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Estimates of reporting rate from the Australian surface fishery based on previous tag seeding experiments and tag seeding activities in 2005/2006

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Abstract

A pilot tag-seeding project was conducted in 2002/2003 on purse caught fish when they were transferred from tow cages to grow out cages in the Australian southern bluefin tuna fishery, and overall, tags from 66.4% of the seeded fish were recovered. Further tag seeding was conducted during the 2003/2004, 2004/2005 and 2005/2006 fishing seasons. The primary purpose of the tag seeding is to obtain estimates of tag reporting rates from this component of the global SBT fishery. This paper presents a report on the seeding conducted during the 2005/2006 surface fishing season. In addition, results from the analysis of the data obtained from the 2002/2003, 2003/2004, and 2004/2005 tag-seeding experiments are reported and compared. In 2003/2004 tag seeding occurred in fish from 22 out of a total of 36 tow cages (an increase from 6 cages out of 37 in the previous year), and overall tags from 49.5% of the fish were recovered. In 2004/2005 tag seeding took place for 34 of the 36 tow cages (an increase on the previous year), and overall tags from 34.9% of the fish were recovered. Harvesting operations for 2005/2006 are still under way and as such the total number of returns is unknown at this point. For all years there have been no reports of any of the tag seeded fish dying prematurely or other negative impacts on fish from the tag seeding.

Analyses of the data (which incorporates the tag shedding estimates and variances) from the 2002/2003, 2003/2004, and 2004/2005 fishing seasons yielded estimates of weighted mean reporting rates across cages of 0.645 (s.e. = 0.061, 0.482 (s.e. =0.052), and 0.363 (s.e. =0.0076), respectively. The estimates of reporting rates presented are low based on past expectations and declining over the years. The most critical statistical estimation issues that need further exploration includes, potential biases particularly the representativeness of the cages tagged, and the low level of the reporting rate. It is suggested that a reduction in direct and personal interactions between industry and the tagging program may be having a negative effect on the subsequent reporting rates.

Introduction

The CCSBT has embarked on a large scale juvenile tagging program as part of its collaborative Scientific Research Programme (SRP). The aim of the tagging component is to provide direct estimates of fishing and natural mortality rates (see Anon 2001). Estimates of tag reporting rates are essential for the SRP tagging program to meet its principle objective. In the design of the tagging program, it was anticipated that for most of the main fisheries components (i.e. the various longline fisheries), reporting rates would be estimated from observer data collected under the scientific observer component of the SRP. However, for the Australian purse seine surface fishery, which catches fish for tuna farming, observers can not provide useful data for estimating reporting rates since fish are not removed from the water at the time of capture. Thus, it is impossible to observe the number of fish with tags at the time of capture. As such, alternative approaches are required to estimate the reporting rate from this important component of the global SBT fishery. As part of its commitment to the SRP, Australia undertook a commitment to explore and develop an approach for estimating reporting rates from the SBT farm sector.

After consideration of alternative approach, tag seeding, or planting, was assessed to be the most (perhaps only) viable approach that would allow for direct estimation of reporting rates. In this approach, tags are inserted in a sample of fish within tuna farms. Since the number of seeded tags released into the farms is known exactly, reporting rates can be directly estimated from the number of tags subsequently returned taking into account any tag shedding. A pilot tag-seeding program was conducted in 2002/2003 to assess whether in fact tag seeding could be implemented to provide reliable reporting rates. The project was a pilot one in that it aimed to demonstrate (1) the viability of tagging fish in the farms without inducing mortality, (2) to determine if sufficient industry support could be gained to allow the tag seeding to go ahead in the future and (3) to provide data that would determine the level of tag seeding required to obtain reporting rate estimates with reasonable levels of precision. Based on the success of the pilot program (particularly the demonstrated ability to conduct the seeding without inducing mortality and to obtain estimates of reporting rates from the recapture of tag-seeded fish), tagging seeding has been carried on in each successive year to ensure that data are available for estimating tag reporting rates from the Australian surface fishery (Polacheck and Stanley 2004, 2005).

Polacheck and Stanley (2005) provided preliminary estimates of reporting rates for the surface fishery based on the data from the available tag-seeding data but identified a number of statistical estimation (particularly with respect to variance estimation and the estimation of shedding rates) needing further exploration. The purpose of the present paper is (1) to develop improved and more robust methods for the estimation of reporting rates and their variances from the tag-seeding data; (2) to provide estimates of reporting rates and associated variances from the Australian surface fishery for the 2002/2003 through 2004/2005 fishing seasons using these methods and (3) to report on tag seeding activities during the 2005/2006 season.

Methods

Seeding operations

Stanley and Polacheck (2003) document the details of the approach taken for tag seeding. The approach developed was based on extensive discussions with industry and was designed to address three major concerns that were raised:

1. Potential for tag induced mortality and thus loss of fish and income;
2. Potential stress and reduction in growth within the farm from handling of fish for tagging;
3. Potential for the confidentiality and proprietary information on growth achieved by individual farmer to be compromised.

