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MARINE RESEARCH

Initial analyses of tag return data from the CCSBT SRP tagging program

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Abstract

Preliminary 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 results suggest high fishing mortality rates in 2003 and 2004 for those fish tagged at age 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 and 2001 cohorts were disproportionately low relative to the 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 may also suggest 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 from the tag attrition model at age 2 were very near zero for the 2000 and 2001 cohorts, which appears 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 serval years. This paper provides some preliminary analyses of the data collected to date in the SRP tagging program, including some initial estimates of fishing mortality rates using a tag attrition model.

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 with almost all of the fish being 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.

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 assume 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

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

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 in release 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 in release group g;

m_a = natural mortality for fish of age a.

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 belonging to release 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.

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 that a fish tagged at age a by a tagger in sub-group k has at least one tag still attached after having 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 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 treats 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. Time did not permit developing estimators that incorporated uncertainty associated with these input parameters.

Reporting Rates

Initial estimates of the reporting rate in the Australian surface fishery are available for the 2003 and 2004 fishing seasons from tag seeding experiments (Polacheck and Stanley 2004, 2005). The mean estimate was 0.66 for 2003 and 0.63 for 2004. The average of these two values (0.645) was used in the analyses here, and it was assumed to apply for all years.

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 for reporting rates and results are presented for two values to provide an indication of the sensitivity of the results to the value assumed. The two values were 0.645 (the same as the surface fishery) and 0.20. 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. He 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

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

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 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 1 provides the estimates of the 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*.

Also included in Table 1 are age specific shedding rates for tagger 2 and tagger 4. Based on preliminary examination of the data there appears to be disproportionately too few returns from age 1 fish. Thus, separate shedding rates were calculated for age 1 and age 2+ releases. However, there were only sufficient data to meaningfully perform these calculations for these two taggers. In both cases, the estimated shedding rates were higher for age 1 releases than older releases. However, only for tagger 2 was the difference significant (but there were only 74 returns from age 1 released fish).

Natural Mortality Rates

Two age specific natural mortality rate vectors were used in the calculation of the fishing mortality rates (Table 2) to provide a measure of the sensitivity of the estimates to assumptions about natural mortality. The two vectors used 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 3 provides a summary of the number of releases and recaptures by cohort. The low number of recaptures from the 2002 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 age 3 and older. Since most of the returns from this year's Australian surface fishery are not yet available, even for releases from the 2002 cohort the tagging data are not yet informative. As such, results are only presented for the 1999-2001 cohorts (the number of releases for the 1998 cohort are too small to provide meaningful results).

Table 4 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 feature of the SRP returns 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 2-4 provide maps of the release and return locations for all longline returns from the SRP tagging experiments. Figure 5 provides some comparative plots for 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 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 5). 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 6). 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 was 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 6). Moreover, in the 1998-2002 period, a substantial percentage (25-55%) of the Japanese longline catch of juveniles aged 3-4 came from the Tasman area (Figure 6), and all of this was outside of the AFZ. However, in 2003 and 2004, these percentages decreased (~10% in 2004) without a decline of similar magnitude in the proportion of fishing effort in the Tasman area. Thus, the Japanese longline catch and effort data would suggest a shift in the spatial distribution of juveniles.

Fishing Mortality Rate Estimates

Sufficient release and return data (e.g. at least ~500 releases at a particular age and at least one year of full recoveries) exist to derive age specific fishing mortality rate estimates for three cohorts, namely cohorts 1999, 2000 and 2001. Figures 6-8 compare estimates of fishing mortality rates based on different tagger groups and ages of release for these three cohorts. It should be emphasized 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 effect 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.

Figures 6-8 suggest that there may be a consistent tagger effect in the fishing mortality rate estimates. Thus, in all cases where the rates were not essentially zero, the estimates for tagger group 1 were higher than those for tagger group 3 (the only two tagger groups with consistently enough releases to make such comparisons), while the estimates based on all taggers is between the two (as would be expected). For some ages (e.g. age 4 estimates based on age 2 releases for the 2000 cohort, and age 3 estimates based on age 1 releases for the 2001 cohort), the differences can be large (i.e. over 300%). The source of this tagger effect is not clear. It may be related to shedding rates because the shedding rates for tagger group 1 are substantially lower than for tagger group 3 (Table 1). These estimates are based on the assumption that the probability of shedding one tag is independent of the other. If this assumption were violated (i.e. shedding of tags tended to be correlated such that there was a greater probability of shedding both than indicated from the proportion that shed only one) then this could generate a consistent difference among taggers. Another possibility could be differences in tagging associated mortality.

Figures 9 and 10 provide examples of the sensitivity of the estimates of fishing mortality rates for the two reporting rate options considered for the longline component of the fishery. As would be expected, the option with the lower reporting rate for the longline component yielded higher mortality rates. The differences are not insubstantial and tend to increase with age. This is expected both because of the increasing proportion of the global catch which comes from longliners with age and the compounding effect of higher mortality rates at younger ages on the estimates for older ages. This emphasizes the importance of having direct estimates of the reporting rates from the longline fisheries. In addition, they suggest that while the longline fisheries are not the primary source of fishing mortality rates on juveniles, they are nevertheless a contributing component.

Figures 11 and 12 provide examples of the sensitivity of the fishing mortality rates to assumptions about the natural mortality rates. Higher estimates are associated with higher estimates of natural mortality rates and increasingly so the longer the period between the age of release and age of the estimate. This is what would be expected since with higher natural mortality rates, the number of fish that would have survived to any age is less, and thus the number of returns at that age will constitute a higher fraction of those still alive. It should be noted that any consideration of the implications of the estimates of fishing mortality rates for the conditioning of the MP operating model will need to be done in the context of the natural mortality vector used in specific scenarios.

Figures 13 and 14 compare the estimated fishing mortality rates for a cohort from tags released at different ages. Note that in these figures, estimates derived from releases in the same year have not been included as they are not directly comparable as noted above. While the number of comparisons is small, the estimates derived from age 1 releases are always lower than those for age 2 or 3 releases. The differences are substantive enough (particularly for the age 3 estimates for the 2001 cohort and the age 4 estimates for the 2000 cohort) to affect interpretations of the strength of recent cohorts. Possible sources for the differences are: (1) higher tag shedding rates for age 1 fish; (2) higher tagging associated mortality for age 1 fish; (3) a greater differential in the combined natural mortality rates for ages 1 and 2 compared to older ages than was assumed in the values used for natural mortality[1]; (4) an unreported catch or discarding of age 2 fish; (5) incomplete mixing of 2 and 3 year old tagged fish (i.e. these fish return preferentially to the GAB).

With respect to the first of these possible factors, using the age specific tag shedding rates for tagger group 1 in Table 1 very slightly reduces the differences between the fishing mortality rates based on age 1 releases compared to releases from older ages (Table 7). However, the substantial differences still remain. The estimates based on age 2 or older releases are essentially the same whichever shedding parameters are used, while the largest increase is in the estimates for age 1 (~10%).

With respect to the other four factors, there are no direct data or information that could be directly incorporated into the estimation to evaluate their effect. Comparison of the distributions of the length at release for recaptured fish versus the distribution for all tagged fish within an age class suggest that there is a marked tendency for the largest fish tagged to be recovered for age 1 releases but not for age 2 releases (Figures 15-18). This could indicate that either the larger age 1 fish have lower mortality rates (either natural or tag induced) or that they have a great propensity to return to the GAB. Similarly, there is also somewhat of a tendency for age 1 fish tagged further to the east to have a higher recovery rate (Figures 19-22), which might suggest incomplete mixing. However, whichever of these factors or combination of factors may be contributing to the difference, it would constitute a substantial difference from the 1990s tagging where such effects were not evident. For example, there was no apparent size effect in the 1990s (Figure 1) and the tagging of one year olds in WA was generally further to the west than in the more recent SRP tagging.

Another anomaly in these return data are 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 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 three 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.

Table 8 provides a range of estimates of fishing mortality rates at ages 3 and 4 in years 2003 and 2004 based on different ages of release. The range corresponds to the range of natural mortality vectors and reporting rate options examined. Also, separate ranges are presented based on estimates using the releases from all taggers and only those from tagger group 1. Overall, they suggest high fishing mortality rates in these years for fish tagged at age 2. 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 and older ages of release.

[1] The reason it would be sufficient for it to be for the combined age 1 and 2 is that the estimated fishing mortality rates for age 2 are essentially zero.

Returns from the First Season for December Releases

Tag returns released 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 and 2004, SRP tagging operations took place in December in the GAB in inshore areas, while fishing operations are concentrated near the shelf edge. Over the next four months, tags were recovered from 9% of the age 3 tagged fish and 13% of the age 4 tagged fish in 2003, and 24% and 26% respectively in 2004. This corresponds to estimates of between 14-20% in 2003 and 37-40% in 2004 actually having been captured, taking into account the estimates of reporting rates from tagging seeding experiments conducted in these years (Table 9). The times of recapture and the location of the recaptures relative to the where the tags were released indicate that these large recapture estimates are not the result of tagging in very close spatial or temporal proximity to where fishing operations were occurring (Figures 23-24). Overall, these results 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 9). Thus, less than 4% of these were actually recovered during the fishing season in spite of the fact that there were sizable catches of two year olds in both years (particularly in 2004 where the catch of two year olds was estimated to comprise 31% of the catch and 7 times the number of four year olds.

Returns Per 1000 fish

Estimates of the number of returns per 1000 fish caught with tags in the surface fishery 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 older ages (Table 10). Note that in these estimates the recaptures during the first year have been excluded to avoid short term effects associated with the timing and location of releases. In the surface fisheries the return rates per 1000 fish caught increase sharply with age for the 1999 and 2000 cohorts between 2003 and 2004 (i.e. by a factor of 61 and 25 respectively) suggesting that 5 and 2% of the fish in the GAB in each of these cohorts had been tagged. Given that the total number of tags released for these two cohorts was 1231 and 5722 respectively, this would suggest that the size of these cohorts at the time of tagging (at least the portion that mixed with the tagged fish) was very small (i.e. 20 and 50 times the number of releases) unless the number of fish caught by age is substantially in error. It should be noted that over-estimation in the estimated numbers of two and three years olds caught would have implications for the estimated strength of the 2001 cohort as estimated in conditioning the MP operating model.

In contrast, for the longline fisheries, estimates of the number of tags returned per 1000 fish tend to suggest that not enough young fish have been caught relative to the number of tags returned (Tables 11-12). For the Japanese longline fisheries, the estimated number of returned tags tends to decrease with age for a cohort (but the number of years of returns is small). If there was complete mixing, the expectation would be that it should be increasing given the increased number of releases. If the estimated catches at age are accurate, then in order for the actual percentages to decrease, the fraction of a cohort represented by the tagged fish would have to have become increasingly less vulnerable to that fishery with age (e.g. the juvenile fish from a cohort in WA and SA initially have a preference for the areas where the longline fisheries operate relative to other members of a cohort and this preference diminishes with age). For the Taiwanese returns, there is not a substantive trend in the return rates per 1000 fish by cohort. However, the return rates per 1000 fish are relatively high for the 2002 and 2003 cohorts given the magnitude of the catches and number of releases.

It should be emphasized that the interpretation of the returns per 1000 fish is confounded by reporting rates. Nevertheless, they suggest inconsistencies with the estimated catch at size/age data.

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Table 1: 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	1.000	0.093	942	238	1180
	4	1.000	0.262	416	354	770
	418	1.000	0.166	40	36	76
	419	0.624	0.000	44	53	97
	444	0.800	0.000	28	14	42
	1439	1.000	0.468	83	56	139
	Z	1.000	0.469	7	17	24
Tagger Group						
1	2	1.000	0.093	942	238	1180
2	418+444	1.000	0.164	68	50	118
3	4+419	1.000	0.267	460	407	867
4	Z+1439	1.000	0.468	90	73	163
Age at Release[1]						
1	2	1.000	0.141	60	81	141
2	2	0.965	0.056	190	891	1081
1	4	1.000	0.322	51	23	74
2	4	1.000	0.246	318	415	733

[1] The age specific shedding rates were significantly different than the pooled age shedding rates for tagger 2 but not for tagger 4.

