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Estimates of reporting rate from the Australian surface fishery based on previous tag seeding experiments and tag seeding activities in 2007/2008

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Abstract

A pilot tag-seeding project was conducted in 2002/2003 on purse seine 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, 2005/2006, 2006/2007 and 2007/2008 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 2007/2008 surface fishing season. In addition, results from the analysis of the data obtained from the 2002/2003, 2003/2004, 2004/2005, 2005/2006 and 2006/2007 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 7 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 38.1% of the fish were recovered. In 2005/2006 tag seeding took place for 32 of the 36 tow cages (a slight decrease on the previous year), and overall tags from 20.4% of the fish were recovered. During 2006/2007 fish were tagged and seeded into farms from 29 of the 33 tow cages, and overall tags from 33.8% of the fish were recovered. During 2007/2008 fish were tagged and seeded into farms from 29 of the 31 tow cages. Harvesting operations for 2007/2008 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, 2004/2005, 2005/2006 and 2006/2007 fishing seasons yielded estimates of weighted mean reporting rates across cages of 0.640 (s.e. = 0.062), 0.503 (s.e. =0.053), 0.396 (s.e. =0.029), 0.215 (se = 0.025), and 0.425 (s.e. = 0.037), respectively. However, further consideration of the 2005/2006 estimate suggests that the estimate may be biased downward by the results of an inexperienced tagger and that an estimate of 0.303 is more appropriate. The estimates of reporting rates show a declining trend over the first four years with an increase in 2006/07 to around the 2004/2005 level. The most critical statistical estimation issues that need further exploration include representativeness of the cages tagged (particularly in the first year) and potential lack of independence in the shedding between the two tags in a seeded fish. An experiment to test for the latter is recommended. A range of alternative reporting rate estimates are presented in order to evaluate the sensitivity of the seeding estimates to various assumptions. While uncertainty exists in the estimates of the reporting rate (as is inevitable in these kinds of tagging experiments), the estimate of the reporting rates from the tag seeding experiment appear to provide a reasonable basis for analysing the tag return data from the surface fishery

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 to explore and develop an approach for estimating reporting rates from the SBT farm sector.

After consideration of alternative approaches, 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 matters (particularly with respect to variance estimation and the estimation of shedding rates) needing further exploration. Polacheck et al. (2006) developed improved and more robust methods for the estimation of reporting rates and their variances from the tag-seeding data, and Hearn et al. (2007) provided estimates of reporting rates and associated variances from the Australian surface fishery for the 2002/2003 through 2005/2006 fishing seasons using these methods and reported on tag seeding activities during the 2006/2007 season. The purpose of the present paper is to update this and also provide estimates of reporting rates and associated variances from the Australian surface fishery for the 2006/2007 fishing season using these methods and report on tag seeding activities during the 2007/2008 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 agreed 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, 2005/2006, 2006/2007 and 2007/2008). 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 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, 2005/2006, 2006/2007 and 2007/2008 seasons 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

We here repeat the model developed in Polacheck et al. (2006). 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:

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

$\lambda_{h,j}$ = 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

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

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

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

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[1] Note that all tagging of seeded fish within any cage was done by only one tagger, but this method could readily be extended to the case of multiple taggers seeding a cage, provided that the tagger of each fish is recorded.

[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

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.

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:

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

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:

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

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 estimators (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 and 2005/2006 a large proportion of the actual tow cages were seeded.

(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.

