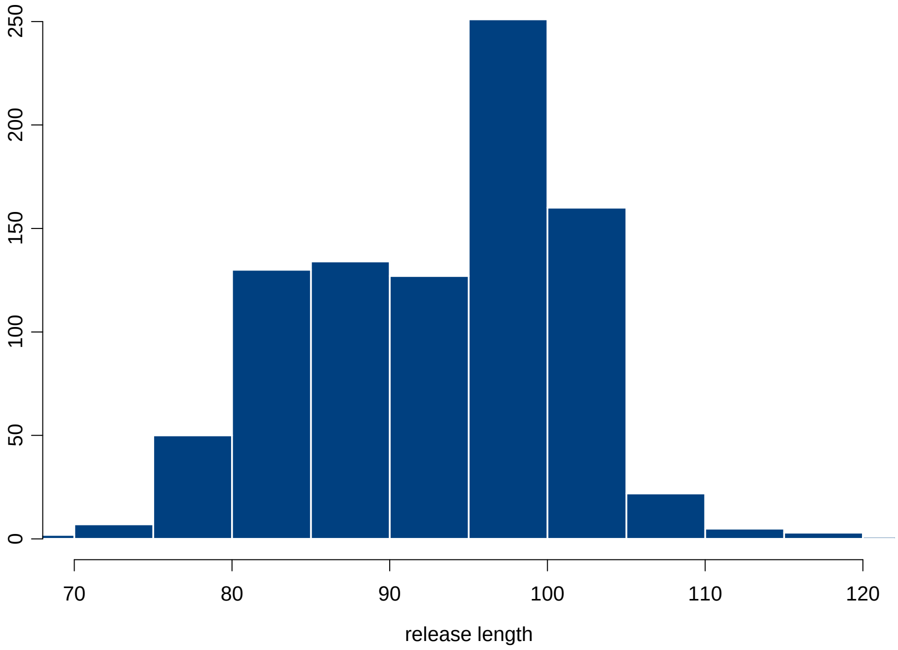


Figure 7: The percentage of age 3 and 4 Japanese longline SBT caught based on Japanese vessel reported logbook data that were taken from the Tasman area (east of 140°) and percent of Japanese longline effort in this area. Note the figures are for quarters 2 and 3 and only include data for statistical areas 4-9. The reliability of these percentage estimates and their interpretation is uncertain because of the large longline overcatches of SBT (Anon. 2006a, b, c, d).



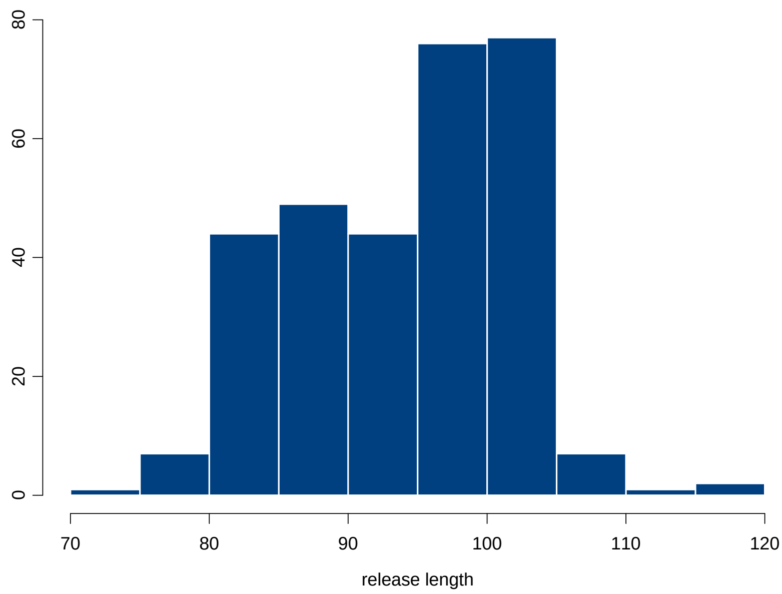


Figure 8: Comparison of the release lengths of tag-seeded fish (upper panel) with the release lengths of those tag-seeded fish that were recovered. Shown are all seeded tags from 2003/2004 to 2005/2006.