Table 2: 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	0.2708	0.2420	0.2153
2	0.4202	0.3703	0.3278	0.2894	0.2538

Table 3: The number of tags released and recapture by cohort.

Cohort	Number Released	Number Recaptures	percent
1998	50	6	12.0
1999	1190	121	10.2
2000	5790	729	12.6
2001	9899	1456	14.7
2002	10291	112	1.1
2003	11353	5	0.0
2004	7034		

Table 4: The number of releases at age and recaptures by age for the 1999-2001 cohorts

cohort	Age at Release	Number released	Number recaptured by age 1	2	3	4	5	6	total	Percent recaptured
1999	2	750	0	0	11	50	10	0	71	9.5
	3	23	0	0	0	1	0	0	1	4.3
	4	414	0	0	0	34	15	0	49	11.8
2000	1	1921	0	4	84	17	0	0	105	5.5
	2	492	0	1	51	34	0	0	86	17.5
	3	3277	0	0	280	251	0	0	531	16.2
	4	32	0	0	0	7	0	0	7	21.9
2001	1	2748	0	9	124	0	0	0	133	4.8
	2	5869	0	24	1049	0	0	0	1073	18.3
	3	1147	0	0	250	0	0	0	250	21.8

Table 5: Percent of longline returns that occurred in the Tasman Sea (defined as east of 142°E)

		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	6.5	6.3	2.9	-	-	-	-
	Japanese returns	28.6	19.4	6.3	-	-	-	-

Table 6: 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.

	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 7: Comparison of the effect of incorporating age-specific shedding rates on the estimates of fishing mortality rates. Results are shown for tagger group 1 (i.e., tagger 2) for reporting rate option 2 and mortality rate vector 1.

			Age specific shedding			Age pooled shedding		
Cohort	Release age		F	Lower 5%	Upper 5%	F	Lower 5%	Upper 5%
1999	2	4	0.28	0.10	0.57	0.28	0.05	0.57
		5	0.37	0.00	1.75	0.37	0.00	1.52
2000	1	2	0.03	0.01	0.08	0.03	0.01	0.08
		3	0.23	0.14	0.35	0.22	0.14	0.32
		4	0.18	0.04	0.37	0.16	0.04	0.34
	2	2	0.02	0.00	0.08	0.02	0.00	0.08
		3	0.35	0.22	0.52	0.35	0.23	0.53
		4	0.80	0.45	1.50	0.80	0.46	1.50
	3	4	0.25	0.21	0.30	0.25	0.21	0.30
2001	1	2	0.03	0.01	0.05	0.03	0.01	0.05
		3	0.44	0.33	0.56	0.42	0.32	0.53
	2	3	0.76	0.68	0.86	0.76	0.68	0.85

Table 8: Summary of the range of age specific fishing mortality rates at ages 3 and 4 in years 2003 and 2004 from tags released at different ages. Results are presented for all tags released and those released only by tagger group 1. The two values presented are the range of values over the two reporting rate options and two mortality vectors considered.

			All taggers			Tagger group 1		
Year	Age	Release age	# Tagged	F range		# Tagged	F range	
2003	3	1	1921	0.16	0.22	401	0.19	0.27
		2	492	0.26	0.68	242	0.28	0.39
	4	2	750	0.25	0.45	58	0.28	0.32
2004	3	1	2748	0.16	0.23	1015	0.32	0.51
		2	5869	0.50	0.66	2301	0.61	0.86
	4	1	1921	0.06	0.13	401	0.08	0.22
		2	492	0.31	0.56	242	0.55	1.05
		3	3277	0.21	0.27	1655	0.21	0.27

Table 9: 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 a reporting rate of 0.645 with no allowance for tag shedding.

Fishing Year	Age at release	Number released	Number Returned	Percent Returned	Est. percent Caught
2002/2003	1	17	0	0	0
	2	894	10	1	2
	3	3004	269	9	14
	4	242	32	13	20
	5	8	3	38	58
2003/2004	1	622	0	0	0
	2	3186	76	2	4
	3	979	234	24	37
	4	27	7	26	40
	5	3	0	0	0

Table 10: Estimated number of fish caught, the number of tags actually returned and the estimated return rate per 1000 fish caught by age and year in the Australian surface fishery. Number of returns does not include returns from fish caught in the year they were released.

	Catch by Age				Returns by Age				Returns per 1000			
Year	2	3	4	5	2	3	4	5	2	3	4	5
2002	18653	231216	26702	3624	4	6	0	0	0.21	0.03	0.00	0.00
2003	42662	176549	53742	3847	6	131	48	2	0.14	0.74	0.89	0.52
2004	91879	193378	12912	292	32	1011	236	16	0.35	5.23	18.28	54.70

Table 11: Estimated number of fish caught, the number of tags actually returned and the estimated return rate per 1000 fish caught by age and year for the Taiwan longline fishery. Number of returns comprises all returns including those caught in the year they were released.

	Catch by Age				Returns by Age				Returns per 1000			
Year	2	3	4	5	2	3	4	5	2	3	4	5
2002	1163	7278	11455	6723	1	1	0	0	0.86	0.14	0.00	0.00
2003	658	3970	6765	7208	10	8	3	0	15.20	2.02	0.44	0.00
2004	815	4615	8327	6968	10	54	14	4	12.27	11.70	1.68	0.57

Table 12: Estimated number of fish caught, the number of tags actually returned and the estimated return rate per 1000 fish caught by age and year in the Japanese longline fishery. Number of returns comprises all returns including those caught in the year they were released.

	Catch by Age				Returns by Age				Returns per 1000			
Year	2	3	4	5	2	3	4	5	2	3	4	5
2002	146	3460	14359	17877	0	3	0	0	0.00	0.87	0.00	0.00
2003	281	1541	5995	20363	5	8	6	0	17.79	5.19	1.00	0.00
2004	365	4352	8505	11713	2	20	10	3	5.48	4.60	1.18	0.26

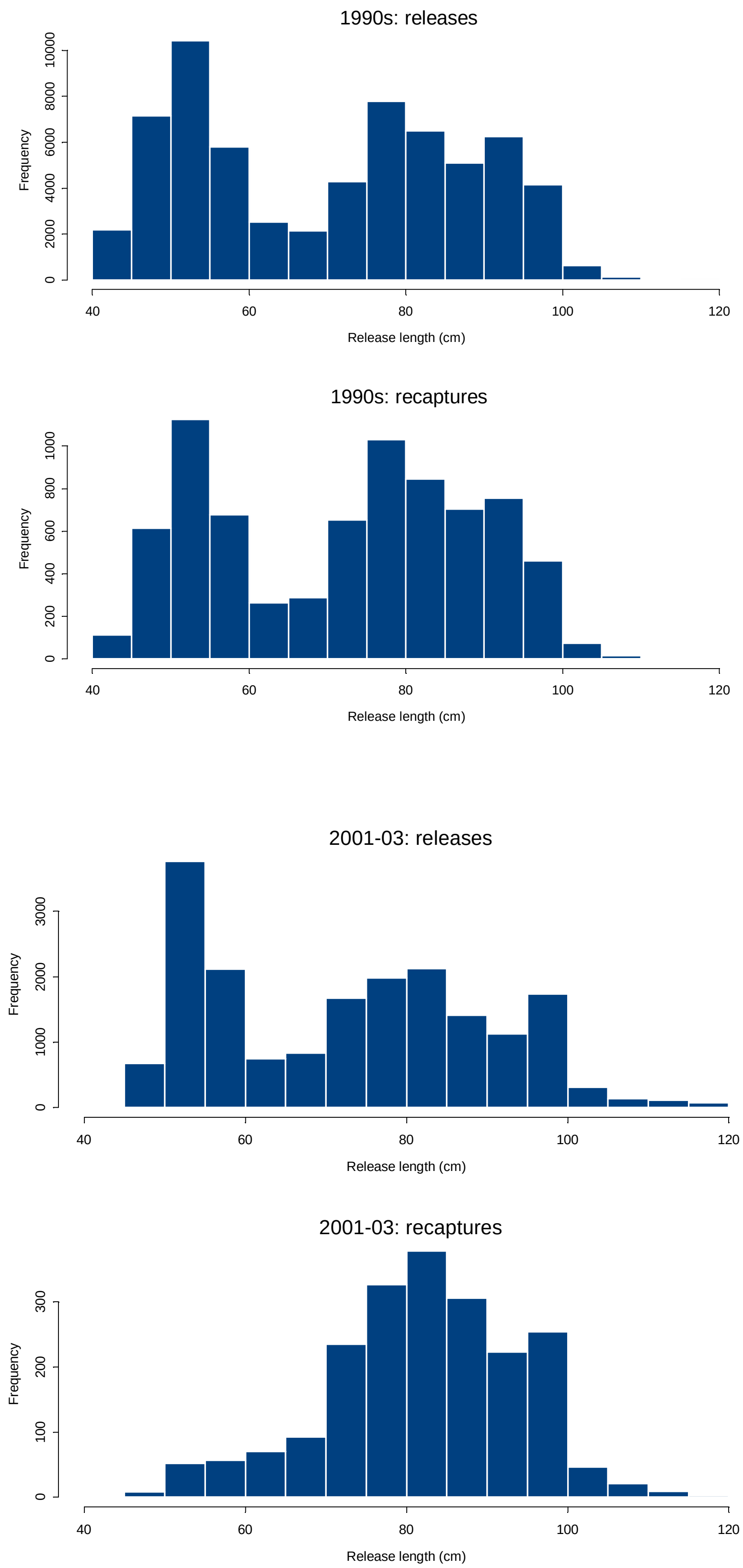


Figure 1: Comparison of the release length distribution for all fish released and for those fish that were recaptured. The upper two panels are for the 1990s releases and the lower two are for the 2000s releases.

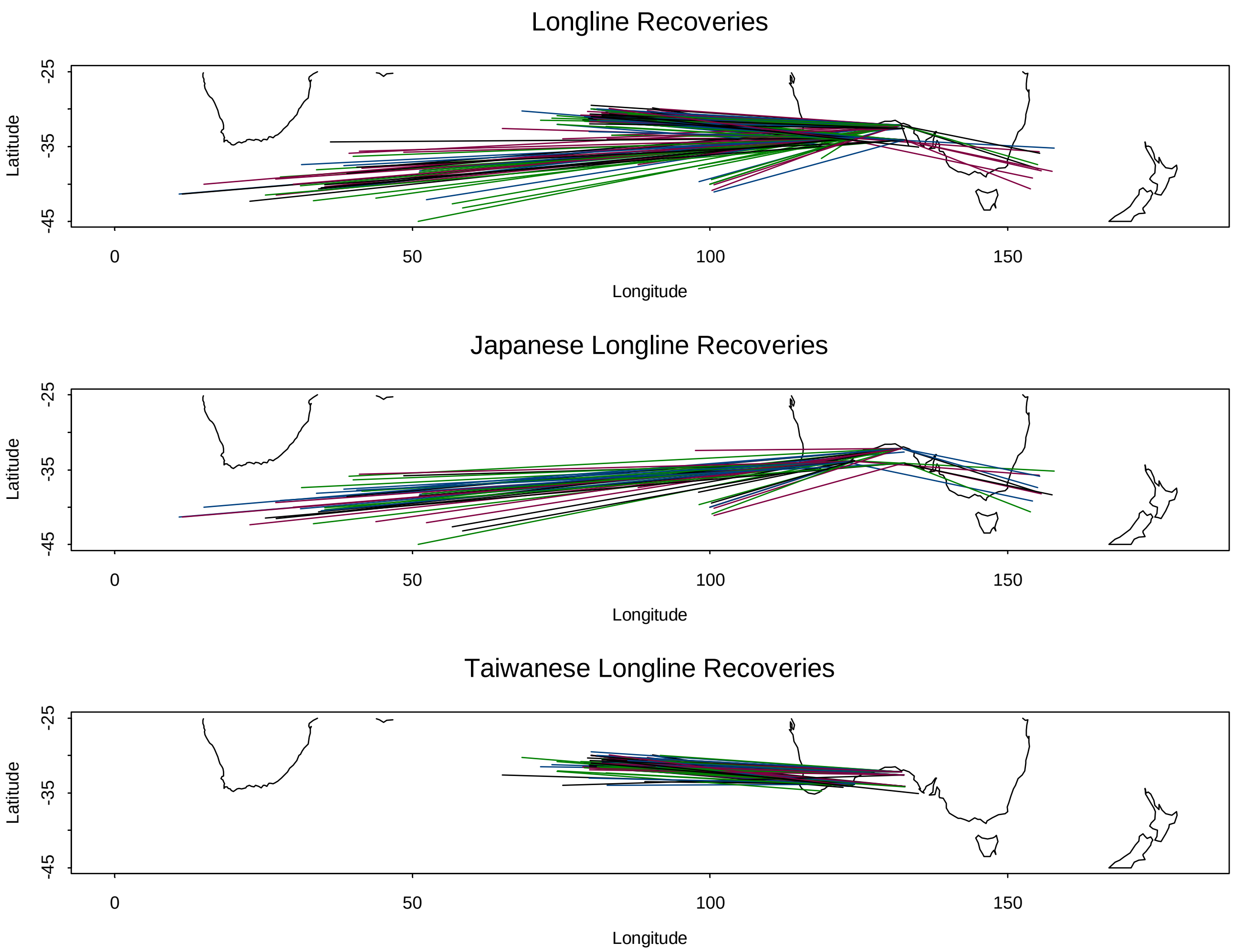


Figure 2: Release and recapture locations for longline returns from the SRP conventional tagging in WA and SA.