Results

2007/2008 Tag Seeding

Information available at the time of this report indicates that fish were tagged and seeded into farms from 29 of the 31 cages in 2007/2008 or (94%). This was slightly more than the 89% and 88% levels achieved in 2005/2006 and 2006/2007 and the same as the 94% rate achieved in 2004/2005. Overall, for the last four years seeding rates have been generally and markedly improved from the 61% level achieved in the first full year of seeding. The failure to achieve 100% coverage is due to two companies unwilling to permit tag seeding in their cages for most years. As of July 1, few seeded tags have been returned to CCSBT 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 double-tagged seeded fish from which tags were returned, the number of these for which two tags were 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 (0.429) 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 and 2005/2006 season they show that the shedding rates were maintained (Table 1). Thus, compared to the 0.429 fraction of single tags in 2003/2004, the fraction declined to 0.375 in 2004/2005, but increased to 0.413 in 2005/2006. 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. A notable result in 2005/2006 has been the substantial improvement in the performance of tagger 5 (previously the lowest performing tagger with regard to the single tag fraction), with fractions of single tagged fish returned of 0.633, 0.583 and 0.400 in years 2003/2004, 2004/2005 and 2005/2006, respectively, which has markedly increased the precision of the estimate of the number of fish that have lost both tags during 2005/2006. This demonstrates that it is important to provide adequate training to all taggers, particularly the low performing ones. However, the fraction of single tagged fish returned for 2006/2007 has increased to 0.582, a disappointing result. This was mainly due to tagger 6, who had tagged only a relatively small number of fish previously and none in 2005/2006, but who tagged a large fraction of the seeded fish in 2006/07. This tagger is now the lowest performing tagger with regard to the single tag fraction, with a fraction of 0.712 single tagged fish returned.

Appendix 1 provides details of the method (from Polacheck et al. 2006) 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 four year/tagger groups in which the shedding rates are not statistically different for those releases within a group, but are statistically different among groups. The estimates of the shedding rates (i.e. the probability of any tag being lost) ranged from ~0.08 to 0.44 among the four different groups (Table 1A4b[5]). For the tagger group with the highest shedding rate (Group IV, which are from tagger 5 for 2003/2004 and 2004/2005, and from tagger 6 for 2006/2007) about 24% of the seeded tagged fish would have been expected to have lost both their tags. For the other groups (including tagger 5 for 2005/2006) less than 9% of the seeded tagged

[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.

fish would have been expected to have lost both their tags. In Polacheck et al. (2006) tagger group II was the highest shedding rate with about 13%, but this group included tagger 5 for 2003/2004 and 2004/2005. This discrepancy was due to the increase in data since 2006 which allows the data to be split into 4 groups by AIC, instead of 3 as in Polacheck et al. (2006). For this report the only differences from Hearn et al. (2007) have been the inclusion of results from 2006/2007 (Table A4a).

The results in Appendix 1 also indicate that the shedding rates are estimated with adequate to 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 than 8% for Group IV and no more than 2% for Groups I to III (Table A4c).

Reporting Rates

Table 2 lists the number of tagged seeded fish that were released, the number that were recovered by tow cage for each year and 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 0.550 and the weighted mean is 0.503 (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, it follows that the weighted estimates would be the most appropriate to be incorporated into the mortality models that analyze data from wild tagged fish.

We re-estimated the reporting rates with shedding rates assumed zero and the percentage decreases in the reporting rates were 2.0% for 2002/2003, 10.4% for 2003/2004, 8.0% for 2004/2005, 6.5% for 2005/2006, and 18.6% for 2006/2007. The lowest shedding rates associated with group I taggers were in 2002/2003, and the highest shedding rates associated with group IV taggers, were in 2003/2004, 2004/2005 and 2006/2007. The magnitude of the differences in the reporting rates corrected and uncorrected for shedding rates in the different years are in accordance with what would be expected based on the differences in the shedding rates. This demonstrates the importance of ensuring that sufficient numbers of fish are double tagged to be able to adequately estimate the shedding rate by tagger. In this regard, it is worth noting that although the overall shedding rates were the highest in 2006/2007, they did not result in a higher coefficient of variation associated with the reporting rate compared with other years. Nevertheless, striving to keep shedding rates low is important to ensure that estimates of reporting and shedding rates are not confounded – particularly situations in which zero or very low numbers of tags are returned and where there is dependence between the two tags on fish.

