Tag shedding and reporting rate estimates for Indian Ocean tuna using double-tagging and tag-seeding experiments

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Abstract

In this paper we present tentative estimates of tag shedding and reporting rates for yellowfin, bigeye and skipjack tuna in the Indian Ocean. The large-scale double-tagging program and the tag-seeding experiments in the Seychelles provide us with the relevant explanatory data. We use a pooled time-at-liberty model for the tag shedding process and employ Bayesian techniques to both efficiently estimate the parameters and explore the uncertainty in the parameters. For the estimates of reporting rate we have only probability of detection estimates for individual seeding experiments, and with too few samples to fully explore issues such as species and size class, but do see a clear year effect in the GLM models applied to these data.

Introduction

If we wish to integrate the mark-recapture information into any sort of abundance estimator or stock assessment model then we need to have reasonable estimates of both how well tags are detected/reported when recaptured commercially and also, given the type of tags placed on the animals, the manner in which the tags can be lost from the tagged animal over time. For any abundance or exploitation rate estimates based on tag data we need to know both how many tagged animals are still at liberty and how many were recaptured in total, not just those reported. For these reasons the usability of these data with respect to estimating stock status and size relies on our ability to estimate these key effects. Clearly, other factors such as tag-induced mortality or changes in growth behaviour due to tagging (Agnew et al, 2006) can also be key factors but both these factors are not assumed to be an issue with respect to the Indian Ocean tuna species considered.

Double-tagging for estimating tag shedding rate

Materials and methods

During the main phase of the Indian Ocean Tuna Tagging Programme, the Regional Tuna Tagging Project – Indian Ocean, a proportion of the fish was double tagged in order to be able to estimate tag-shedding rate. The technique for double tagging is the same a for single tagging with the difference that a second tag is inserted on the other side of the second dorsal fin of the tagged tuna, making sure that the anchor of the second tag was not damaging the first one. This operation was done on days or for tag series preliminary chosen by the Cruise Leaders on both pole-and-line chartered for the projects.

During the RTTP-IO, 168 163 tuna had been tagged and released (54 663 YFT, 34 570 BET, 78 324 SKJ and 606 unidentified tuna). Of this, an 19,5% of the YFT, 21,8% of the BET and 12,3% of the SKJ, giving an overall of 16,5%, were double tagged.

Estimating tag shedding properties

Numerous papers have been published on the subject of tag shedding behaviour (Hampton and Kirkwood, 1990; Xiao, 1996; Adam and Kirkwood, 2001). Almost always the process of tag shedding is measured as a two-step process: **Type I shedding** – where there is an instantaneous chance of losing the tag(s) placed on the animal; **Type II shedding** – where the loss of tags after this initial shedding event is linked in some way to the time-at-liberty.

Most models of continuous tag loss usually consider the tag retention probability over time in the following manner:

$$\pi^{ret}(\tau) = \varphi \exp(-\eta\tau), \qquad (1)$$

where τ is the time-at-liberty, φ is the instantaneous (Type I) shedding proportion and η is the tag shedding rate. The obvious assumption made in Eq. (1) is that, after the initial Type I tag loss, the tag retention probability decreases exponentially with time-at-liberty. Obviously, one could relax this exponential loss rate to a more gentle algebraic loss rate but the principle of continuous-time tag shedding models is that there is some functional relationship (usually monotonically decreasing) between tag retention probability and time-at-liberty.

The second commonly seen model for tag loss is the pooled time-at-liberty approach: a partition of time periods is defined over which we define a suitable tag loss/retention probability. For a given time partition for time-at-liberty:

$$\tau \in \{\tau_1, \ldots, \tau_N\} \qquad (2)$$

we then estimate the probability that a tag would be retained in each member of the partition, $\pi_{\tau_i}^{ret}$, so that the probability of retaining a tag to time-at-liberty τ is simply given by the following product:

$$\pi^{ret}(\tau) = \prod_{i=1}^{\tau-1} \pi_i^{ret} \; . \qquad (3)$$

One potential advantage of this type of model over the continuous time shedding model is that we place no constraint on the temporal nature of the tag retention – no constant decrease or increase in tag retention is imposed. However, this can also be considered something of a flaw of the model as well:

We require sufficient data so that we have a suitable number of tag shedding observations in each member of the time-at-liberty partition, so the abundance of data will dictate the resolution of the partition and the accuracy of the predicted tag retention probabilities. For our analyses we chose to work with the pooled time-at-liberty paradigm, for reasons that will hopefully become clearer as we detail the results.