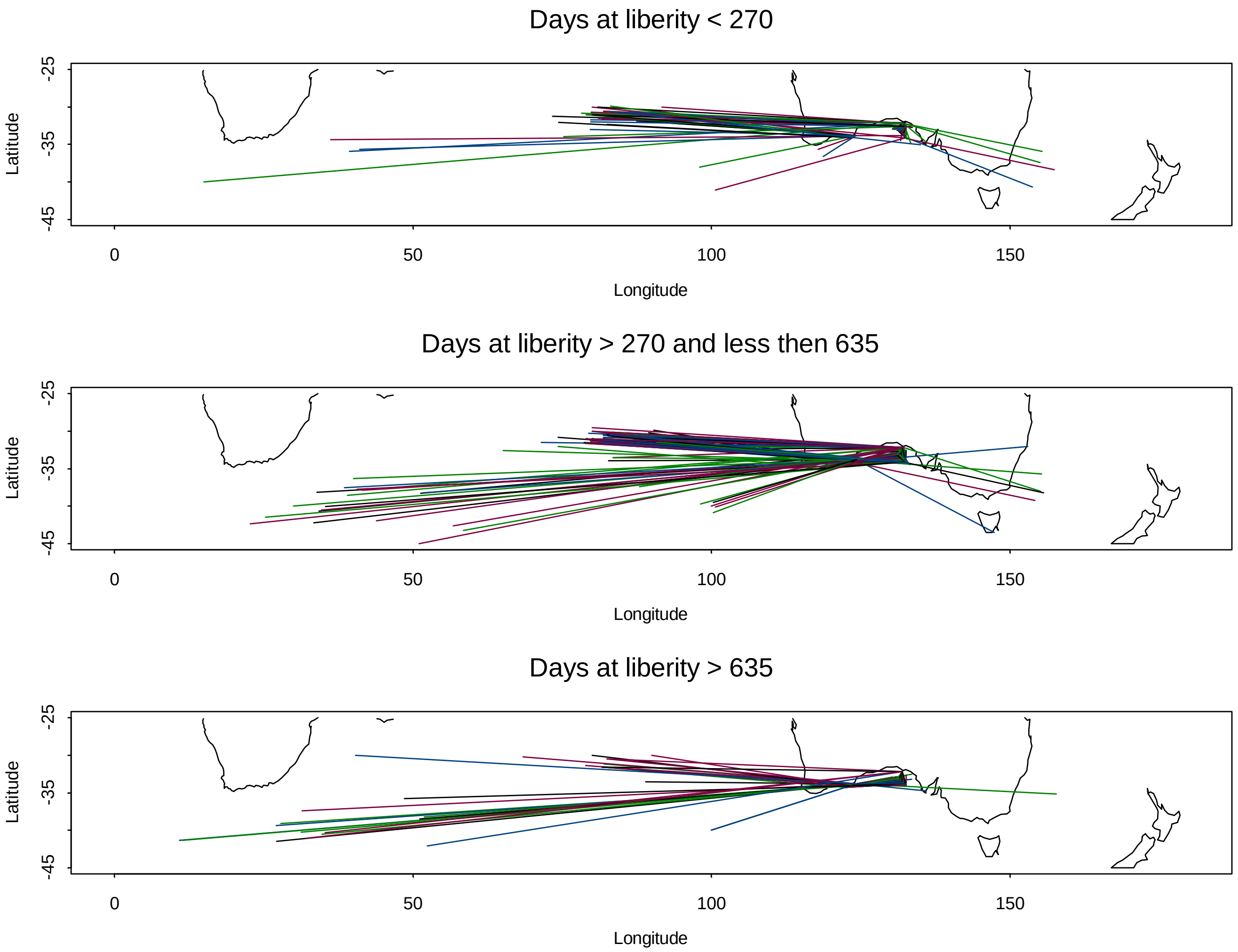


Figure 3: Release and recapture locations for longline tag returns for different times at liberty from the SRP conventional tagging in WA and SA.

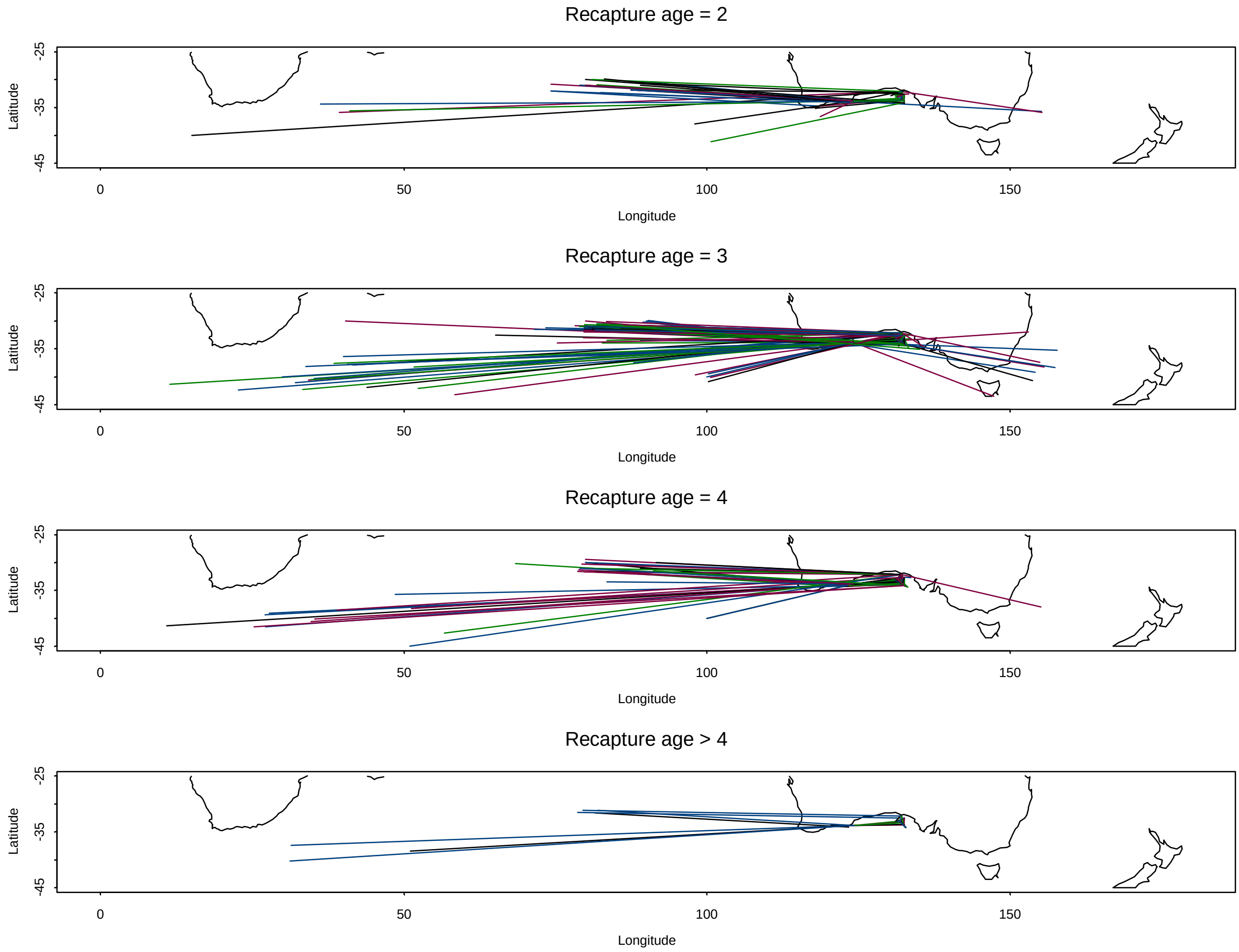


Figure 4: Release and recapture locations for longline tag returns for different ages at recapture from the SRP conventional tagging in WA and SA.