The protocol developed was to require that all tagging was to be undertaken by experienced taggers. In addition, to minimize stress and increased handling of fish, all fish that would be tagged would be taken from the 40 fish sampled for weight and length at the time fish are transferred from the towing cages to fish pens. This means that tag seeding would not require any additional fish to be taken from the water and physically handled. Moreover, tagging would thus entail a minimal of additional time that a fish sampled for weight and length would be out of the water. In order, to ensure that the confidentiality and proprietary nature of any potential information on growth was maintained, it was agreed that no data on the length or weight of fish at the time of harvesting would be retained in the scientific tagging data base. Such data would not contribute to the interpretation of the results and thus their non-retention would not compromise the reason for conducting tag-seeding experiments.

Given the above, a target was set of tagging 10 fish from the 40 fish that are sampled for weight and length from as many tow cages as possible. In all cases, tagging was at the discretion of the company that owned the fish. (If a farmer desired to have more than 10 fish tagged, then up to 40 fish would be tagged.). All fish were to be doubled tagged so that tag shedding (which may be higher for fish tagged in cages) could be accounted for in the estimation of reporting rates. Standard conventional tags labelled with return to CSIRO were used in 2002/2003 pilot experiment, and thereafter CCSBT labelled tags.

Based on the success of the 2002/2003 experiment in terms of no reported negative concerns having been reported by industry relative to mortality and growth of seeded tagged fish, the same approach has been used in each successive season (i.e. 2003/2004, 2004/2005 and 2005/2006). The only substantive difference between tagging from that in the 2002/2003 pilot experiment and subsequent tag seeding was that CCSBT labelled tags were used. This helps ensure that the intended "double blind" nature of the seeding experiments is realized (i.e. that seeded and un-seeded tags are indistinguishable) since almost all recent SBT tagging has been done with CCSBT labelled tags. In 2003/2004, some of the taggers performing the tagging in the seeding experiments were inexperienced because of unanticipated need for Protec Marine, the company that undertakes the 40 fish sampling, to engage extra staff. It became apparent when the results of the 2003/2004 seeding experiments were available, that high shedding rates were high for some taggers (see results below). Consequently, a preseason tag training workshop was conducted prior to the tag seeding of the 2004/2005 and 2005/2006 season to train those that had not previously tagged and to refresh/standardized tagging techniques among all taggers. Only personnel that had been trained conducted tag seeding in these years in order to reduce shedding rates. The training workshops covered the rationale of tag seeding and instructed the taggers in tag insertion techniques.

Estimation Model for Reporting Rates

The data available for estimating reporting rates are (1) the number of tags seeded into each tow cage, (2) the number of fish in each tow cage (including those for cages with no seeded tags), (3) the individual conducting the tag seeding, (4) the number of tag-seeded fish for which two tags were returned from a tow cage, (5) the number of tag-seeded fish for which only a single tag was return from a cage and (6) the number of tag-seeded fish for which no tags were returned. These data can be used to provide a straightforward estimate of the reporting rate from a tow cage:

$$\lambda_{h,j} = \frac{r_{h,j}}{(1-\gamma_j)n_{h,j}} \qquad (1)$$

$\lambda_{h,j}$ = the estimated reporting rate for the h^{th} tow cage with seeded fish tagged by the j^{th} tagger;

γ_j = the estimated tag shedding rate for the j^{th} tagger[1];

$n_{h,j}$ = the number of tags seeded into the h^{th} tow cage tagged by j^{th} tagger;

$r_{h,j}$ = the number of recovered seeded tags from the h^{th} tow cage tagged by j^{th} tagger;

Note that the shedding rate (γ_j) is defined as probability of a seeded tagged fish having shed both of its tags prior to being recaptured As long as the shedding rate of seeded tags within a cage is independent of the reporting rate for a cage, the variance of $\lambda_{h,j}$ equals

$$\text{Var}(\hat{\lambda}_{hj}) = \text{Var}\left(\frac{r_{h,j}}{n_{h,j}}\right)\hat{W}_j^2 + \left(\frac{r_{h,y}}{n_{h,j}}\right)^2 \text{Var}(\hat{W}_j) \qquad (2)$$

[1] Note that all tagging of seeded fish within any cage was done by only one tagger.

where $\hat{W}_j$ = the estimate of $\frac{1}{1-\gamma_j}$.

Assuming that that the probability of returning a tag from a cage for a fish which has not shed both of its tags is independent (i.e. binomial process), the variance of r_h/n_h (the proportion of tags that were returned from seeded fish that had retained at least one tag) is:

$$\mathrm{Var}\left(\frac{r_h}{n_h}\right) = \frac{r_h}{n_h}\left(1-\frac{r_h}{n_h}\right)\frac{1}{n_h-1} \tag{3}$$

Estimates of the variance of $\hat{W}_j$ were obtained using the bootstrap procedure described in Appendix I. Note that equation 3 ignores the correction for the fact that the number of fish in each tow cage is finite as the correction factor is negligible in this situation[2].

In terms of the shedding rates, it should be noted that the number of seeded double-tagged SBT released into a cage has almost always been ten. As such the numbers of returns from the double tagged tag-seeded fish are inadequate for obtaining a meaningful estimate of the shedding rate and its variances on an individual cage basis. Some pooling of recapture data among cages is necessary to obtain estimates of the tag shedding rates for the seeded tags[3]. In the analyses here we have assumed that differences in shedding rates are a tagger effect and cage independent[4]. We also allowed for shedding rates for a tagger to vary among year (e.g. as a result of the tag training that has been conducted). Where no significant differences were found between taggers or years, data were pooled to form tagger groups in which the rates were similar for the taggers and years included within a group (See Appendix 1 for details).