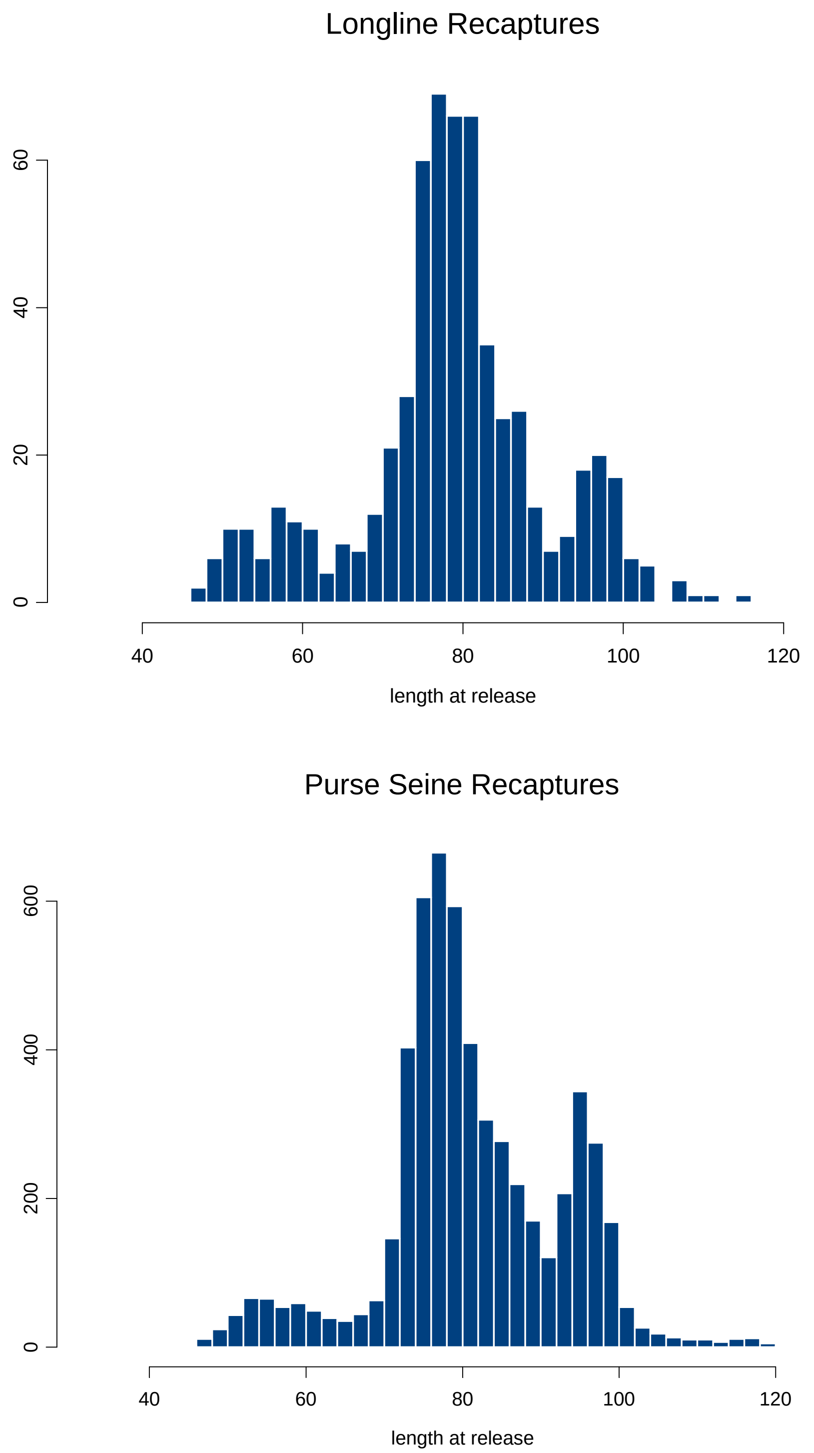


Figure 9: Comparison of the release lengths for tagged fish recaptured by longline and purse seine vessels.