Model for tag retention probability

The paper by Xiao et al. (1996) presented an exhaustive and detailed model for essentially the whole tagging process, integrating fishing and natural mortality, emigration, tag shedding and tag reporting into one estimation framework. In this work we merely develop the tag shedding ideas seen in that paper a little and use Bayesian techniques to efficiently estimate the parameters and their associated uncertainty. We used the recapture data of double-tagged tunas as the basis of our data set, using only at-sea and Seychelles based recoveries and those recoveries marked as being reliable, in terms of length at recapture and time-at-liberty. For each period in the time-at-liberty partition we would expect to have recaptures of fish with both tags still attached, one tag still attached and no tags attached – this final event is, however, for all intents and purposes unobservable. So in each period we have a number of still double-tagged fish (*DT*), single-tagged fish *(ST)*, and fish with both tags lost *(NT)*. Each of these potential outcomes has an associated probability of occurrence, so we can model the tag retention process as a multi-nomial process:

$$p(DT, ST, NT \mid \pi_D, \pi_S, \pi_N) = \frac{(DT + ST + NT!)}{DT!ST!NT!} \pi_D^{DT} \pi_S^{ST} \pi_N^{NT}. \tag{4}$$

There are several assumptions made when using this sort of model – we are assuming that losses of tagged animals to natural and fishing mortality are not influenced by having two, one or no tags attached, so that the differences in the numbers of double/single/none-tagged animals is purely a result of tag loss properties, not differential catchability effects between these three groups of animals. Also, we assume that an animal with two tags attached is just as likely to be reported as one with only one tag attached. Somewhat obviously, one would expect that $NT = 0$ – we may well recapture animals that have lost both their tags but we would not be able to identify such animals, giving them zero sample size. This somewhat helpfully reduces the extent of the model seen in Eq. (4) as the *NT* terms simply disappear. By making some further assumptions we can reduce the model complexity down even further: If we assume that the probabilities of retaining one tag or another on a double-tagged animal are equal and independent, then we can express the problem in terms of one probability as follows:

$$p(DT, ST \mid \pi^{ret}) = \frac{(DT + ST)!}{DT!ST!} (\pi^{ret})^{DT} \times (1 - \pi^{ret})^{ST}, \tag{5}$$

which is really just a binomial model when we consider the number of trials as the total number of double-tagged animals recaptured and observed with either one or both tags still attached, and the number of successes as the number of tags found with both tags still attached. By assumption, the probability of losing both tags is $(1-\pi^{ret})^2$. We use a Bayesian approach to estimating the tag retention probabilities, for each time period in the partition, and we assume that the prior distribution of the retention probabilities follows a beta distribution:

$$p(\pi^{ret}) = \mathrm{B}(\alpha,\beta) = \frac{\Gamma(\alpha+\beta)}{\Gamma(\alpha)\Gamma(\beta)}\left(\pi^{ret}\right)^{\alpha-1}\left(1-\pi^{ret}\right)^{\beta-1}, \qquad (6)$$

where Γ is the Gamma function. The reason for assuming this form for the prior is that this distribution is *conjugate* to the binomial distribution – by this we mean that the resultant posterior distribution is of a known form and is, in fact, a beta distribution:

$$p\left(\pi^{ret} \mid DT, ST, \alpha, \beta\right) = \mathrm{B}(\alpha + DT, \beta + ST). \qquad (7)$$

This now makes it incredibly simple to estimate all the relevant statistical properties of the retention probabilities as the beta distribution is a well known closed-form distribution.