The reporting rate estimates from equation 1 were combined to provide an overall annual average reporting rate ($\hat{\lambda}_y$). In previous analyses (Polacheck and Stanley 2004, 2005), this was done by taking a simple average across all cages. While this provides unbiased estimates of the reporting rate, a more efficient estimate is to take a weighted mean of the reporting rates among cages taking into account the variability in the number of fish in each tow cage:

$$\hat{\lambda}_y = \sum_{h=1}^{N_{p,y}} \frac{g_{h,y}}{G_{p,y}} \hat{\lambda}_{h,y} \tag{4}$$

where $N_{p,y}$ = the total number of cages with seeded tags in year y,
$g_{h,y}$ = the number fish in the h^{th} tow cage in year y and
$G_{p,y} = \sum_{h=1}^{N_{p,y}} g_{h,y}$, the total number of fish in the cages with seeded tags.

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[2] The finite correction fact equals one minus the sampling fraction. The sampling fraction in this case is on the order of .001 (i.e. 10 out of around 10,000 fish in a tow cage).

[3] Note that comparisons of shedding rates for seeded tags and wild tag releases indicate that the rates are different. In addition, taggers doing the seeding are different than those that have done the tagging in the wild and significant differences in shedding rates exist among different taggers. As such, it is not clear to what extent the differences in shedding rates are tagger effect or the result of releasing tagged fish directly into a farm cage (e.g. contact with the net may increase shedding in the initial period after tagging before tags become firmly embedded in muscle tissue). In any case, separate estimates of the shedding rates for seeded tags are required in order to avoid introducing biases into the reporting rates.

[4] No obvious company effects were apparent and it is not clear what would be plausible factors that would generate company specific differences in shedding rates.

For comparison, we provide estimates of the simple and weighted mean reporting rate estimates. For the case of the simple mean, its variance is estimated as:

$$Var\left(\hat{\lambda}_y\right) = \frac{\left(1-f_y\right)}{N_{p,y}} \sum_{h=1}^{N_{p,y}} \frac{\left(\hat{\lambda}_y - \hat{\lambda}_{h,y}\right)^2}{N_{p,y}-1} + \frac{f_y}{N_{p,y}^2} \sum_{h=1}^{N_{p,y}} Var\left(\hat{\lambda}_{h,y}\right) \quad (5)$$

where f_y = among-cage sampling fraction in year y (i.e. the proportion of cages with seeded tags - $N_{p,y}/N_y$).

For the weighted mean, its variance is estimated as:

$$Var\left(\hat{\lambda}_y\right) = \left(1-f_y\right) N_{p,y} \sum_{h=1}^{N_{p,y}} \left(\frac{g_{h,y}}{G_{p,y}}\right)^2 \frac{\left(\hat{\lambda}_{h,y} - \hat{\lambda}_y\right)^2}{N_y - 1} + f_y \sum_{h=1}^{N_{p,y}} \left(\frac{g_{h,y}}{G_{p,y}}\right)^2 Var\left(\hat{\lambda}_{h,y}\right) \quad (6)$$

Note that f_y is defined slightly differently in equation 6. In this case, it is the fraction of farm fish that were in those cages that were seeded. The variance estimator (equations 5 and 6) used here represents an improvement over that used in the preliminary analyses of the tag-seeding data in Polacheck and Stanley (2004, 2005). The current estimator takes into account both the within and between cage variance in the reporting rate estimates and also the fact that in 2004/2005 a large proportion of the actual tow cages were seeded.

Results

2005/2006 Tag Seeding

Fish were tagged and seeded into farms from 32 of the 36 cages (89%) in 2005/2006. This was a slight decrease from the 94% rate achieved in 2004/2005, but still a substantial improvement from the first full year rate of 61%. The failure to achieve 100% coverage was due two companies unwilling to permit tag seeding in their cages. As of July 1, few seeded tags have been returned to CCSBT (i.e. ~5%) but most of the farm fish have yet to be harvested.

Tag shedding

Table 1 provides a summary by tagger for each season of number of tag seeded fish from which tags were returned, the number of these for which two tags were returned, the number for which only a single tag was returned and the fraction for which only a single tag was returned. As noted previously the fraction of fish for which only one tag was returned in 2003/2004 was quite high (0.43) indicating relatively high shedding rates in this year. Preliminary results presented in Polacheck and Stanley (2005) indicate that tag shedding rates in 2004/2005 had been reduced considerably over 2003/2004 as a result of training provided to taggers. Now that complete results are available for the 2004/2005 season they confirm that the shedding rates were substantially reduced (Table 1). Thus, compared to the 0.43 rate in 2003/2004, the fraction of the returns with only a single tag was 0.36 in 2004/2005. However, the results in Appendix 1 suggest that this may be due to the difference in the proportion of tags seeded by different taggers and sampling variability. Among the few seeded tags that have been returned so far for the 2005/2006, taggers appear to have achieved similar, if not improved, performance to those achieved in 2004/2005. However, the results are too preliminary to draw any definitive conclusions. Nevertheless, it is important to provide adequate training to all taggers.