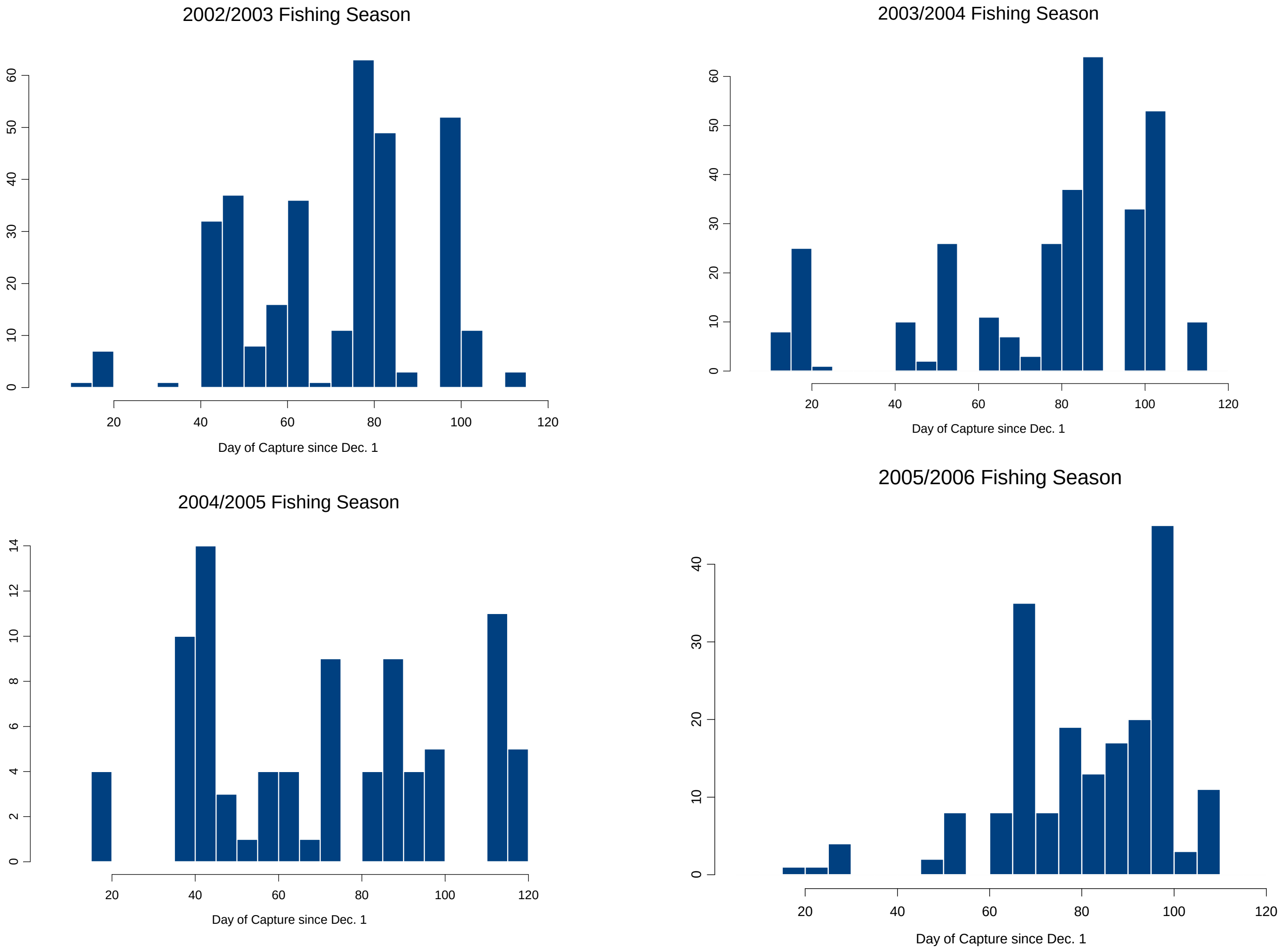


Figure 10: Number of days after December 1 in which a tagged fish released in December in the GAB in 2003, 2004, 2005 and 2006 was recaptured in the same fishing season. Note that day of recapture is approximate because all recaptures from a single tow cage are assigned the same date of recapture.