As reported in Polacheck and Eveson (2007), the low estimates of the reporting rates for 2005/2006 in Table 3 combined with the actual number of tags released results in some very high (and possibly unrealistic) estimates of the fishing mortality in 2006 for some ages and groups of releases. Polacheck and Eveson (2007) explored possible factors that could possibly be biasing the estimates of the reporting rates from the tag seeding data. Of the four factors identified, high rates of dependent initial shedding of both tags by an inexperienced tagger in this year possibly due to poor tag placement is a concern. This inexperienced tagger had little or no tag training. (He had not been part of the training provide prior to the fishing season). Nevertheless, he was used to tag a substantial number of tow cages in 2005/2006 (16 out of 32 cages in which seeding took place). In 9 out of the 16 cages in which this individual did the seeding, no seeded tags were recovered, and the overall recovery rate for seeded tags from this individual was 12%. In contrast, for the remaining 16 cages in which more experienced taggers did the seeding, only in 2 cages were there no returns of seeded tags and the overall return rate of seeded tags was 28%. In addition, comparison of the by-cage return rates for wild releases per 1000 fish with the by-cage return rates of seeded tags results in a negative correlation between these for 2005/2006 if all cages are included and a positive correlation if the cages in which this inexperienced tagged did the seeding are excluded. The cages in which the inexperienced tagger did seeding were spread across a range of different tuna farm operations and it appears that the low return rate for this tagger is unlikely to be related to the cages in which he tag seeded. All of this suggests that there was likely to have been high levels of dependent tag shedding for the seeded fish that were tagged by this inexperienced tagger (e.g. the tags were inserted poorly because of lack of experience and were shed rapidly after release).

Although there are some substantial differences in the shedding and reporting rates from individual taggers, initial examination of the data by tagger does not provide a clear basis for excluding the data for any of the other taggers based on the training provided. We would note, however, that among the other two taggers in 2005/2006 tagger 5 had less previous experience then tagger 4 and similarly for tagger 6 in 2006/07. In both cases, the reporting rates for the less experienced taggers were lower – 0.24 versus 0.50 in 2005/06 and 0.40 versus 0.47 in 2006/2007. However, while the somewhat lower rate in 2006/07 was associated with a reasonably high shedding rate for the more inexperienced tagger, this was not the case in 2005/2006. There are large differences in the reporting rates among cages, as large differences are evident in the reporting rates among cages seeded by the same tagger. Therefore, by random selection of cages, differences in reporting rates among taggers could be expected. Simply excluding data from taggers with lower reporting rates would be inappropriate and would lead to biased estimates.

Given the above, it would seem appropriate to exclude the data from the inexperience tagger in estimating the reporting rates in 2005/06. Table 4 provides revised sets of estimates in which the data from this tagger have been excluded.

Discussion

As discussed in Polacheck et al. (2006), 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) 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 different 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 the reporting rates[6]. This effect was greatest for the

[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.

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.

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. Note that the tagger (tagger 5 in 2003/2004 and 2004/2005) previously with the lowest retention rate (i.e. highest shedding rate) improved in 2005/2006 after training. However, the results of tagger 6 in 2006/2007 now yield the lowest retention rate, which is disappointing.

Between 2002/2003 and 2005/2006, the estimated variances for the annual reporting rates have progressively declined (Table 2). It increased in 2006/2007, but still remains low. This is primarily due to three reasons. 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 rates decreased markedly between 2004/2005 and 2005/2006 and then up again in 2006/2007, and high and uncertain shedding rates[7] 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 been rather steady (i.e. between 7.3% and 11.6% - Table 3). This mainly reflects the fact that the decline in the variances has occurred simultaneously with a decline in the reporting rate.

The estimates of the reporting rates progressively declined during the first four years of these experiments by an average of about 30% per year (i.e. from 0.640 in 2002/2003 to 0.503 in 2003/2004 to 0.396 in 2004/2005 and to 0.303 in 2005/2006 based on the weighted mean estimates, Table 4). Then the estimate bounced back to 0.425 in 2006/2007. This is of concern, as it leads to 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

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

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, 2004/2005, 2005/2006, and 2006/2007 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.

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 returned is the primary factor that 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. However, when reporting rates estimates reach the low level that were obtained in 2005/2006, the magnitude of the correction factors to account for unreported tags becomes so large that the reliability of the fishing mortality rate estimates based on such low reporting rates becomes a concern as the result of potential unaccounted source of variance and potential biases in reporting rate estimates.

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. For example, a near 100% reporting rate without a precise statistical knowledge of its value is of limited use in stock assessments. Several possible approaches were discussed in Hearn et al 2007 and the reader is referred to that paper for details. However, we would stress the importance of work in this area and would note that increased promotional and liaison activities have been ongoing during the 2007/08 fishing season.