Appendix 1 provides details of the method and analyses used to estimate the tag shedding rates from these tag-seeding experiments. The results of these analyses suggest that for the estimation of shedding rates, the data can be pooled into three year/tagger groups in which the shedding rates are not statistically different for those releases within a group. The estimates of the shedding rates (i.e. the probability of any tag being lost) ranged from ~0.11 to 0.36 among the three different groups (Table 1A4c[5]). Despite this range, the estimates also indicate that tag shedding is not a large factor affecting the number of returns that have been recovered from these tag-seeding experiments. Thus, even for the tagger group with the highest shedding rate only ~13% of the seeded tagged fish would have been expected to have lost both their tags.

The results in Appendix 1 also indicate that the shedding rates are estimated with high levels of precision. Thus, the estimates of the coefficient of variation for correction factor W_j (which accounts for the effects of tag shedding on the reporting rates) are less then 4%. (Table A4c)

Reporting Rates

Table 2 lists the number of tagged seeded fish that were released and the number that were recovered by tow cage for each year. Also given is the percentage returned from each cage, which is an estimate of the reporting rate for that cage uncorrected for tag shedding. Based on these data, Table 3 provides weighted and unweighted (simple) estimates of the mean annual reporting rate which take into account the effects of tag shedding. The simple and weighted annual mean estimates are quite similar. The largest difference is for the 2004 where the simple mean estimate is 0.53 and the weighted mean is 0.48 (a difference of ~ 9 %). As would be expected, even in this case the difference between the weighted and simple mean estimates is not statistically different. Since the weighted mean reporting rate gives more weight to cages with large numbers of fish and these in turn would be expected to contain more wild tagged SBT, the weighted estimates would be the most appropriate to incorporated into the mortality models that analyze data from wild tagged fish.

Discussion

The estimated reporting rates presented here represent a substantial improvement over the preliminary estimates presented in Polacheck and Stanley (2004, 2005) as a number of statistical estimation matters that were identified as needing further exploration have been addressed. In particular, the current estimates provide (1) a more robust and efficient error models for incorporating the effects of tag shedding, (2) allow for pooling of shedding rates when these were statistical similar either among taggers or across years and (3) account for the differential number of fish in different tow cages. In addition, the estimator for the shedding rate corrects an error in the estimator used in Polacheck and Stanley (2004, 2005), which resulted in an overestimate of the shedding rate and a corresponding underestimate of

[5] Note that the estimates in Table 1A4b are given in terms of the retention rate (i.e. the probably that a tag has been retained at the time of harvest) and the shedding rates are simply one minus these values.

the reporting rates[6]. This effect was greatest for the 2003/2004 estimate and decreases the estimate of the overall reporting rate by ~0.10 (i.e. this is the primary source of the difference between the estimate of 0.63 given in Polacheck and Stanley (2005) for 2003/2004 with those in Table 3). For 2002/2003, the effect was negligible (i.e. a difference of ~0.005) due to the much lower shedding rates in that year.

It should also be noted that one seeded tag from the 2003/2004 seeding was returned from a recreational fisherman fishing outside the cages in Port Lincoln, and similarly 4 from the 2004/2005 seeding. These presumably represent escapees from the farms. While the expectation is that such escapes are rare, they could potentially slightly confound the interpretation of the seeding results – i.e. some (small) fraction of the non-reported seeded tags could represent escapees from the farm. In terms of the analyses of the overall tagging data, the question would be whether such escapees essentially die in the Port Lincoln area as a result of having been caught and placed in the farm (e.g. because of having developed a dependency on the farms for feeding or get caught by recreational fishermen) or whether they return to the wild stock. In the former case, it would be appropriate to include escapee as part of the non-reported returns, in the latter they should be counted as non-captured tagged fish.

The estimates of the reporting rates have progressively declined during the three years of these experiments by about 15% per year (i.e. from 65% in 2002/2003 to 48% in 2003/2004 to 34% in 2004/2005 on the weighted mean estimates). This is of concern, as it would lead to an increased uncertainty in any mortality rate estimates if other conditions remain constant. The decline between 2002/2003 and 2003/2004 was accompanied by a marked increase in the percentage of cages with seeded tags (i.e. 19% to 94%). It is unlikely that this increase in itself was responsible for a change of reporting rates. Nevertheless, there were two factors in the 2002/2003 experiment that potentially may have resulted in the estimate for that year being biased.

(1) The seeded tags were CSIRO labeled tags while the wild fish tags in the cages had CCSBT labeled tags (with the possible exception of a few older fish). This could have resulted in a difference in the reporting rate between seeded tagged fish and wild tagged as the two types of tags were distinguishable. As the tag and labeling have been the same for seeded and wild tagged fish in subsequent years, this factor would not affect the latter reporting rate estimates.

(2) There was initially substantial reluctance by industry to allow the seeding of tags into their cage and those cages that were actually seeded may not have constituted a representative sample. Those companies that did agree to cooperate the seeding may have been more cooperative/conscientious with respect to returning of tags. If this were the case, the estimate for 2002/2003 could be substantially biased upwards. In 2003/2004 and 2004/2005 the high proportion of cages that were seeded would mean that the effect of any such correlation between actual reporting rates and those cages which were seeded would be much less. Nevertheless, if such a correlation did exist, the latter reporting rates would also be biased upward. Ideally, seeding should take place in 100% of the cages.