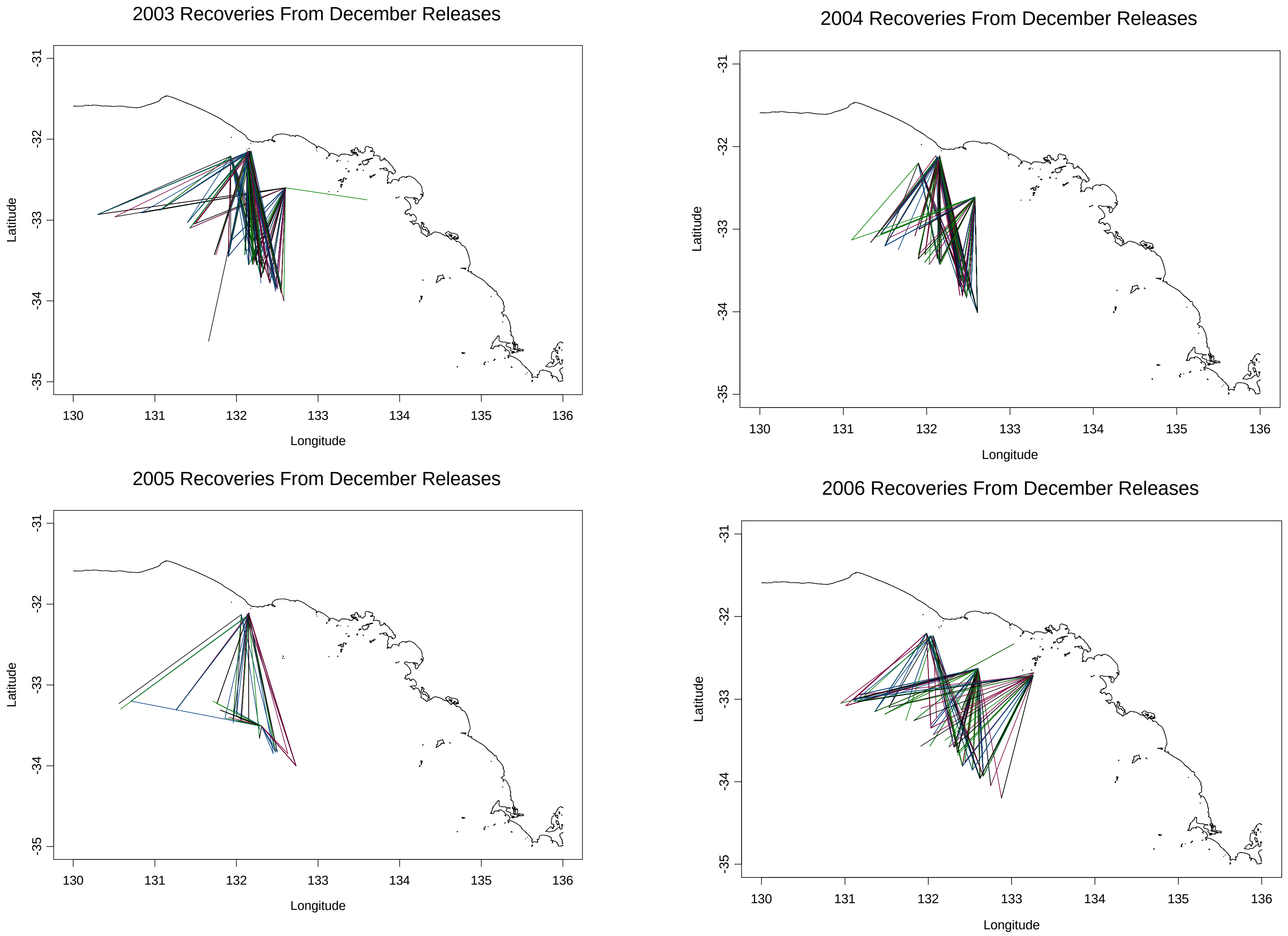


Figure 11: Release and recapture locations for returned tagged fish released in December in the GAB in 2003, 2004, 2005 and 2006 and recaptured in the same fishing season. Note that day of recapture is approximate because all recaptures from a single tow cage are assigned the same location of recapture.