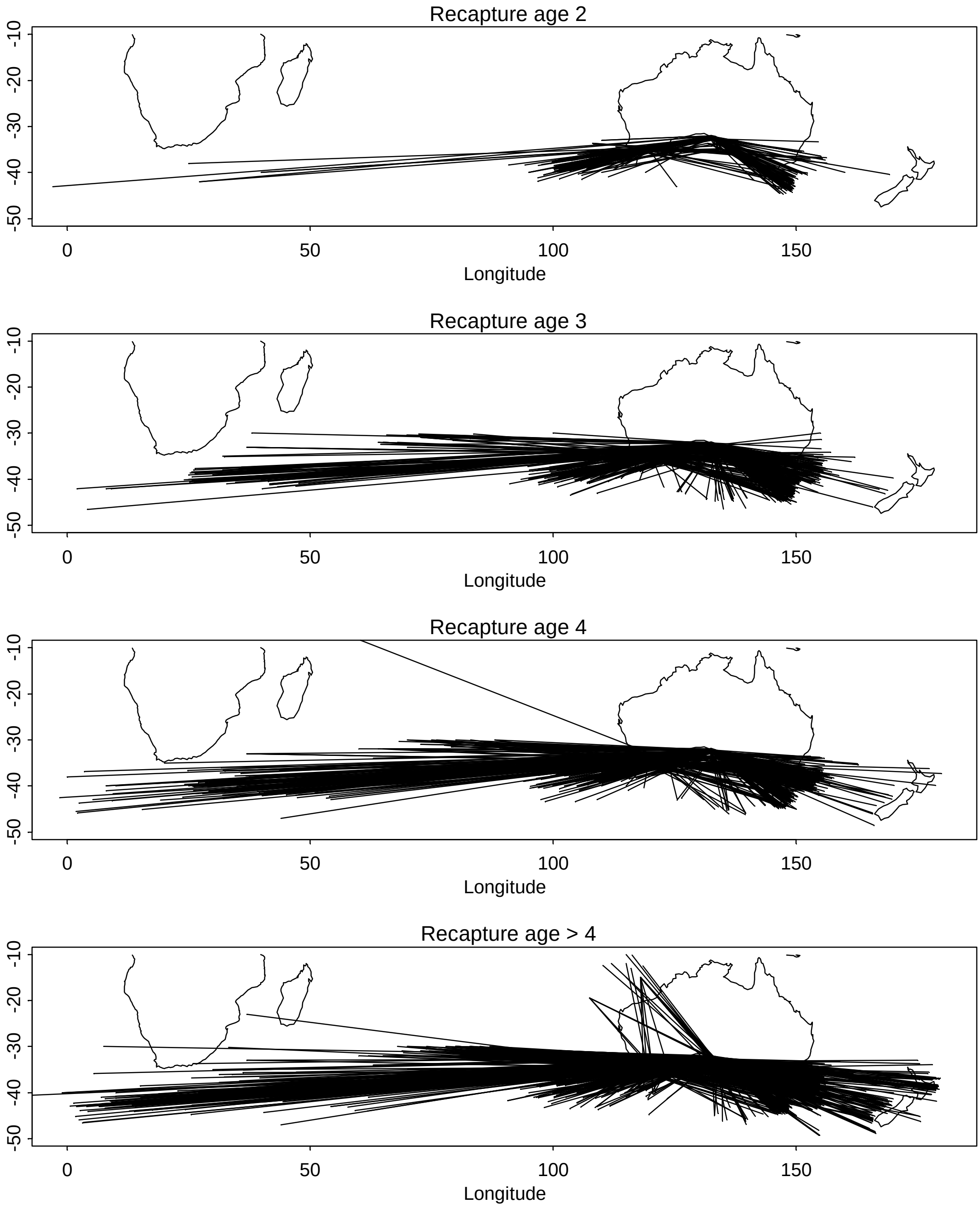
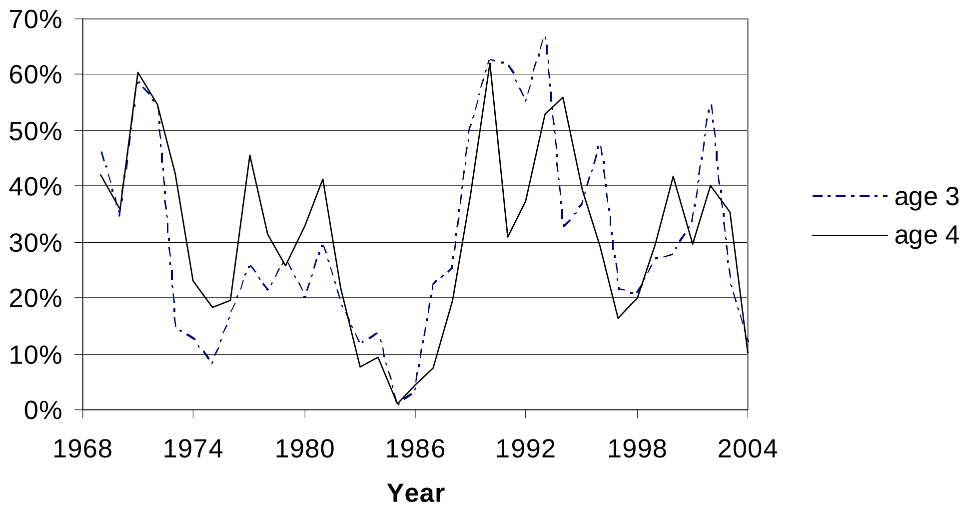


Figure 5: Release and recapture locations for longline tag returns for different ages at recapture from the RMP conventional tagging in WA and SA in the 1990s.



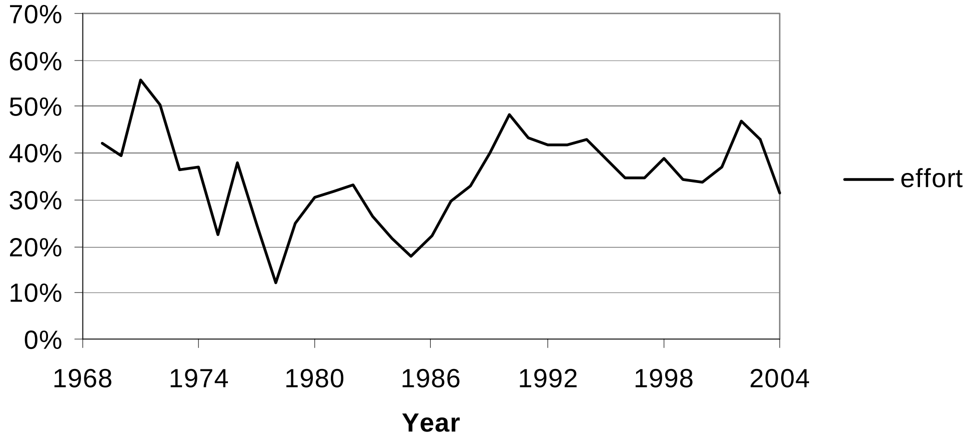


Figure 6: The percentage of age 3 and 4 Japanese longline SBT caught that were taken from the Tasman area (east of 140°) and percent of Japanese longline effort in this area. Note the figures are for quarters 2 and 3 and only include data for statistical areas 4-9.

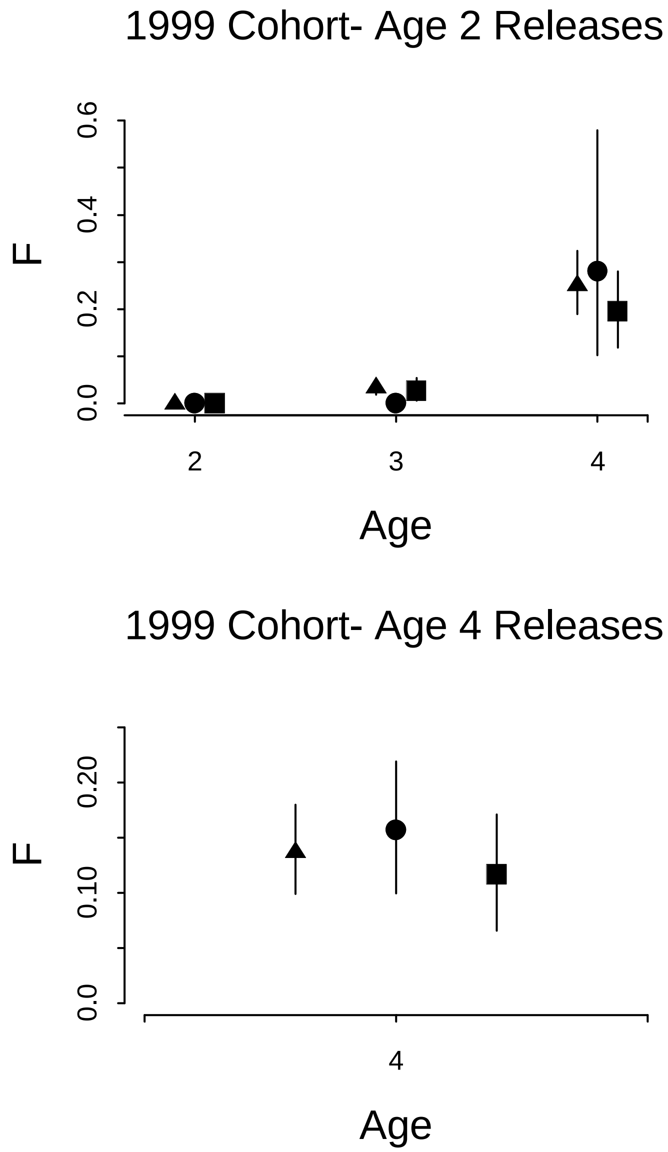


Figure 6: Comparison of fishing mortality rates for different tagger groups and different release ages for the 1999 cohort. Triangles are for all taggers; circles are for tagger group; and square are for tagger group 3. All estimates are for natural mortality rate vector 1 and for a reporting rate of 0.645 for all fisheries. Error bars are 90% bootstrap confidence intervals conditional on the estimates of mortality, shedding and reporting rates.

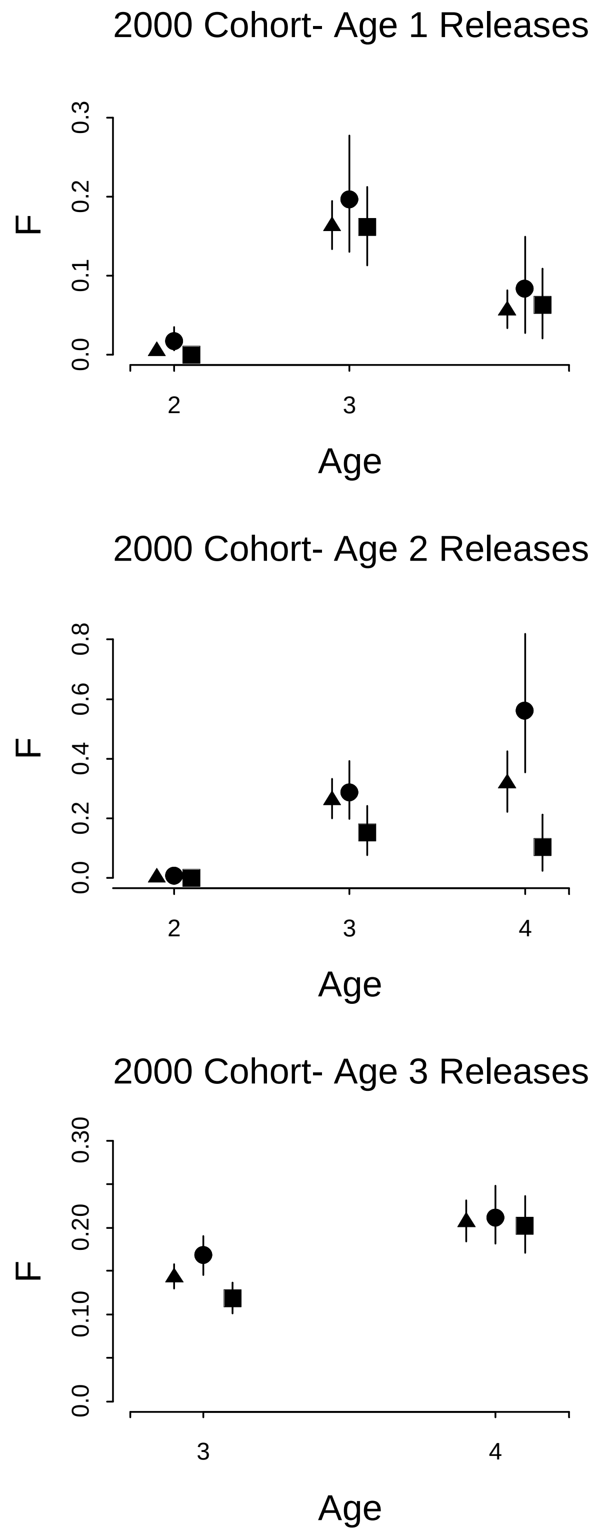


Figure 7: Comparison of fishing mortality rates for different tagger groups and different release ages for the 2000 cohort. Triangles are for all taggers; circles are for tagger group 1; and squares are for tagger group 3. All estimates are for natural mortality rate vector 1 and for a reporting rate of 0.645 for all fisheries. Error bars are 90% bootstrap confidence intervals conditional on the estimates of mortality, shedding and reporting rates.