[6] The estimator of the shedding rate in Polacheck and Stanley (2004, 2005) mistakenly used the conditional probability of that a fish had shed one tag given that it was recovered (i.e. 1-Q of Appendix 1) as an estimate of the unconditional probability of shedding a tag.

Low reporting rates will increase the uncertainty of any estimates derived from the tagging of wild caught animals. For example, the actual number of tags returns is the primary factor which determines the level of precision that will be achieved in a tagging experiment designed to estimate mortality rates (e.g. Brownie models). Having precise estimates of reporting rates and sufficient number of tag releases to ensure a reasonable number of returns can mitigate low reporting rate and reasonably precise mortality rate estimates are still achievable. Nevertheless, there is an obvious need to improve the reporting rate to maximize the benefits from the current and any future tagging. However, care needs to be taken when instituting any method to improve the reporting rates to ensure that it does not compromise/bias the overall tagging results. In particular, an approach that resulted in increased reporting rates but compromised the ability to precisely and accurately estimate the actual reporting rates could result in substantial increased uncertainty and should be avoided.

Approaches that could be considered to increase reporting rates would include

(1) having tag collectors routinely and frequently visit farm harvesting operations to make the returning of tags as easy as possible and being readily accessible for the collection of tags;

(2) enabling tag collectors to provide on the spot rewards;

(3) increasing the value of the reward provided;[7]

(4) increasing the publicity and liaison activities (personal contacts) used for promoting awareness of the tagging program

(5) using tags that can be automatically detected (e.g. PIT tags) or

(6) the institution of a system using tag-collection observers who would monitor fish when they are harvested from the grow-out cages (ideally at the point at which they are removed from the water).

In terms of the last of these, unless coverage approached 100%, ensuring representative coverage of the harvest would be important. However, this may be difficult given that some fish are harvested for auction on the fresh market and others harvested for sale to freezer boats. The size of fish in these two categories is likely to be different as the relative proportion and timing of harvesting will vary among farm operators. In particular, harvesting for the fresh market occurs over an extended period with generally small numbers being harvested on any day and would present logistical difficulties assuming access could be arranged.

Ensuring that tag shedding is as minimal as possible is important for reducing uncertainty in the reporting rate estimates. This emphasizes the importance of tagger training and monitoring, and implementing a strict tagging protocol in order to reduce tag shedding to low levels. Although tag shedding may be accounted for in single-tagged fish if a tagger has double-tagged sufficient number of fish, it is preferable that all seeded tagged fish are double-tagged to achieve both high levels of precision and to be able to test for consistency over time.

Between 2002/2003 and 2004/2005, the estimated variances for the annual reporting rates have progressively and markedly declined (Table 2). This is primarily due to three reasons.

[7] Cash rewards were increased from $10 to $15 at the start of the CCSBT tagging program

Firstly the large increase in the sampling fraction to ~90% means that the among-cage component of the variance must become small (i.e. with 100% sampling it becomes zero). Secondly, the increase in the number of cages with seeded tags, from 6 to 32-34 yields a substantial decline in the estimate of the within-cage component (i.e. all else being equal the within cage component of the variance is inversely proportional to the number of cages seeded. These two factors are the main source of the decrease in the variance between 2002/2003 and 2003/2004 and off-set the increase in the shedding rate in that year. Thirdly, the shedding rate decreased markedly between 2003/2004 and 2004/2005 and high and uncertain shedding rates[8] can be a major contributor to the within cage component (i.e. equation 2).

While there has been a marked decline in the variances, the coefficients of variation (CV) associated with the reporting rates have not declined as sharply (i.e. from at most 11 to 7% - Table 3). This mainly reflects the fact that the decline in the variances has occurred simultaneously with a decline in the reporting rate.

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[8] Low shedding rates inherently will have low variances.

Table 1: Summary of the number of tag returns for tag-seeded fish from the tag seeding experiments by year.

Year	Tagger	No. Tagged fish recovered	No. With two tags	Fraction with only one tag
2002/2003	1	36	31	0.06
	2	6	5	0.17
	3	16	13	0.20
2003/2004	3	22	11	0.54
	4	40	31	0.23
	5	30	11	0.50
	6	7	3	0.71
	7	6	4	0.33
2004/2005	3	32	18	0.44
	4	58	44	0.24
	5	24	10	0.58
	6	4	3	0.25
2005/2006	8	4	4	0.00
	5	2	2	0.00
	4	11	8	0.27

Table 2: Summary of tag returns by tow cage for the 2002/2003, 2003/2004 and 2004/2005 tag seeding experiments.