Appendix 1

Consideration of the Data Collected by the Freezer-Boat Tag Recovery Agent

Consideration of the Data Collected by the Freezer-Boat Tag Recovery Agent

In 2006, the CCSBT Executive Secretary arranged for an agent to attend 20 days of processing on freezer vessels to recover all tags present on fish being processed and record the number of fish where there was evidence of the recent removal of tags earlier in the processing chain. The tag recovery agent also recorded data on the number of fish he observed for tags, the tow/farm cage from which the fish being processed were taken from and comments about the apparent tag recovery activities for the associated tuna farms. He was unable to provide information on the size distribution of either the fish recovered with tags or of the fish being processed.

Evaluation of these data potentially could provide insight and independent information related to reporting rates. However, there are a number of factors that confound a simple evaluation of this including:

- It is unclear what proportion of the tags that the tag recovery agent retrieved would have been recovered and reported in his absence (i.e. he was inspecting the fish at the point the fish were being transferred to the freezer vessel);
- The farm companies were aware of the tag recovery agent's presence and this may have changed their tag recovery and reporting behaviour;
- A large percentage of the farm fish from 2006 were processed on the freezer vessels with the remainder processed by the companies themselves (primarily for the fresh sashimi market). The recovery and reporting rate from the latter may differ from the freezer operations;
- The size distribution of fish processed from the freezer vessels is likely to differ from those processed for the fresh sashimi market with larger fish more likely to be harvested for the fresh market. Similarly, the true number of tagged fish in the population is likely to be greater for larger/older fish. As such the actual recovery rate would be expected to be greater for the fish harvested for the fresh fish market and the rates obtained from the freezer operation may not be representative even if reporting rates were the same for the two;
- It is not clear how reliably one is able to detect evidence of recent tag removals and whether the agent had sufficient time to carefully inspect all fish he observed for evidence of this (see below);
- The determination of the harvest date from the farm and the tow cage from which a fish came when a tag is recovered can be uncertain. This creates uncertainty when comparing the tag agent's data on fish for which there was evidence of tag removals with the reported tags in the CCSBT database.

In the remainder of this section, we consider what the data from the freezer boat tag agent suggests about reporting rates. However, it is important to be aware of the above factors when interpreting the results from these data.

Table A1 provides a summary of the data collected by the freezer boat tag agent and related data from the CCSBT tag database. The percent of the fish observed by the freezer tag agent which had a tag or for which reported evidence of a recent tag removal is approximately equal to the percent of fish which went into the farm cage for which tags were reported. Thus, the tag agent reported finding tags on 67 fish and evidence of recent removals for an additional 27 fish out of a total of 14,480 fish that he observed. In other words, he detected evidence of tags on 0.65% of the fish. This compares with tags having been returned from 2,045 wild releases from 323,241 fish that were place in farm cages[2] or tags were reported from 0.63% of the fish in the farms. While these two percentages are very similar, they should not be taken as an indication that the actual reporting rate from the farm was close to 100%. Looking more closely at these two data sources indicates that the tag agent most likely missed a large number of fish from which tags had been removed. Thus, in addition to the tags from fish that the freezer agent directly observed, the CCSBT database has 48 additional tags being reported to the CCSBT from the tow cages on the specific dates that he was observing the processing from tow cage. This compares to 27 fish that he found evidence of tags being removed. This would suggest that the agent failed to detect at least 44% of the fish from which tags had been removed.