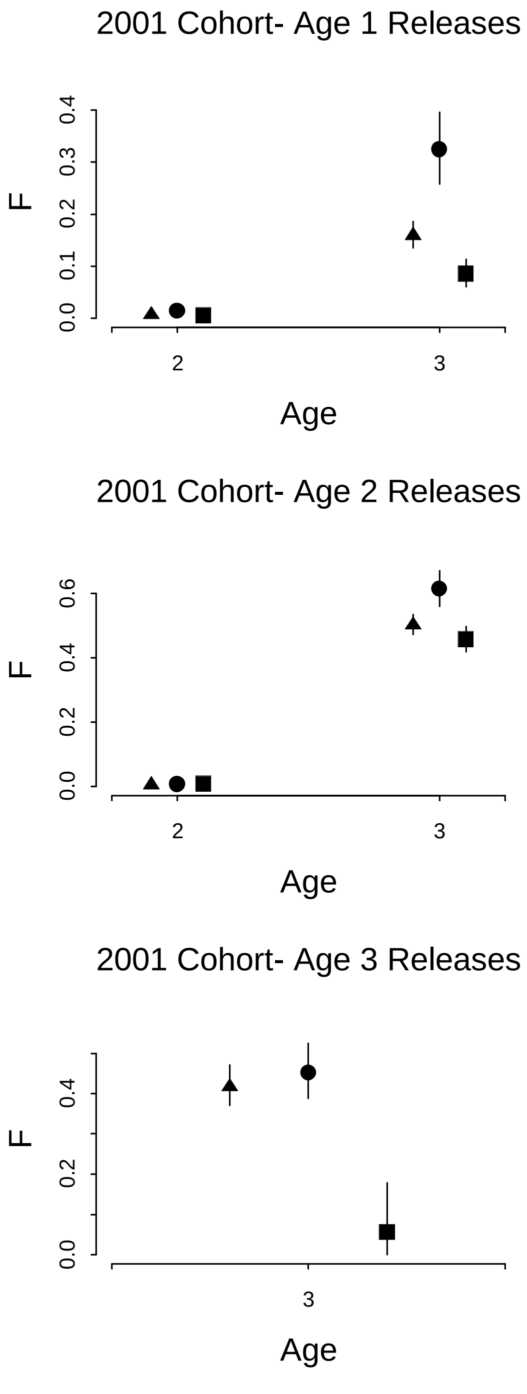


Figure 8: Comparison of fishing mortality rates for different tagger groups and different release ages for the 2001 cohort. Triangles are for all taggers; circles are for tagger group 1; and squares are for tagger group 3. All estimates are for natural mortality rate vector 1 and for a reporting rate of 0.645 for all fisheries. Error bars are 90% bootstrap confidence intervals conditional on the estimates of mortality, shedding and reporting rates.

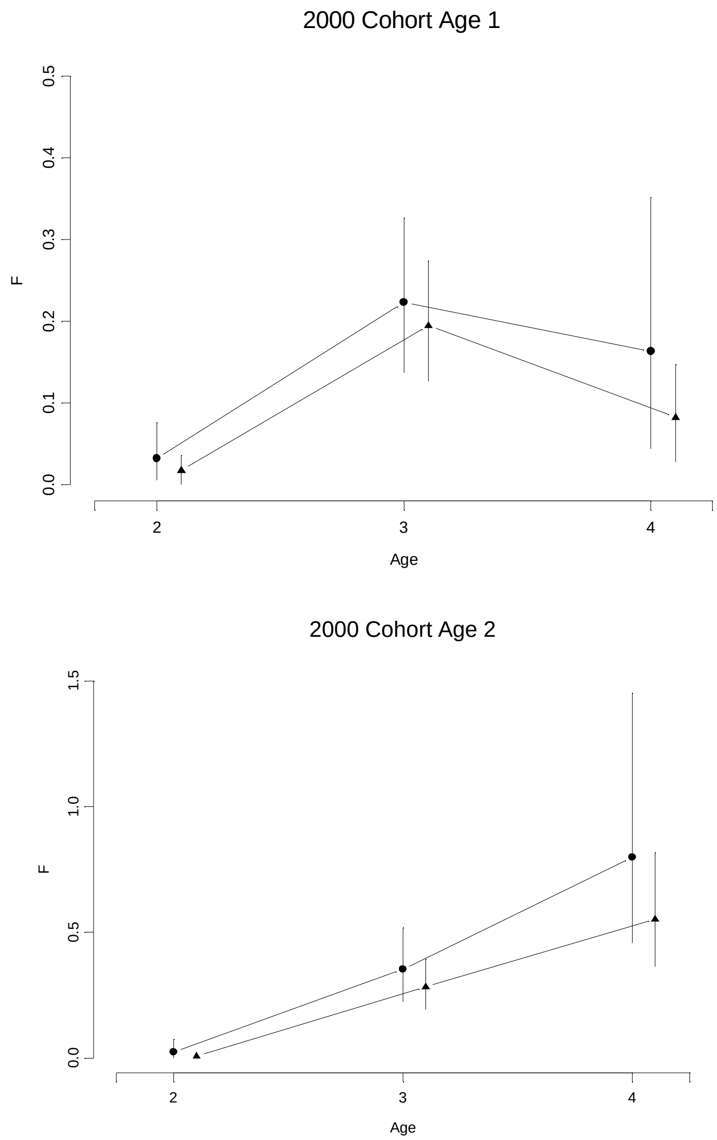
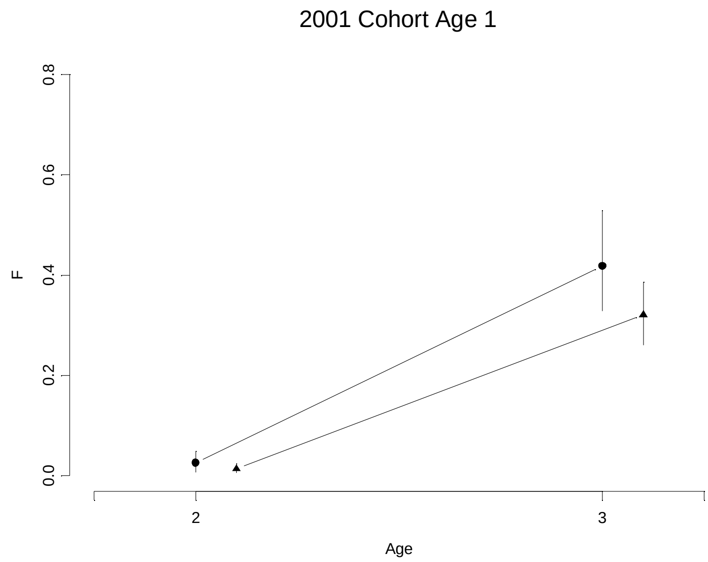


Figure 9: Comparison of fishing mortality rates ages for different reporting rates and different release ages for the 2000 cohort. Triangles are for a reporting rate of 0.645 in both fisheries and circles are for a reporting rate of 0.645 in the surface fishery and 0.20 in the longline fisheries. All estimates are for tagger group 1 and natural mortality rate vector 1. Error bars are 90% bootstrap confidence intervals conditional on the estimates of mortality, shedding and reporting rates.



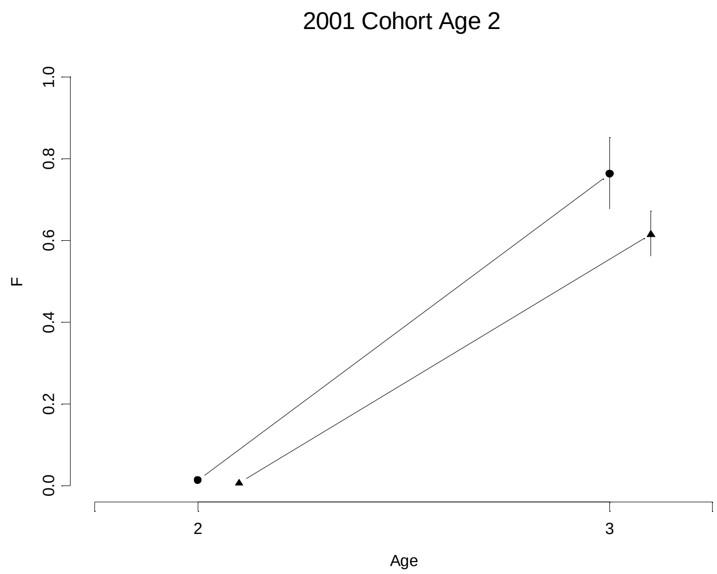


Figure 10: Comparison of fishing mortality rates ages for different reporting rates and for different release ages for the 2001 cohort. Triangles are for a reporting rate of 0.645 in both fisheries and circles are for a reporting rate of 0.645 in the surface fishery and 0.20 in the longline fisheries. All estimates are for tagger group 1 and natural mortality rate vector 1. Error bars are 90% bootstrap confidence intervals conditional on the estimates of mortality, shedding and reporting rates.

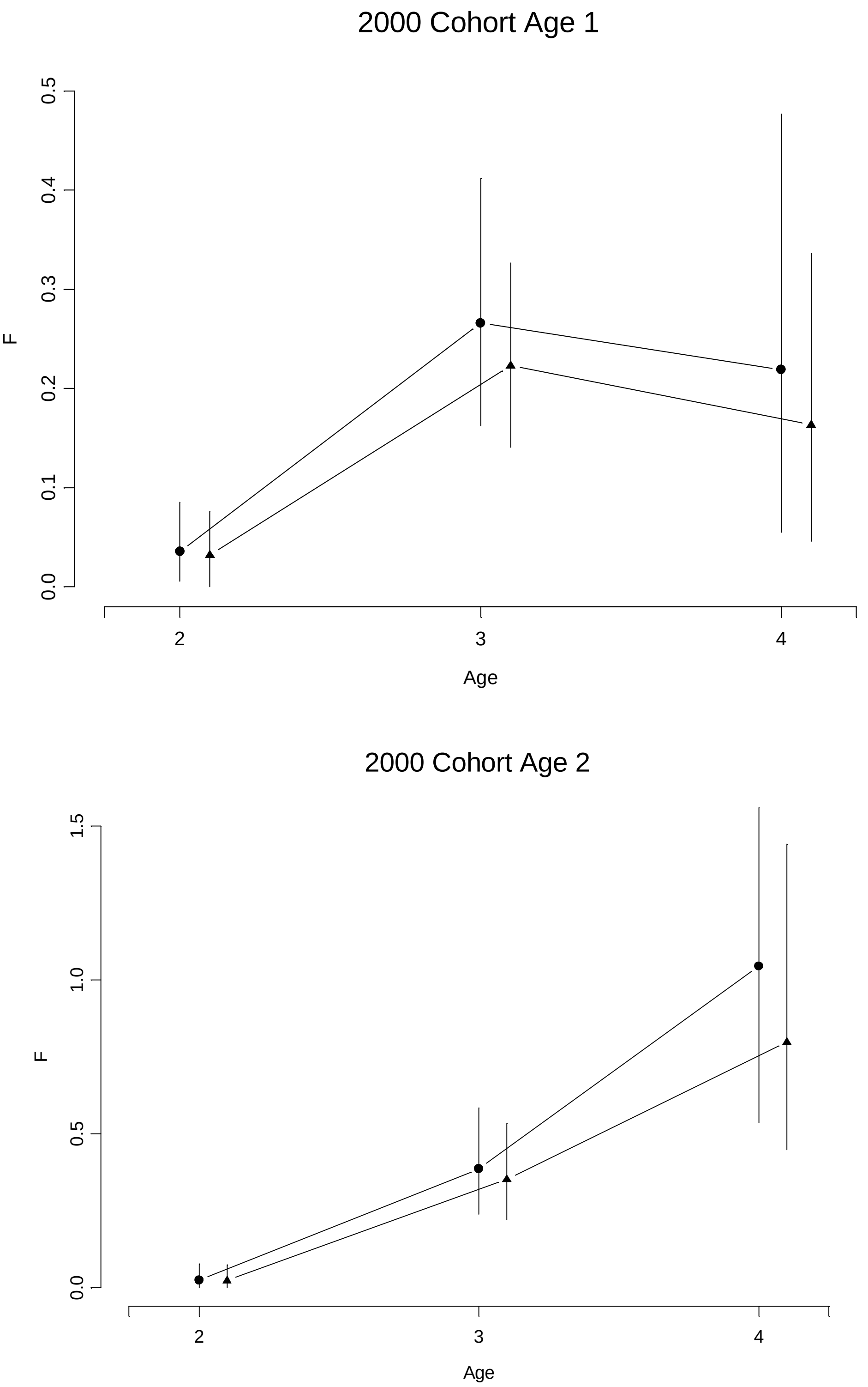
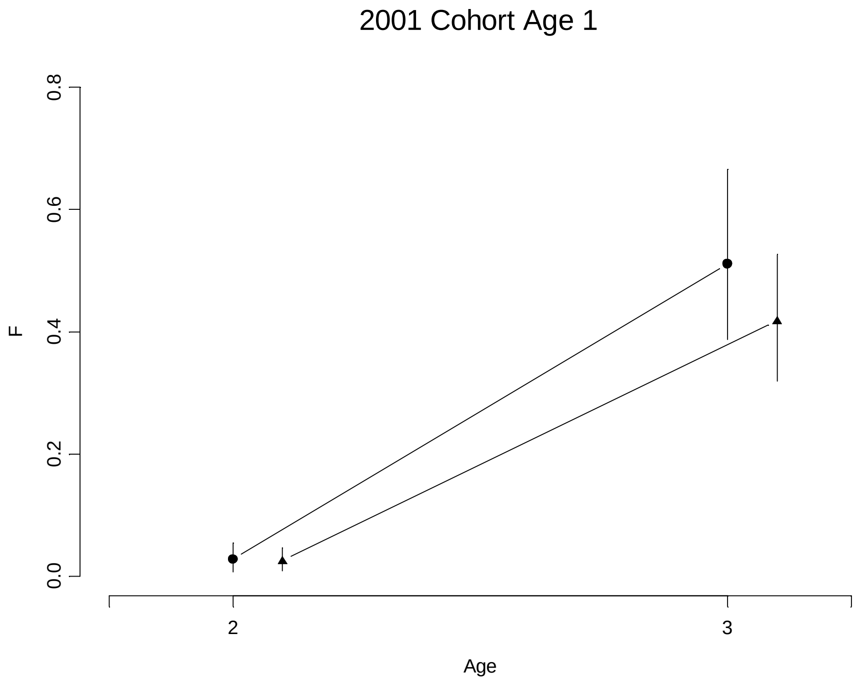


Figure 11: Comparison of fishing mortality rates for different natural mortality rates and different release ages for the 2000 cohort. Triangles are for natural mortality vector 1 and circles are for vector 2. All estimates are for tagger group 1 and reporting rate option 2. Error bars are 90% bootstrap confidence intervals conditional on the estimates of mortality, shedding and reporting rates.