As noted above, the low reporting rate estimate for 2005/2006 raised the question of whether in fact the tag seeding results are providing unbiased estimates of the reporting rate (Polacheck and Eveson 2007). Although removing the inexperienced tagger increased the reporting for this year (Table 4), the rate was still substantially and significantly lower than that seen in the other years. In terms of the seeding experiments, the one factor that could potentially bias the results would be high levels of dependent shedding among the two tags within individual seeded fish. This would be a violation of the underlying independence assumption for estimating shedding rates from double tagging. In particular, the possibility exists that there may be relatively high initial shedding of both tags after seeding due to tags rubbing against the cage nets, etc. One way to test for this would be to conduct an experiment in which both single and double tagged fished are seeded into cages. Based on the results from the double tagged fish, the expected number of single tagged fish that should be recovered can be calculated if in fact the independence assumption has not been violated. If the actual number of single tag recoveries is significantly greater than the expected number, then this would indicate that the independence assumption did not hold. Given the importance of the reporting rate estimates for the interpretation to the tagging results, we would strongly recommend that the feasibility of such an experiment be investigated. We would note that such an experiment would entail additional seeding into the farm and would require the collaboration and permission of the fishing industry.

Given the importance of the reporting rate estimates for the overall interpretation of the tagging results, we have calculated a range of alternative estimates in order to get an indication of the robustness of the estimates:

A1- Best estimate from the tag seeding results (Table 3)

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

A3 – estimates based only on Tagger 4; the most consistently used tagger and also one with extensive experience.

A4 - assumes reporting rates have been constant and uses the rate of return from the re-release of wild tagged fish from the 40 fish samples as an estimate of the reporting rate (see Polacheck and Eveson, 2007 for details).

A5 - assumes reporting rates were the same in 2002/2003 to 2003/2004 and 2004/2005 to 2005/2006 and uses the rate of return from the re-release of wild tagged fish from the 40 fish samples for these two periods to estimate the reporting rates (see Polacheck and Eveson, 2007 for details).

Table 5 provide the estimates for these five options. Despite the differences among the values in Table 5, they still suggest that the estimates are relatively robust in that overall they suggest that they have been around 0.50 but with a declining trend. In this regard, the re-release of wild tag fish into the farms are highly informative as there are no issues with respect to shedding, lack of independence, tagger-experience or differential reporting rates of seeded and wild tagged fish. As such, while uncertainty exists in the estimates of the reporting rate (as is inevitable in these kinds of tagging experiments), the estimates of the reporting rates from the tag seeding experiment would appear to be providing a reasonable basis for analysing the tag return data from the surface fishery

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Table 1: Summary of the number of tag returns for double-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	0.14
	2	6	5	0.17
	3	16	13	0.19
2003/2004	3	22	11	0.50
	4	40	31	0.23
	5	30	11	0.63
	6	7	3	0.57
	7	6	4	0.33
2004/2005	3	33	18	0.45
	4	67	49	0.27
	5	24	10	0.58
	6	4	3	0.25
2005/2006	4	19	11	0.42
	5	25	15	0.40
	10	19	11	0.42
2006/2007	4	46	26	0.43
	6	52	15	0.71

Table 2: Summary of tag returns by tow cage for the 2002/2003, 2003/2004, 2004/2005, 2005/2006 and 2006/2007 tag seeding experiments, including single-tagged fish (except one cage where no tag shedding information was available).

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	2	33
	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	11	2	18
	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	10	2	20
	12	4	10	3	30
	13	5	10	1	10
	14	5	10	6	60
	15	4	10	3	40
	16	5	10	5	50

Table 2 (continued)

Year	Cage	Tagger	No. Tagged	No. Returned	% Returned
2004/2005	17	5	10	4	40
	18	4	10	8	80
	19	4	10	4	30
	20	4	10	8	80
	21	4	10	4	40
	22	6	10	2	20
	23	4	10	5	50
	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	3	30
	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
2005/2006	1	4	10	6	60
	2	4	10	3	30
	3	4	10	3	30
	4	4	10	7	70
	5	5	12	1	8
	6	5	10	2	20
	7	5	10	3	30
	8	5	8	0	0
	9	5	10	2	20
	10	5	10	4	40
	11	5	10	1	10
	12	5	10	1	10
	13	5	10	0	0
	14	5	10	1	10
	15	5	10	10	100
	16*	5	19	4	21
	17	10	10	0	0
	18	10	10	1	10
	19	10	10	0	0
	20	10	10	0	0
	21	10	9	4	44
	22	10	10	0	0
	23	10	10	6	60
	24	10	10	4	40
	25	10	10	0	0
	26	10	10	0	0