However, the percent that the tag agent failed to detect is likely to have been even greater then this 44% figure. For the 44% figure to be accurate would require the assumption that all tags for which the agent had found evidence of removals were in fact returned to the CCSBT. The data from the CCSBT database do not support this. Thus, on five of the days where the agent reported evidence of tags being recently removed, or for a total of 10 fish, there is no record of a tag having been reported from that tow cage on the day that the agent reported finding evidence of tags being removed, and in only one case was a tag reported from the corresponding tow cage on the following day. This would suggest that at least 37% of the tags for which the agent found evidence of tags having been removed were not returned to the CCSBT, although the problem of assigning dates and tow cages needs to be kept in mind. Alternatively, one can consider only those cages and days for which the number of tagged fish from the CCSBT database exceeds the number of fish reported as having evidence of tags having been removed. There were three cases of this. For these cases, a total of 32 fish with tags are contained in the CCSBT database compared to only 8 fish having been detected by the observer as having evidence of tags being removed[3]. This would suggest that the agent detected no more than 25% of the fish from which tags had been removed (i.e. the 25% figures assumes that 100% of the tags in these three cases were actually reported to the CCSBT). If this 25% figure is used to estimate the number of fish that actually had tags removed for which the agent failed to detect evidence of the removal, this would suggest that ~108 fish would have had their tags removed and that around 1.21% of the fish would have had tags compared to the 0.63% of the farm fish reported to have had tags from the returns in the CCSBT database.

The number of seeded tags recovered by the tag agent could potentially be informative in interpreting the results of the tag seeding experiments used for the estimation of reporting rates. Only 1 seeded tag was recovered by the tag agent out of the 67 tags he retrieved and the 14,480 fish he observed. The question can be asked if this is consistent with the number of seeded tags that would have been expected to have been retrieved given the number of seeded tags that had been released into the cages. A superficial look at this would suggest that in fact insufficient seeded tags were retrieved by the tag agent. In particular, the tag agent observed 4.5% of the farm catches and thus he might have been expected to have retrieved 4.5% or 14-15 out the

[2] The 323,241 figure is the number of fish that were actually transferred from tow cages into farm cages and does not include the number of reported mortalities during the catching and towing process.
[3] For these three cases, the agent found no actual tags suggesting that the farms were removing all tags prior to sending them to the freezer vessel.

328 fish that had seeded tags. However, this is not a correct estimate of the expected number of seeded tags that he should have retrieved for a number of reason including: (1) for a substantial (but hard to estimate) fraction of the fish observed, tags were removed prior to the tag agent having access to them (some of these are expected to have been seeded tags); (2) ~20% of the fish with seeded tags would have been expected to have shed both of their tags prior to having been harvested, and (3) by chance 4 out of the 15 tow cages (27%) that the tag agent observed had no seeded tags in them compared to 4 out of the total 36 tow cages (or 89%) in the 2006 fishing season (i.e. the fish observed by the agent were biased towards fish that did not have seeded tags).

While these latter two reasons would have reduce the expected number of seeded tags by around a third, they would still be insufficient to explain the low number of seeded tags retrieved by the tag agent. The first of the above reasons is the most difficult to quantify. Thus, in 10 out of the 20 cage-days, or for ~50% of the fish observed by the agent, he reported evidence of recent tag removals. Thus, if there were seeded tags they would not have been detected. For another 2 cage-days, or an additional 5%, he detected no tags or evidence of recent removals. In this case it is not clear whether this was because there were actually no tagged fish or because there had been tags recently removed which the agent failed to detect. If one only considers cage days in which the agent detected tags and also found no evidence of recent removals (i.e. the conservative assumption that there were no recent removals in these cases), then for these days, the agent observed 1.8% of the catch and might have been expected to have retrieved 4-5 seeded tags compared to the 1 that he did retrieve.

There appears to be a large amount of heterogeneity in the recovery and return rate of seeded tags relative to tags from wild releases, which also confounds interpretation of the seeded tag results from the freezer boat agent. Thus, for the cages and days that the freezer agent was observing, there was only 1 seeded tag reported in the CCSBT database (i.e. the one the tag agent recovered) and 115 recoveries from wild released fish. However, for the same cages on the following day, there were tags reported from 5 tag seeded fish while there were recoveries from 34 wild released fish. This large difference in the ratio of seeded to wild caught fish may reflect actual heterogeneity in the recovery of the two types of tags or simply the problems and difficulties in assigning exact harvest dates and tow cages to tags recovered from the farms.