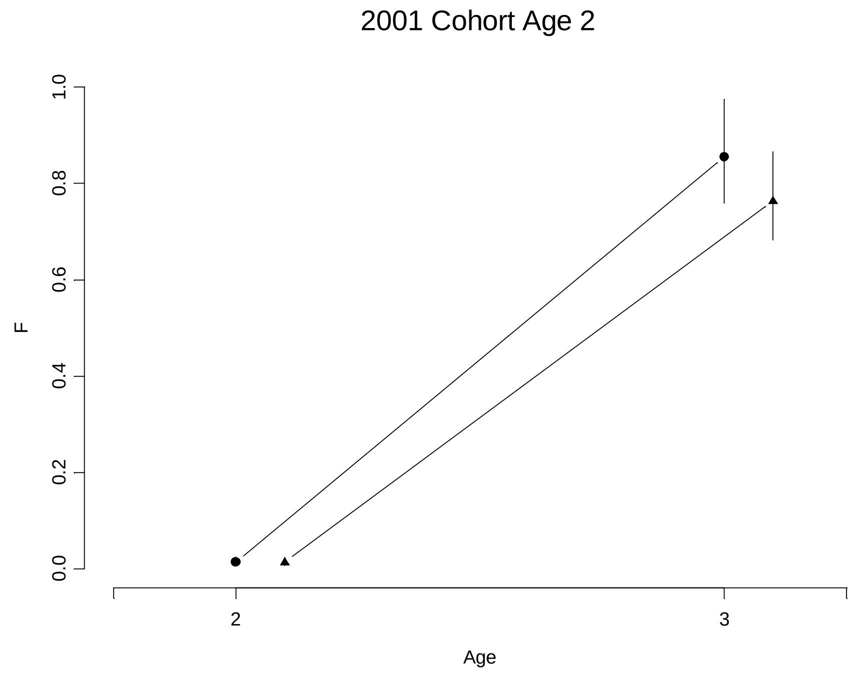


Figure 12: Comparison of fishing mortality rates for different natural mortality rate vectors and different release ages for the 2001 cohort. Triangles are for natural mortality vector 1 and circles are for vector 2. All estimates are for tagger group 1 and reporting rate option 2. Error bars are 90% bootstrap confidence intervals conditional on the estimates of mortality, shedding and reporting rates.

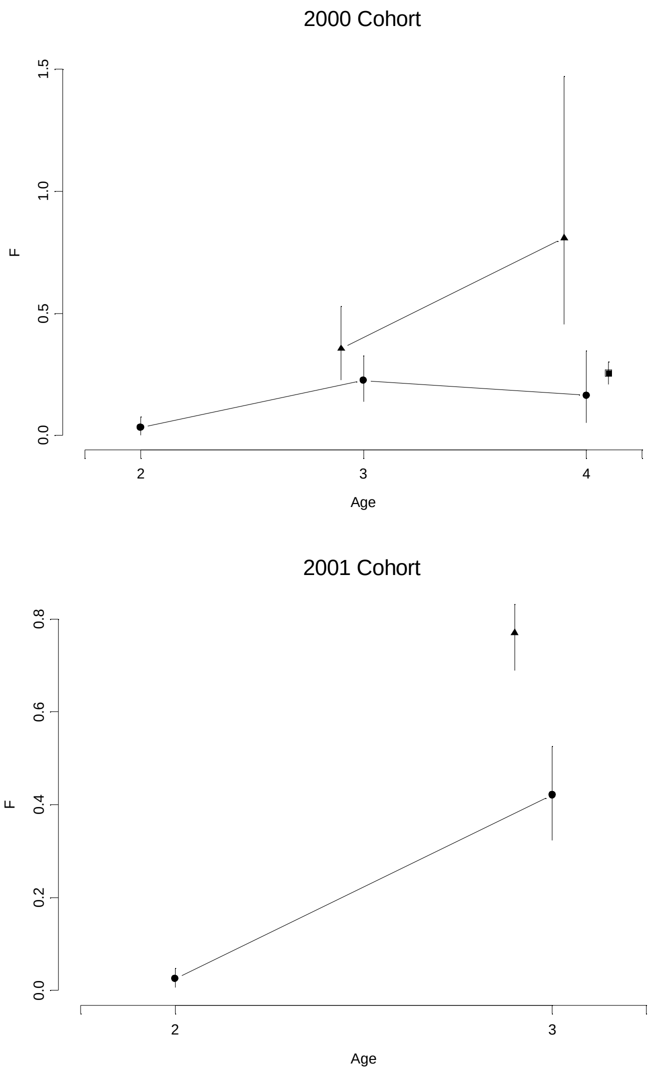


Figure 13: Comparison of fishing mortality rates different release ages and cohorts for tagger group 1. All estimates are for natural mortality rate vector 1and a reporting rate of 0.645 in all fisheries. Circles are for releases at age 1, triangles are for releases at age 2, and squares are for releases at age 3. Note no results are shown for the 1999 cohort as it only had usable estimates for one release year. Error bars are 90% bootstrap confidence intervals conditional on the estimates of mortality, shedding and reporting rates.

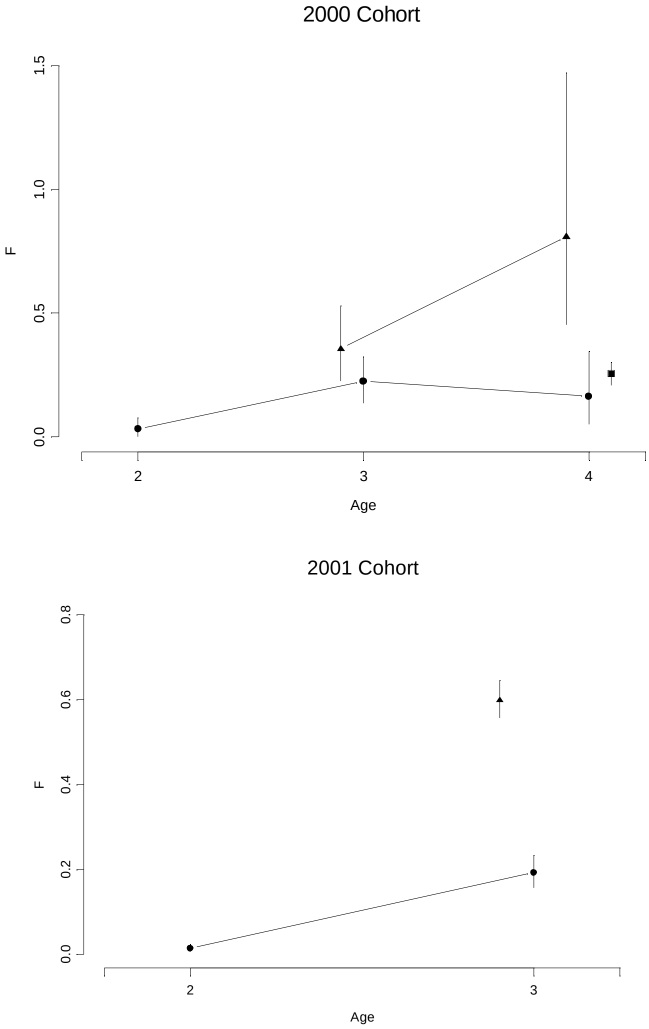


Figure 14: Comparison of fishing mortality rates for different release ages and cohorts for all tag releases. All estimates are for natural mortality rate vector 1and a reporting rate of 0.645 in all fisheries. Circles are for releases at age 1, triangles are for releases at age 2, and squares are for releases at age 3. Note no results are shown for the 1999 cohort as it only had usable estimates for one release year. Error bars are 90% bootstrap confidence intervals conditional on the estimates of mortality, shedding and reporting rates.

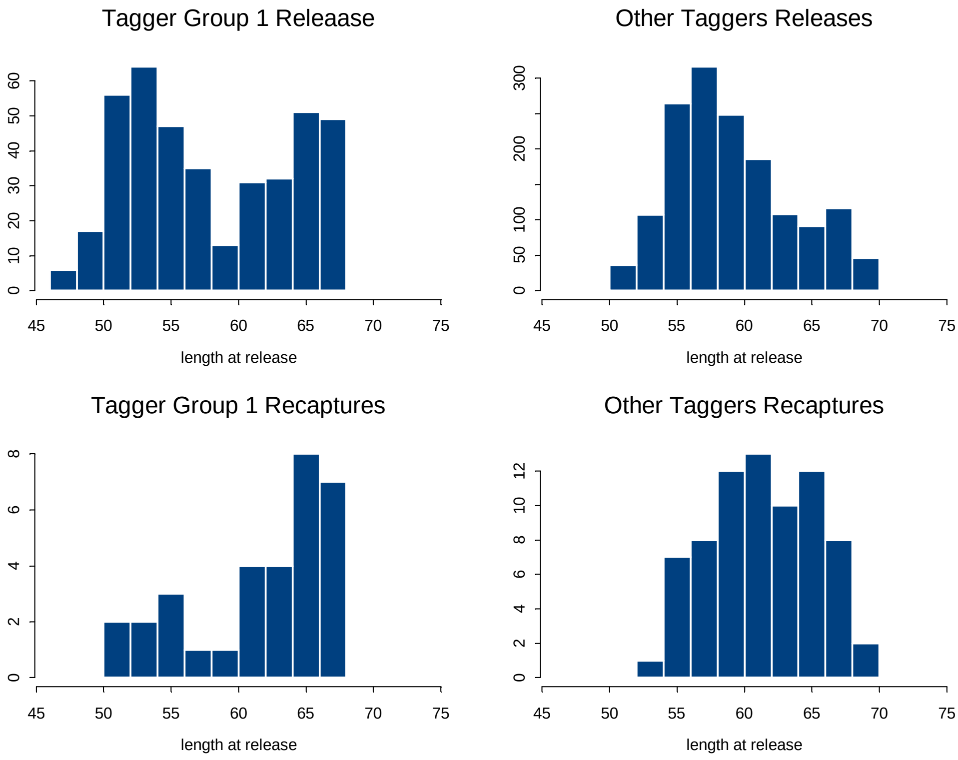


Figure 15: Comparison of the release length distribution for all fish released at age 1 from the 2000 cohort and for those fish that were recaptured.