Year	Cage	Tagger	No. Tagged	No. Returned	% Returned
2002/2003	1	1	20	20	100
	2	1	20	16	80
	3	2	10	6	60
	4	3	10	5	50
	5	3	11	7	64
	6	3	10	4	40
	7*	4	38	21	55
2003/2004	1	4	10	7	70
	2	5	10	5	50
	3	4	10	7	70
	4	6	10	1	10
	5	6	9	3	33
	6	5	10	0	0
	7	5	10	8	80
	8	3	10	8	80
	9	3	10	8	80
	10	3	10	6	60
	11	6	10	2	20
	12	5	10	3	30
	13	4	10	2	20
	14*	5	6	1	17
	15	4	10	10	100
	16	4	10	9	90
	17	5	9	9	100
	18	7	10	6	60
	19	5	10	1	10
	20	5	10	0	0
	21	5	10	4	40
	22	4	10	5	50
2004/2005	1	4	10	3	30
	2	4	10	2	20
	3	3	9	1	11
	4	4	10	1	10
	5	4	10	0	0
	6	5	10	7	70
	7	4	10	1	10
	8	4	10	0	0
	9	3	10	6	60
	10	6	10	2	20
	11	5	9	1	11
	12	4	10	3	30
	13	5	10	1	10
	14	5	10	6	60
	15	4	10	0	0
	16	5	10	5	50
	17	5	10	4	40

Table 2 (continued)

Year	Cage	Tagger	No. Tagged	No. Returned	% Returned
2004/2005	18	4	10	8	80
	19	4	10	3	30
	20	4	10	8	80
	21	4	10	4	40
	22	6	10	2	20
	23	4	10	0	0
	24	3	10	2	20
	25	4	10	3	30
	26	4	10	6	60
	27	4	10	1	10
	28	3	10	7	70
	29	3	10	2	20
	30	4	10	4	40
	31	4	10	3	30
	32	3	10	6	60
	33	3	10	8	80
	34	4	10	8	80

* The taggers in these cases mistakenly only single tagged the fish. In addition 10 fish were single tagged by another tagger whom tagged no other fish in these experiments. The data from this latter tagger have been excluded from the table and all analyses.

Table 3: Estimates of reporting rates, their variances and standard errors for the Australian surface fishery for years 2002/2003 to 2004/2005.

Year	Unweighted				Weighted			
	$\hat{\lambda}$	$\mathrm{Var}(\hat{\lambda})$	$\mathrm{SE}(\hat{\lambda})$	CV	$\hat{\lambda}$	$\mathrm{Var}(\hat{\lambda})$	$\mathrm{SE}(\hat{\lambda})$	CV
2002/2003	0.655	0.00495	0.070	10.7	0.645	0.00369	0.061	9.5
2003/2004	0.532	0.00262	0.051	9.6	0.482	0.00272	0.052	10.8
2004/2005	0.376	0.00072	0.027	7.2	0.363	0.00076	0.028	7.7

Appendix 1: Estimation of Shedding in the Tag Seeding Experiments

William Hearn and Michael Rowlands

The data from the tag seeding experiments provide a data set of the number of tag seeded fish from in which the primary (A) tag only was returned, the companion (B) tag only was returned and both (A&B) are returned (These are referred to as r_A, r_B, and r_{AB}, respectively, with r_T their sum). For each tagger the above numbers are summed over cages in each year and are listed in Table A1.

We now estimate the proportions of tags not shed (i.e. Q_A and Q_B for A and B tags), respectively, and Q for either tag under the assumption that $Q_A = Q_B$. Note that Q_A , Q_B and Q are estimate of retention rate of a single tag and that the probability of shedding a single tag is 1 minus these quantities. Assuming independence in the shedding of the A and B tags, the probabilities that a fish has retained both tags, tag A only, tag B only, or no tags, are Q_AQ_B, Q_A(1-Q_B), Q_B (1-Q_A), and (1-Q_A)(1-Q_B), respectively. However, a fish shedding two tags cannot normally be identified. However, the first three terms can be estimated from the observed data conditional on a fish having retained at least one tag are:

$$p_{AB} = \frac{Q_A Q_B}{Q_A + Q_B - Q_A Q_B} \qquad \text{for fish with both A and B tag.}$$

$$p_A = \frac{Q_A(1-Q_B)}{Q_A + Q_B - Q_A Q_B} \qquad \text{for fish with an A tag only}$$

$$p_B = \frac{Q_B(1-Q_A)}{Q_A + Q_B - Q_A Q_B} \qquad \text{for fish with an B tag only.}$$

We use a maximum likelihood approach to estimate the retention rates. The likelihood for all r_T observed recaptures is proportional to

$$\Lambda = (p_A)^{r_A}(p_B)^{r_B}(p_{AB})^{r_{AB}}$$

and the negative log-likelihood is –LL=–ln(Λ) (to within a constant). It is straightforward to show that the maximum likelihood estimates of the Q parameters are

$$Q_A = \frac{r_{AB}}{r_{AB} + r_B} \qquad \text{(A1)}$$

$$Q_B = \frac{r_{AB}}{r_{AB} + r_A} \qquad \text{(A2)}$$

and if $Q = Q_A = Q_B$

$$Q = \frac{r_{AB}}{r_{AB} + 0.5(r_A + r_B)}. \qquad \text{(A3)}$$

Estimates of $-LL$ are listed in Table A2 for each tagger with data spanning two or more fishing seasons, together with the

$$AIC = 2(-LL + \mathrm{df}),$$

where df = the number of degrees of freedom (2 if $Q_A \neq Q_B$, and 1 if $Q = Q_A = Q_B$).