The question of whether the number of seeded tags that the tag agent recovered was fewer than should have been expected is important because it provides one (and currently the only) independent information on the reasonableness of the tag-reporting rate from the seeded tagging experiments. This is particularly important given the low reporting rate estimate for the 2005/2006 season from the tag seeding results. If substantially/significantly more seeded tags should have been detected by the tag agent taking into account the number of fish with seeded tags, the number examined and the shedding rate for seeded tags, it would indicate that the reporting from the seeding experiments may be too low. The primary ways this could come about would be: (1) if large and disproportionate numbers of seeded tagged fish died in the cages and tags from these were not reported to CCSBT, (2) if the shedding rate for the two tags within a fish was not independent and a large fraction of the tag-seeded fish had shed both tags, or (3) farmers could distinguish between seeded and wild released tags and were preferentially not returning the former. In terms of the first of these, there have been no reports by tuna farmers of any unusual mortalities of tag-seeded fish. Since this was a major concern when the seeding was begun and was the primary reason tuna farmers were reluctant to cooperate with the seeding experiment, if mortalities were occurring the expectation would be that farmers would have reported them. In terms of the third, the seeding is done in a manner which aims to make wild and seeded releases indistinguishable (although it may not be fully successful) and it is not clear what the motivation would be to differentially withhold seeded tags. It is the second of these possibilities that is always a concern in double tagging experiments, while direct evidence for testing the independence assumption is difficult to obtain. It should be noted that some of the taggers and basic tagging procedures in the tag seeding experiments have been consistent for the four years that these have been conducted (with the notable exception of one inexperienced tagger in 2006). As such, any lack of independence in shedding may have been similar and thus seems unlikely to be the source of the decreasing trend in the reporting rate estimates from the tag seeding experiments. In addition, the 64% reporting rate in the first year would suggest an upper bound for the extent to which lack of independence could be biasing the reporting rate estimates.

In summary, the recovery of only 1 seeded tag by the freezer boat tag recovery agent is not necessarily inconsistent with the tag seeding results given the issues and problems in interpreting the results from this experiment (see above). Nevertheless, the low number does raise some concerns about shedding rates and lack of independence in shedding for double tagged fish released directly into farm cages.

Table A1: Summary of data collected by the freezer boat tag recovery agent and related data from the CCSBT tag database.

Tow Cage Number[1]	Freezer Boat Tag Recovery Agent				CCSBT Database – Wild Recoveries		CCSBT Database – Seeded Tags			
	Number Observed	Tags Recovered	Recent Removal	Total Recovered from Cage	Recovered on day observed	Recovered on day after observed	Number Released	Total Recovered	Recovered on day observed	Recovered on day after observed
1 & 2[2]	783	11	0	47 & 58	11	0	10	1 & 0	0	0
2 & 3[2]	900	5	1	58 & 39	5	0	10	0 & 2	0	0
3	572	5	0	39	5	0	10	2	0	0
	499	5	0		5	1			0	0
4	872	0	3	3	0	0	0	0	0	0
	622	1	2		1	0			0	0
5	570	2	3	119	2	0	10	0	0	0
	798	0	1		0	0		0	0	0
6	743	4	0	19	3	2	10	2	0	0
7	603	8	0	24	7	0	10	4	1	0
8	698	0	0	67	1	5	10	3	0	1
	735	0	2		4	0			0	0
9	733	9	0	43	8	0	10	1	0	0
10	754	0	1	10	1	0	10	0	0	0
11	1026	9	0	75	9	8	10	0	0	0
12	732	0	2	78	12	11	10	7	0	3
	657	0	4		16	6			0	1
13	538	0	8	24	7	0	0	0	0	0
14	857	0	0	53	10	0	0	0	0	0
15	788	8	0	37	8	1	0	0	0	0
Total	14480	67	27	696[3]	115[3]	34	110[3]	20	1	5

1. Arbitrary number assigned to unique tow cages
2. Fish observed came from two tow cages and number of tags in this row is the sum from both cages
3. Total represents the total from all of the tow cages observed (i.e. does not include double counting in the first three rows).