Table 2 (continued)

Year	Cage	Tagger	No. Tagged	No. Returned	% Returned
2005/2006	27	10	10	1	10
	28	10	10	2	20
	29	10	10	0	0
	30	10	10	0	0
	31	10	10	0	0
	32	10	10	1	10
2006/2007	1	4	10	8	80
	2	4	10	3	30
	3	4	10	2	20
	4	4	10	3	30
	5	4	10	4	40
	6	4	10	4	40
	6	6	1	0	0
	7	4	10	1	10
	8	4	10	1	10
	9	4	10	7	70
	10	4	10	6	60
	11	4	10	7	70
	12	6	10	0	0
	13	6	10	0	0
	14	6	10	2	20
	15	6	10	0	0
	16	6	10	5	50
	17	6	10	1	10
	18	6	10	4	40
	19	6	9	5	56
	20	6	10	1	10
	21	6	10	6	60
	22	6	10	1	10
	23	6	10	4	40
	24	6	10	2	20
	25	6	10	7	70
	26	6	10	7	70
	27	6	10	0	0
	28	6	10	5	50
	29	6	10	2	20

* 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 2006/2007.

Year	Unweighted $\hat{\lambda}$	Unweighted $\text{Var}(\hat{\lambda})$	Unweighted $\text{SE}(\hat{\lambda})$	Unweighted CV %	Weighted $\hat{\lambda}$	Weighted $\text{Var}(\hat{\lambda})$	Weighted $\text{SE}(\hat{\lambda})$	Weighted CV%
2002/2003	0.652	0.00498	0.071	10.9	0.640	0.00383	0.062	9.7
2003/2004	0.550	0.00268	0.052	9.5	0.503	0.00286	0.053	10.5
2004/2005	0.417	0.00082	0.028	6.7	0.396	0.00085	0.029	7.3
2005/2006	0.218	0.00059	0.024	11.0	0.215	0.00065	0.025	11.6
2006/2007	0.411	0.00124	0.035	8.6	0.425	0.00134	0.037	8.6

Table 4: "Best" estimates of reporting rates, their variances and standard errors for the Australian surface fishery for years 2002/2003 to 2006/2007 based on the tag seeding experiments (see text for detail).

Year	Weighted $\hat{\lambda}$	Weighted $\text{Var}(\hat{\lambda})$	Weighted $\text{SE}(\hat{\lambda})$	Weighted CV%
2002/2003	0.640	0.00383	0.062	9.7
2003/2004	0.503	0.00286	0.053	10.5
2004/2005	0.396	0.00085	0.029	7.3
2005/2006	0.303	0.00294	0.054	17.8
2006/2007	0.425	0.00134	0.037	8.6

Table 5: The set of alternative *ad hoc* reporting rate estimates considered for the surface fishery. See text for detail.

Reporting Rate Vector	2002/2003	2003/2004	2004/2005	2005/2006	2006/2007
A1	0.64	0.50	0.40	0.30	0.43
A2[1]	1.00	0.78	0.63	0.47	0.67
A3	-	0.63	0.34	0.50	0.47
A4[2]	0.45	0.45	0.45	0.45	0.45
A5[2]	0.67	0.67	0.37	0.37	0.37

1) These are calculated by assuming that the reporting in 2002/2003 is 100% and that seeded tags not reported after release are due to shedding of both tags shortly after seeding. This yields a scaling factor of 1.563 for the reporting rate in that year which is used to scale up the weighted reporting rates in the other years.
2) Updated from Polacheck and Eveson (2007) to reflect the fact that 12 wild tagged fish were captured and released into farm cages during the 40 fish sampling from the Australian surface fishery in 2006/2007 and tags from 5 of these were subsequently recovered.