We pooled tagger data over years in a way that minimizes the AIC (Table A2). For tagger 5, the AIC for the pooled 2003/2004 and 2004/2005 data is 121.645, which is smaller than the summed 2003/2004 AIC and the 2004/2005 AIC, namely 125.439. Therefore, it is valid to pool the data of tagger 5 over years 2003/2004 and 2004/2005 and this suggests that tagger 4 was consistent in his tagging technique between years. The same pertains to tagger 6. However, for tagger 4 the AIC for the pooled 2003/2004 and 2004/2005 data is 141.587, which is larger than the summed 2003/2004 AIC and the 2004/2005 AIC, namely 140.768. Therefore, it is invalid to pool the tagger 4's data over years 2003/2004 and 2004/2005.

The situation is more complex for tagger 3 who tagged over more years, i.e. 2002/2003 through 2004/2005. In Table A2 for tagger 3, the summed 2002/2003 to 2004/2005 AICs is 137.919, which is larger than the AIC =135.742 for the pooled 2002/2003 to 2004/2005 data, which in turn is larger than sum of the AICs of the 2002/2003 data and the pooled 2003/2004 and 2004/2005 data, namely 135.475. Therefore, the data for 2003/2004 and 2004/2005 are pooled before analyses, but the 2002/2003 data are analysed separately.

We now investigate pooling of return data over taggers. We list in Table A3 the estimates of Q_A, Q_B and Q and the associated –LL and AIC values by tagger. In this list some tagger data are pooled over years as presented in Table A2. In all cases but one (tagger 4 in 2004/2005) the model $Q = Q_A = Q_B$ gave the best fit, i.e. lowest AIC. We assign the data for tagger 4 in 2004/2005 as data group III. The other data are pooled into 2 groups, group I if $Q \geq 0.8$ in Table A3 (low shedding), and group II if $Q < 0.8$ (high shedding), which gives the least AIC. The numbers of returns in groups I-III are listed in Table A4a.

The estimates of shedding parameters Q_A, Q_B and Q , which are derived from the pooled data sets (Table A4a), are listed in Table A4b, together with the associated –LL and AIC values. In Table A4b the least AICs correspond to $Q = Q_A = Q_B$ for data groups I and II and $Q_A \neq Q_B$ for group III.

The shedding factor W

To take account of shedding in estimating the reporting rates we multiply the numbers of returns from each cage by a factor W_j where

$$\hat{W} = 1 + \frac{r_A r_B}{r_{AB} r_T}, \qquad \text{if } Q_A \neq Q_B, \qquad \text{(A4)}$$

or

$$\hat{W} = 1 + \frac{(r_A + r_B)^2}{4 r_{AB} r_T}, \qquad \text{if } Q_A = Q_B = Q. \qquad \text{(A5)}$$

For data group, j, we need to estimate $\text{Var}(\hat{W}_j)$, conditional on the number of returned seeded tagged fish r_T, to allow an estimate of $\text{Var}(\hat{\lambda}_{hj})$ from equation (2). We used a bootstrap estimation procedure to obtain a variance estimate for each tagging group. For each group and bootstrap run i (i = 1, 2, …,1000), a number r_T ($= r_A + r_B + r_{AB}$) of returns were randomly selected of which r_{iA} had A tags, r_{iB} had B tags and r_{iAB} has both A and B tags ($r_{iA} + r_{iB} + r_{iAB} = r_T$). From which run W_{ji} is estimated from the appropriate above equations. The variance of W_j is then estimated as

$$\mathrm{Var}\left(\hat{W}_j\right) = \frac{1}{999}\left(\sum_{i=1}^{1000}\hat{W}_{ji}^2 - \frac{1}{1000}\left(\sum_{i=1}^{1000}\hat{W}_{ji}\right)^2\right), \quad \text{(A6)}$$

The resulting estimates of W_j and their variances are listed on Table A4c for each tagger groups. The results suggest that the estimates of W_j are highly precise (i.e. coefficient of variations of less then 4%). The results also indicate that tag shedding is not a large factor in accounting for the relatively low reporting rates that have been estimated from these tag seeding experiments. Thus, even for the tagger group with the highest shedding rate (i.e. a 36% probability that a tag will be shed), only ~13% of the seeded tagged fish would have been expected to have lost both tags.

It should be noted that for cage 7 in 2002/2003 all 38 fish that were seeded into were only single tagged. The tagging in this case was done by tagger 4 and this was the only cage that he tagged in 2002/2003. In order to use the data from this cage in estimating the reporting rates we assumed tagger 4's proficiency in this case was as when he double-tagged cage fish in 2004/2005. Hence, the parameter estimates from group I were used to estimate W and Var(W) for this cage. However, W was estimated as W=1/Q to account for the fact that that single tagging occurred. In addition, cage 14 in 2003/2004 all seeded tags were single releases and in this one case two taggers were doing the tagging. One of these we have no data for double-tagged fish so we excluded his data.

Table A1: The number of seeded tag fish by year and tagger for which only the primary tag was returned (r_A), for which only the companion tag was returned (r_A) and for which both tags were returned (r_{AB}). (Note year refers to the last year in a season – i.e. 2003 indicates the 2003/2004 fishing season and 04-05 refers to the combined 2003/2004 and 2004/2005 seasons).