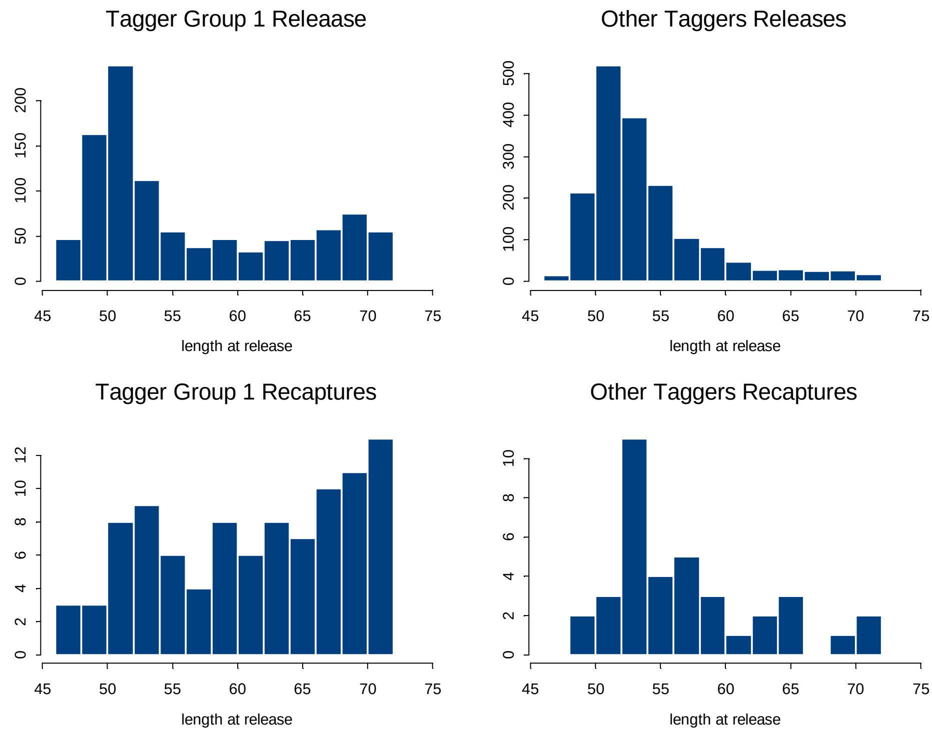


Figure 16: Comparison of the release length distribution for all fish released at age 1 from the 2001 cohort and for those fish that were recaptured

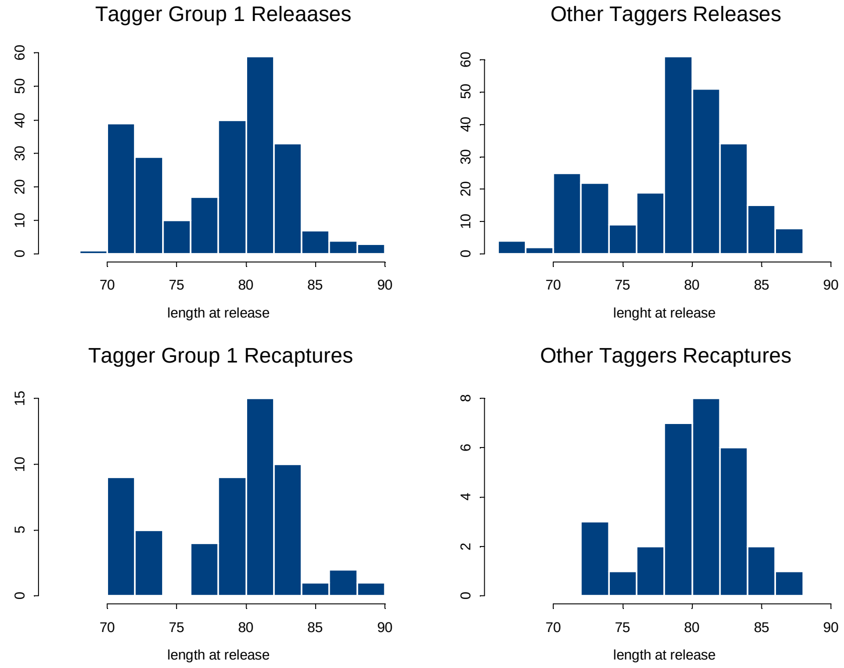


Figure 17: Comparison of the release length distribution for all fish released at age 2 from the 2000 cohort and for those fish that were recaptured.

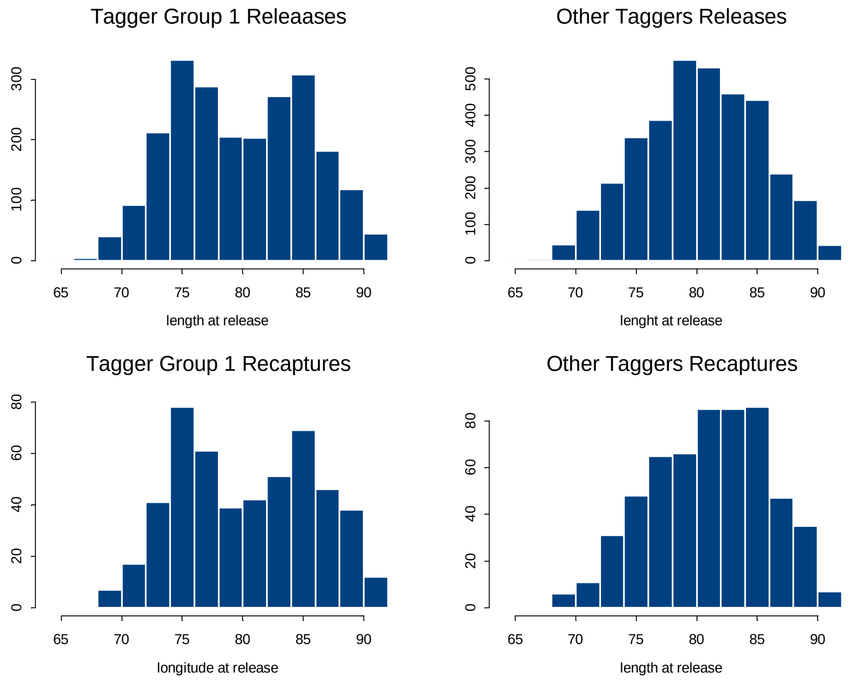


Figure 18: Comparison of the release length distribution for all fish released at age 2 from the 2002 cohort and for those fish that were recaptured.

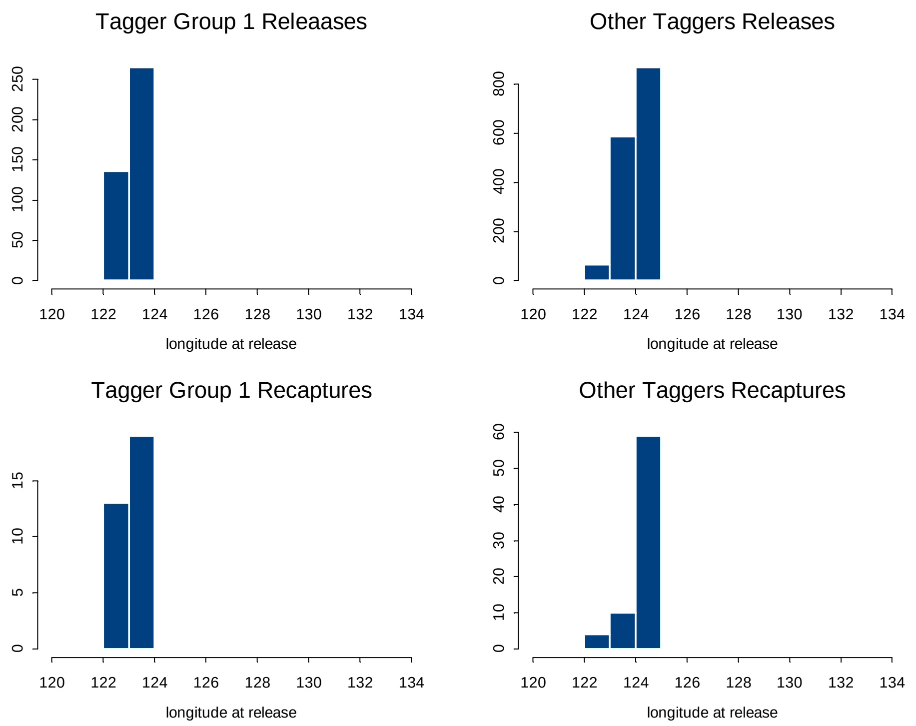


Figure 19: Comparison of the distribution of longitudes for all fish released at age 1 from the 2000 cohort and for those fish that were recaptured.

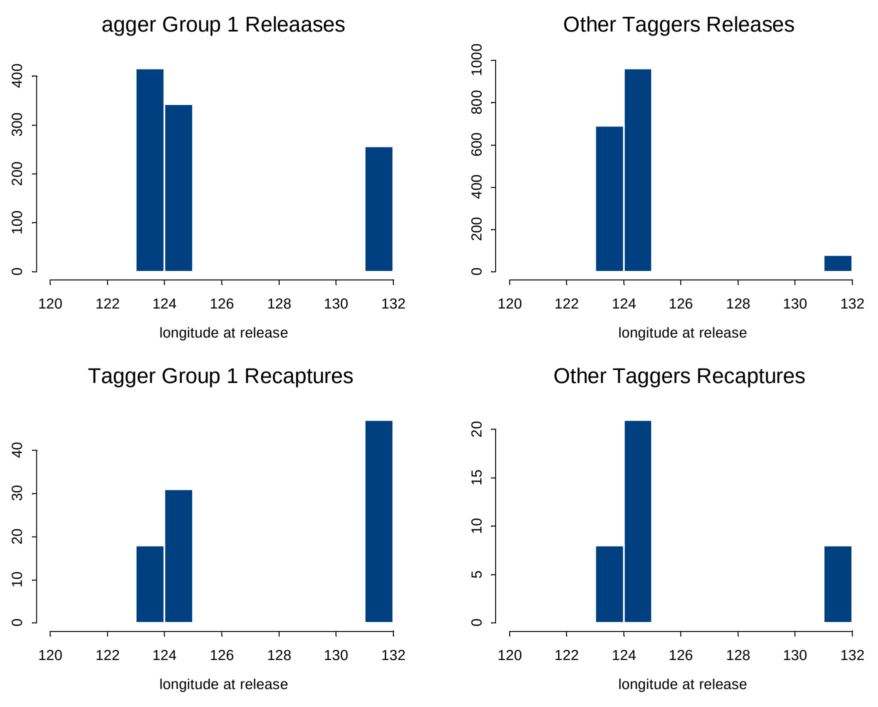


Figure 20: Comparison of the distribution of longitudes for all fish released at age 1 from the 2001 cohort and for those fish that were recaptured

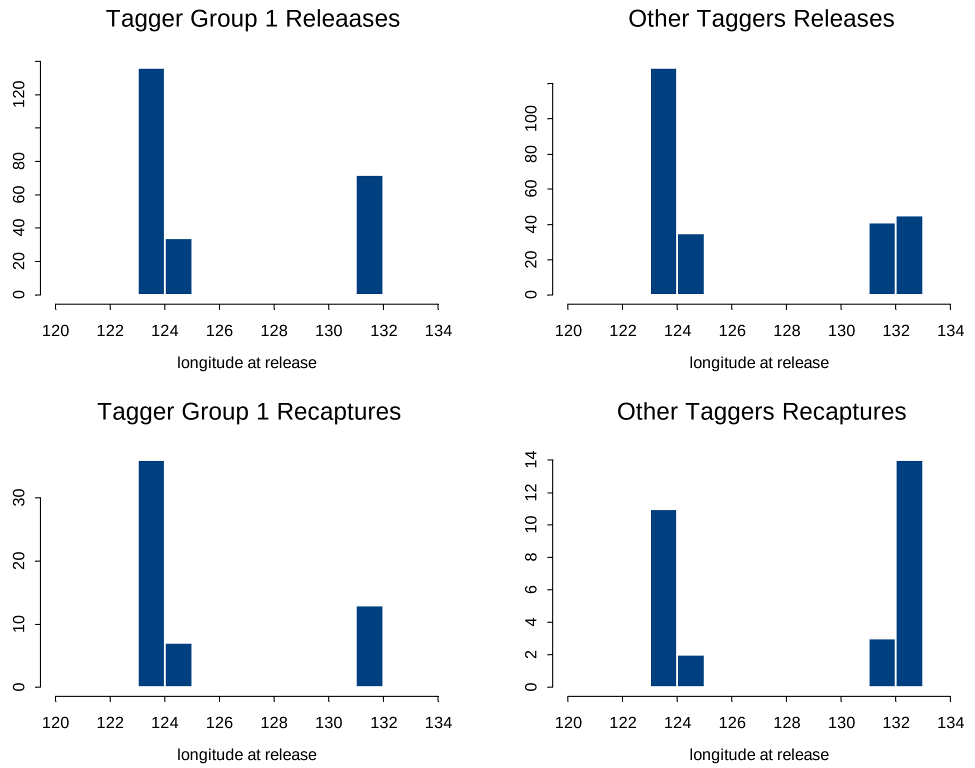


Figure 21: Comparison of the distribution of longitudes for all fish released at age 1 from the 2001 cohort and for those fish that were recaptured. .