Appendix 1: Estimation of Shedding in the Tag Seeding Experiments

William Hearn

We use the shedding model given in Polacheck et al. (2006, Appendix 1) that is repeated below. 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, $Q_A(1\text{-}Q_B)$, Q_B $(1\text{-}Q_A)$, and $(1\text{-}Q_A)(1\text{-}Q_B)$, 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 $-LL = -\ln(\Lambda)$ (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 (the minimum AICs are marked with * in Table A2). Tagger 3 tagged over three years, i.e. 2002/2003 through 2004/2005. In Table A2 for tagger 3, the AIC for the pooled 2002/2003, 2003/2004 and 2004/2005 data is 138.529 which is smaller than the sum of the AICs for each of the separate 2002/2003, 2003/2004 and 2004/2005 data sets, namely 140.853. However, the sum of the AIC for the pooled 2003/2004, 2004/2005 data sets and the AIC for the 2002/2003 data set, i.e., 137.991, is lower still. Therefore, the data for 2003/2004 and 2004/2005 are pooled before analyses, but the 2002/2003 data are analysed separately, which is in agreement with the findings of Polacheck et al. (2006).

For tagger 4 the AIC for the pooled 2003/2004, 2004/2005, 2005/006 and 2006/2007 data is 295.665, which is smaller than the sum of the separate AICs for each of the 2003/2004, 2004/2005, 2005/006 and 2006/2007 data sets, i.e. 296.822. However, the sum of the AIC for the pooled 2003/2004, 2004/2005 and 2005/2006 data and the AIC for the 2006/2007 data is 295.206, which is lower still. Therefore, the data for 2003/2004, 2004/2005 and 2005/2006 data sets are pooled before analyses, but the 2006/2007 data are analysed separately.

For tagger 5, the AIC for the pooled 2003/2004, 2004/2005 and 2005/2006 data is 172.484, which is smaller than the sum of the separate AICs for the 2004/2005, 2005/2006, and 2005/2006 data sets, of 175.307. However, the sum of the AIC of the pooled 2003/2004 and 2004/2005 data and the AIC of the 2005/2006 data set, namely 171.513 (Table A2) is smaller still. Therefore, the shedding rates of tagger 5 significantly changed (in fact reduced) in 2005/2006 (Table A3), likely due to training.

For tagger 6, the AIC for the pooled 2003/2004, 2004/2005 and 2006/2007 data is 142.330, which is lower than the sum of AICs for each of the 2003/2004, 2005/2006 and the 2006/2007 data sets, namely 144.304. However, the sum of the AIC of the pooled 2003/2004 and 2004/2005 data, and the AIC for the 2006/2007 data set, namely 141.908, is even lower. Therefore, the shedding rates of tagger 6 significantly changed in 2006/2007. In fact they increased (Table A3), which is disappointing. For all taggers other subsets of yearly groupings were investigated, but no lower AICs than those above were found.

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 the model $Q = Q_A = Q_B$ gave the best fit, i.e. lowest AIC. The data are pooled into 4 groups in Table A4a, group I if $Q > 0.85$ (see Table A3), group II if $0.80 \leq Q < 0.85$, group III if $0.65 \leq Q < 0.80$, group IV if $Q < 0.65$, which gives the least AIC. The numbers of returns in groups I-IV 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 all data groups.

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 $\mathrm{Var}(\hat{W}_j)$, conditional on the number of returned seeded tagged fish r_T, to allow an estimate of $\mathrm{Var}(\hat{\lambda}_{hj})$ 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 equation above. The variance of W_j is then estimated as

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

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 precise (i.e. coefficient of variations of less then 8%). 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. For tagger group IV (i.e. tagger 5 for 2003/2004 and 2004/2005 and tagger 6 for 2006/2007) with the highest shedding rate (i.e. a 49% probability that a tag will be shed), ~24% of the seeded tagged fish would have been expected to have lost both tags (i.e. 1-1/(1.32)). However, for other groups (which includes tagger 5 for 2005/2006) the expected fraction losing both tags is expected to be less than 9%.

It should be noted that for cage 7 in 2002/2003 all 38 fish that were seeded into it 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 the same 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. Also in cage 14 in 2003/2004 all seeded tags were single releases and in this one case two taggers were doing the tagging. For one of these we have no data for double-tagged fish so we excluded his data and analysed the remaining data in the same way as data from cage 7 in 2002/2003. Again in cage 17 in 2005/2006 all seeded tags were single releases, which were analyzed in the same way.