Tagger	Year	r_A	r_B	r_{AB}	Total
1	2003	3	2	31	36
2	2003	1	0	5	6
3	2003	1	2	13	16
	2004	3	8	11	22
	2005	7	7	18	32
	03-05	11	17	42	70
	04-05	10	15	29	54
4	2004	6	3	31	40
	2005	3	11	44	58
	04-05	9	14	75	98
5	2004	9	10	11	30
	2005	6	8	10	24
	04-05	15	18	21	54
6	2004	1	3	3	7
	2005	0	1	3	4
	04-05	1	4	6	11
7	2004	1	1	4	6

Table A2: Negative log-likelihood values and AIC statistic for models with year specific retention rate estimates by tagger compared to models in which retention rates are assumed equal in some years. Results are only shown for taggers that tagged in more then a single year. (Note year refers to the last year in a season – i.e. 2003 indicates the 2003/2004 fishing season and 04-05 refers to the combined 2003/2004 and 2004/2005 seasons).

Tagger	Year	-LL	df	AIC	Σ-LL	df	ΣAIC
3	2003	9.631	2	23.262			
	2004	21.695	2	47.389			
	2005	31.634	2	67.268	62.960	6	137.919
	2003	9.631	2	23.262			
	04-05	54.107	2	112.214	63.738	4	*135.475
	03-05	65.871	2	135.742	65.871	2	135.742
4	2004	27.055	2	58.110			
	2005	39.329	2	82.657	66.384	4	*140.768
	04-05	68.793	2	141.587	68.793	2	141.587
5	2004	32.858	2	69.716			
	2005	25.861	2	55.723	58.720	4	125.439
	04-05	58.823	2	121.645	58.823	2	*121.645
6	2004	7.030	2	18.059			
	2005	2.249	2	8.499	9.279	4	26.558
	04-05	10.081	2	24.162	10.081	2	*24.162

* Model with the lowest AIC.

Table A3: Comparison of estimates of tag retention rates for primary and secondary tags with the estimates of the rates under the assumption that rates are same for both tags by tagger-year categories based on the results from Table A2. Also provided are the negative log-likelihood values and AIC statistics for the estimates under the two different assumptions. (Note year refers to the last year in a season – i.e. 2003 indicates the 2003/2004 fishing season and 04-05 refers to the combined 2003/2004 and 2004/2005 seasons).

		$Q_A \neq Q_A$					$Q_A = Q_A$			
Tagger	Years	Q_A	Q_B	-LL	df	AIC	Q	-LL	df	AIC
1	2003	0.9394	0.9118	17.8709	2	39.7419	*0.9254	17.9716	1	*37.7419
2	2003	1.000	0.8333	2.7034	2	9.4067	*0.9091	3.3965	1	*8.7930
3	2003	0.8667	0.9286	9.6308	2	23.2616	*0.8966	9.8007	1	*21.6014
3	04/05	0.6744	0.7436	54.1070	2	112.2139	*0.6988	54.6103	1	*11.2207
4	2004	0.9118	0.8378	27.0552	2	58.1104	*0.8732	27.5649	1	*57.1298
4	2005	*0.8000	*0.9362	39.3287	2	82.6573	0.8627	41.7586	1	85.5172
5	04/05	0.5385	0.5833	58.8227	2	121.6455	*0.5600	58.9593	1	*119.9186
6	04/05	0.6000	0.8571	10.0811	2	24.1622	*0.7059	11.0448	1	*24.0897
7	2004	0.8000	0.8000	5.2054	2	14.4108	*0.8000	5.2054	1	*12.4108

* estimates with the smaller AIC.

Table A4a. List of numbers for SBT seeded tag data groups for *A* tags only (r_A), *B* tags only (r_A) and *A&B* tags (r_{AB}). (Note year refers to the last year in a season – i.e. 2003 indicates the 2003/2004 fishing season and 04-05 refers to the combined 2003/2004 and 2004/2005 seasons).

Group	Tagger	Year	r_A	r_B	r_{AB}	Total
I	1,2&3	2003				
	4&7	2004	12	8	84	104
II	3,5&6	04/05	26	37	56	119
III	4	2005	3	11	44	58

Table A4b: Comparison of estimates of tag retention rates for primary and secondary tags with the estimates of the rates under the assumption that rates are same for both tags by tagger groups defined in Table A4c. Also provided are the negative log-likelihood values and AIC statistics for the estimates under the two different assumptions.

	$Q_A \neq Q_A$					$Q_A = Q_A$			
Group	Q_A	Q_B	-LL	df	AIC	Q	-LL	df	AIC
I	0.913	0.875	64.374	2	132.747	0.894	64.776	1	*131.553
II	0.602	0.683	124.982	2	253.963	0.640	125.947	1	*253.894
III	0.800	0.936	39.329	2	*82.657	0.863	41.759	1	85.517

* Solution with the least AIC.

Table A4c. Estimates of the shedding factors (*W)*, their variances ((Var(*W*)), and standard errors, (SE(*W*)) by tagger groups for SBT seeded tags based on the model with the smallest AIC from Table A4b.

Group	*W*	Var(*W*)	SE(*W*)
I	1.0114	0.000030	0.0055
II	1.1489	0.001806	0.0425
III	1.0129	0.000137	0.0117