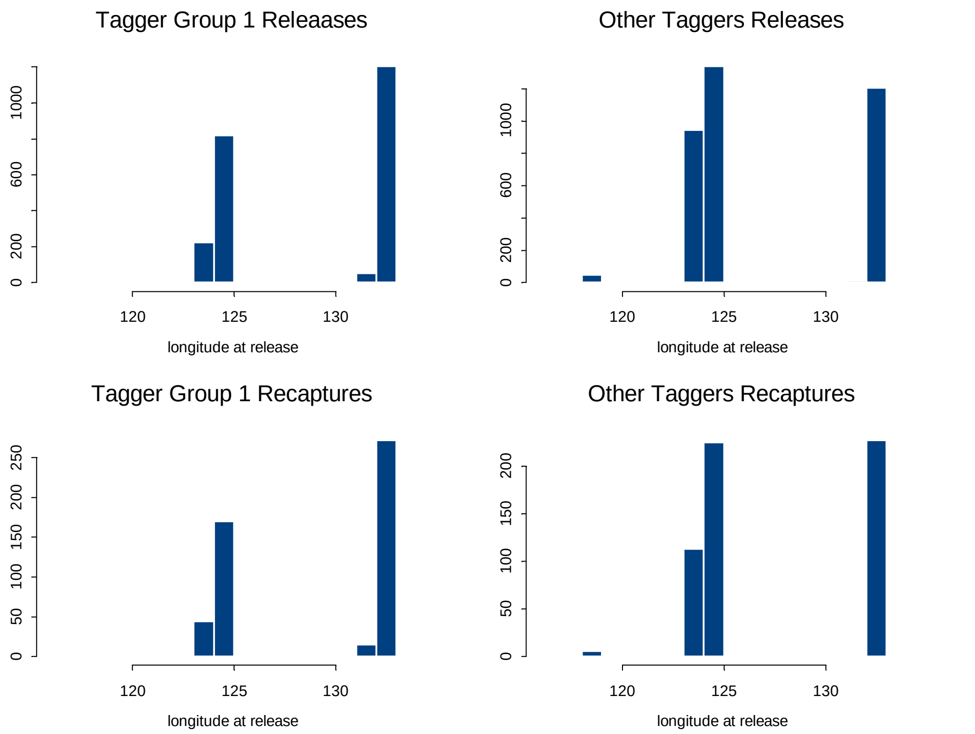


Figure 22: Comparison of the distribution of longitudes for all fish released at age 2 from the 2001 cohort and for those fish that were recaptured.

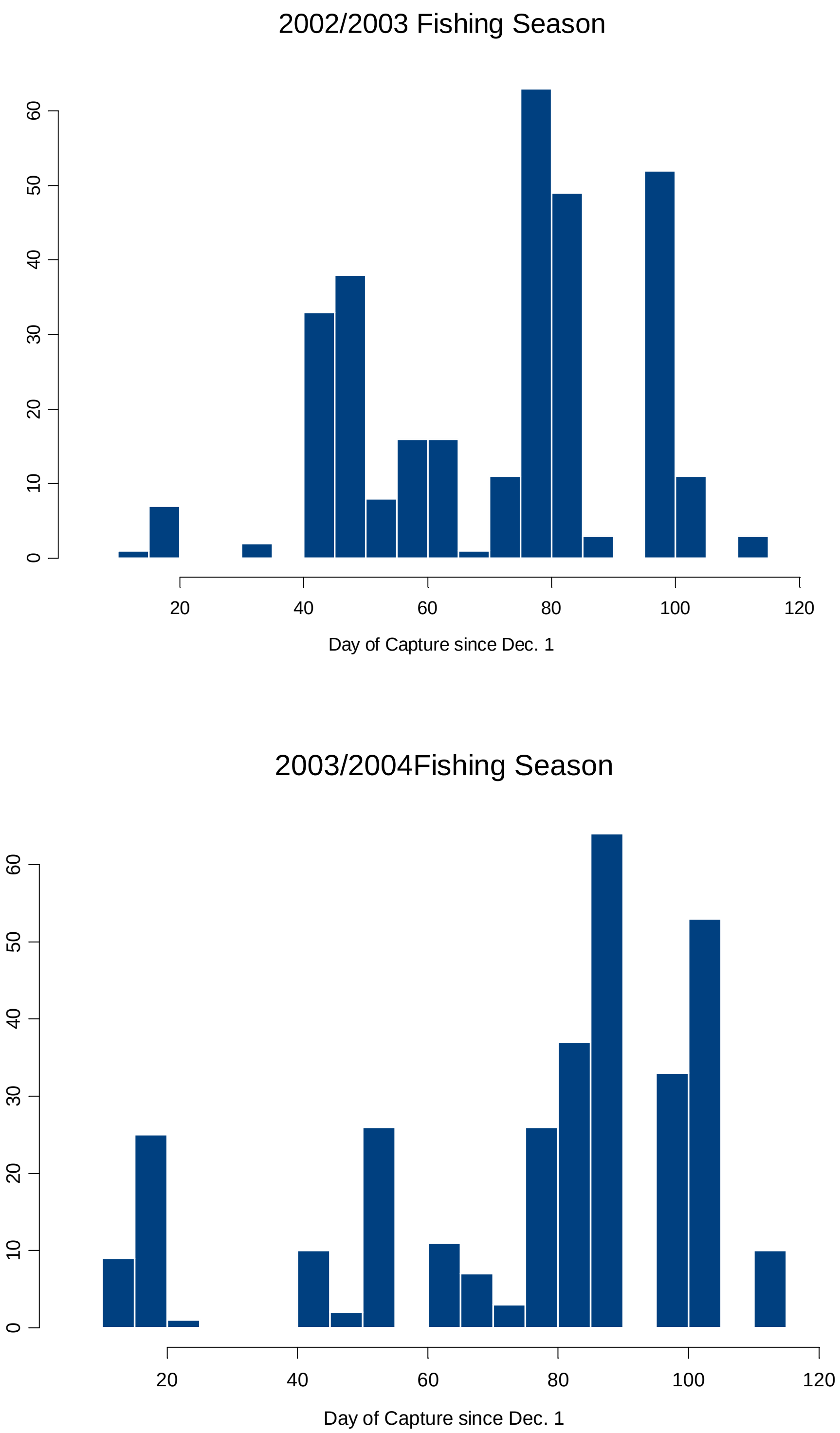
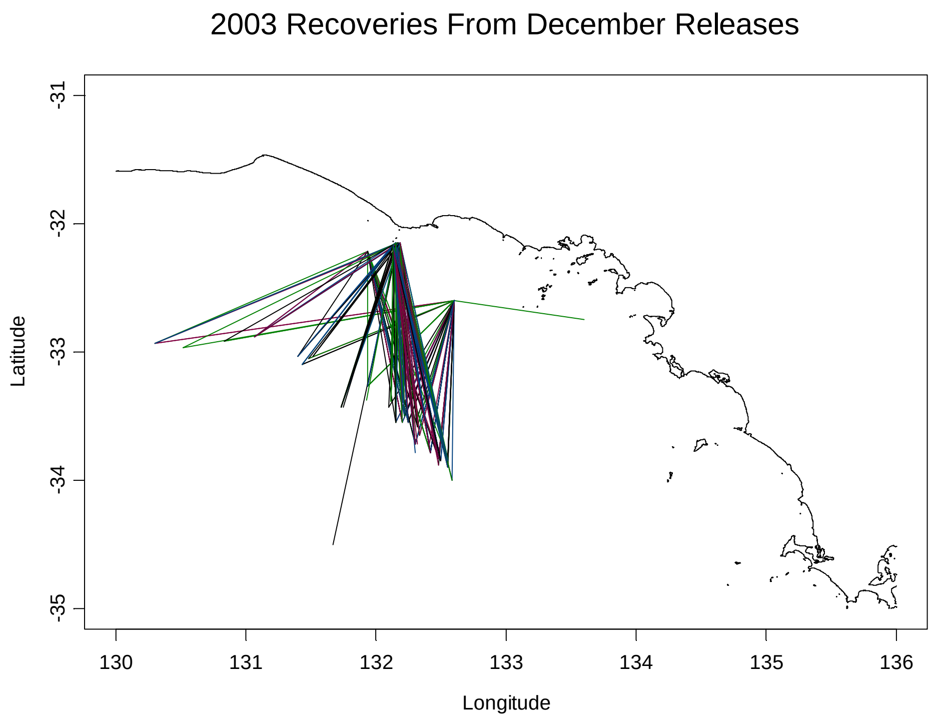


Figure 23: Number of days after December 1 in which a tagged fish released in December in the GAB in 2003 and 2004 was recaptured in the same fishing season. Note that day of recapture is approximate because all recaptures from a single tow cage are assigned the same date of recapture.



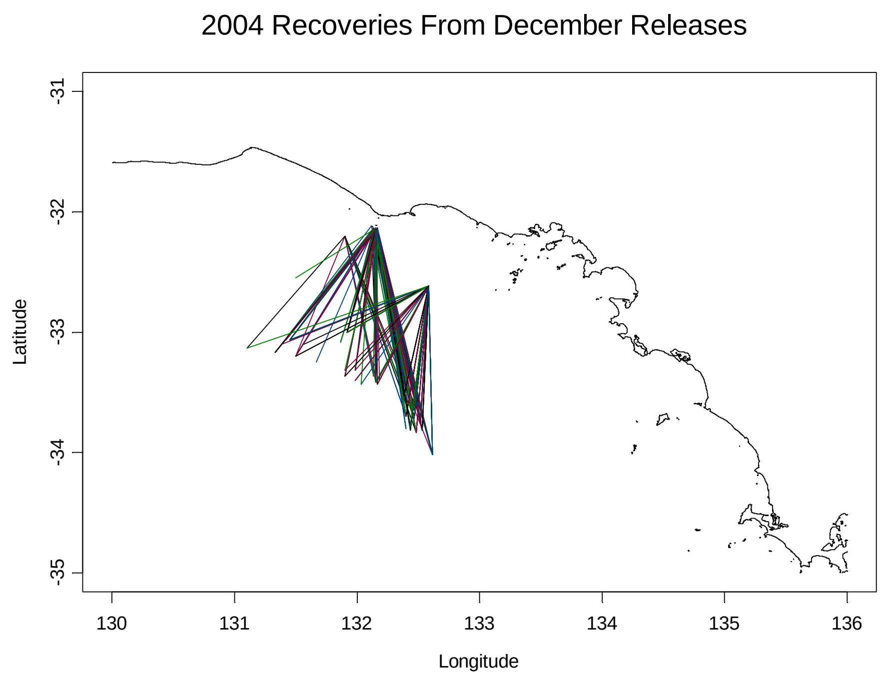


Figure 24: Release and recapture locations for returned tagged fish released in December in the GAB in 2003 and 2004 and recaptured in the same fishing season. Note that day of recapture is approximate because all recaptures from a single tow cage are assigned the same location of recapture.