Table A1: The number of seeded double-tagged 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. 2004 indicates the 2003/2004 fishing season, 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	8	18	33
	03-05	11	18	42	71
`	04-05	10	16	29	55
4	2004	6	3	31	40
	2005	5	13	49	67
	2006	4	4	11	19
	2007	11	9	26	46
	04-07	26	29	117	172
	04-06	15	20	91	126
5	2004	9	10	11	30
	2005	6	8	10	24
	2006	7	3	15	25
	04-06	22	21	36	79
	04-05	15	18	21	54
6	2004	1	3	3	7
	2005	0	1	3	4
	2007	19	18	15	52
	04-07	20	22	21	63
	04-05	1	4	6	11
7	2004	1	1	4	6
10	2006	5	3	11	19

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. 2004 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	33.101	2	70.202	64.427	6	140.853
	03-05	67.265	2	138.529	67.265	2	138.529
	2003	9.631	2	23.262			
	04-05	55.364	2	114.729	64.995	4	*137.991
4	2004	27.055	2	58.110			
	2005	49.624	2	103.247			
	2006	18.477	2	40.954			
	2007	45.255	2	94.510	140.411	8	296.822
	04-07	145.833	2	295.665	145.833	2	295.665
	04-06	98.348	2	200.696			
	2007	45.255	2	94.510	143.603	4	*295.206
5	2004	32.858	2	69.716			
	2005	25.861	2	55.723			
	2006	22.934	2	49.868	81.653	6	175.307
	04-06	84.242	2	172.484	84.242	2	172.484
	04-05	58.823	2	121.645			
	2006	22.934	2	49.868	81.757	4	*171.513
6	2004	7.030	2	18.059			
	2005	2.249	2	8.499			
	2007	56.873	2	117.746	66.152	6	144.304
	04-07	69.1649	2	142.330	69.165	2	*142.330
	04-05	10.081	2	24.162			
	2007	56.873	2	117.746	66.954	4	141.908

* 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. 2004 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	17.871	2	39.742	*0.9254	17.972	1	*37.742
2	2003	1.000	0.8333	2.703	2	9.406	*0.9091	3.397	1	*8.793
3	2003	0.8667	0.9286	9.631	2	23.262	*0.8966	9.801	1	*21.601
3	04-05	0.6444	0.7436	55.364	2	114.729	*0.6905	56.063	1	*114.126
4	04-06	0.8198	0.8585	98.348	2	200.696	*0.8387	98.706	1	*199.413
4	2007	0.7647	0.7027	45.255	2	94.510	*0.7222	45.355	1	*92.711
5	04-05	0.5385	0.5833	58.823	2	121.645	*0.5600	58.959	1	*119.919
5	2006	0.8333	0.6818	22.934	2	49.868	*0.7500	23.757	1	*49.514
6	04-05	0.6000	0.8571	10.081	2	24.162	*0.7059	11.045	1	*24.090
6	2007	0.4545	0.4412	56.873	2	117.746	*0.4478	56.886	1	*115.773
7	2004	0.8000	0.8000	5.205	2	14.411	*0.8000	5.205	1	*12.411
10	2006	0.7857	0.6875	18.225	2	40.449	*0.7333	18.477	1	*38.954

* 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. 2004 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	5	4	49	58
II	7&	2004				
	4	04-06	16	21	95	132
III	5,10,	2006				
	4,	2007				
	3&6	04-05	34	35	87	156
IV	5&	04-05				
	6	2007	34	36	36	106

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 A4a. 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	0.925	0.907	31.214	2	66.428	0.916	31.270	1	*64.540
II	0.819	0.856	103.615	2	211.230	0.837	103.954	1	*209.908
III	0.713	0.719	154.910	2	313.820	0.716	154.917	1	*311.835
IV	0.500	0.514	116.415	2	236.830	0.507	116.443	1	*234.887

* Solution with the least AIC.

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

Group	*W*	Var(*W*)	SE(*W*)	CV%
I	1.0071	0.000030	0.0055	0.5
II	1.0273	0.000092	0.0096	0.9
III	1.0877	0.000490	0.0221	2.0
IV	1.3210	0.009502	0.0975	7.4