Defining the time-at-liberty partition

Clearly, to apply the pooled time-at-liberty model detailed in Eqs. (4-7) we need to first define a time-at-liberty partition. This is, by its very nature, subjective and very much influenced by the resolution and amount of data at hand. For all three species we have a fairly large set of observations with which we can attempt to estimate tag retention behaviour. It is more than reasonable to suspect that there will be both type I and II shedding going on for all three species, and so the choice of the length of the initial time partition should be chosen to be short enough so that we can account for the potential for type I shedding. Also, we must chose the rest of the partition in such a way as to be able to both display the potential time trends in type II shedding and efficiently use the number of observations we have available. After inspection of the double-tagging data we chose the following illustrative time-at-liberty partition: 0-30 days, 30-100 days, 100-200 days, 200-300 days, 300-700 days. The final element in the partition was chosen to be so long compared to the others as we lacked the data to define a more detailed long-term partition as the number of recaptures is very low after 1 year at liberty. It should be noted that we also lack the data with which to estimate length-specific retention probabilities and all the data refer to all the observed length classes. Tables 1(a) to (c) show the relevant observations for this tag partition for all three species.

Table 1 (a) Yellowfin, (b) Bigeye, and (c) skipjack tuna double tagging data, in terms of number of animals recapture with on or both tags still attached, for the given time-at-liberty partition.

(a)

τ	0-30	30-100	100-200	200-300	300-700
DT	29	227	308	208	228

ST	4	11	28	14	30

(b)

τ	0-30	30-100	100-200	200-300	300-700
DT	19	104	183	155	110
ST	0	1	7	2	4

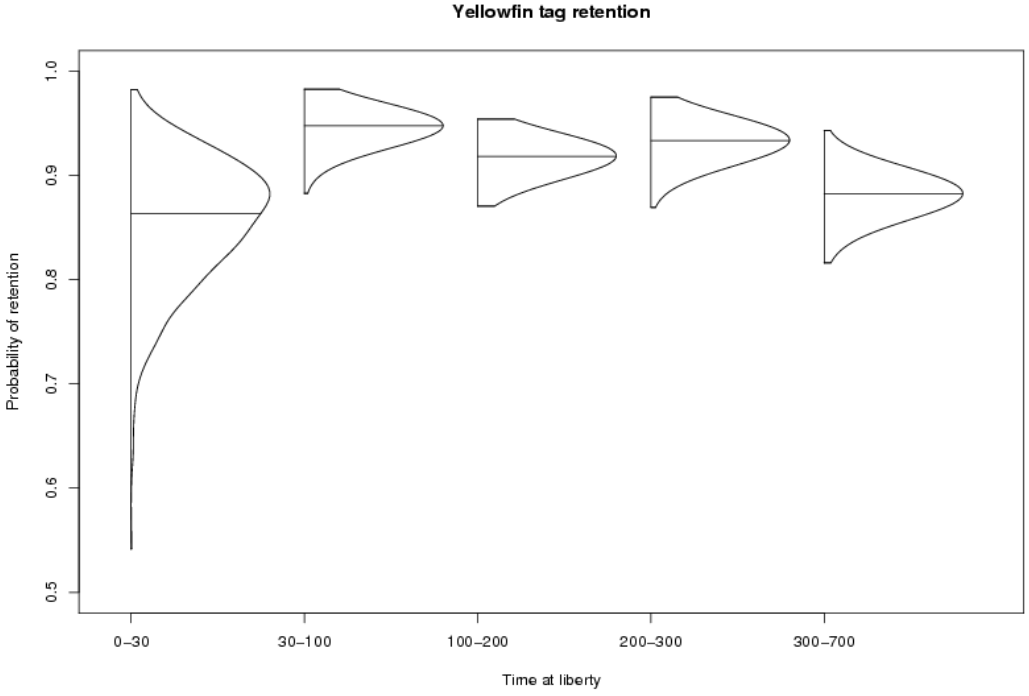
(c)

τ	0-30	30-100	100-200	200-300	300-700
DT	50	183	275	198	190
ST	2	6	8	4	4

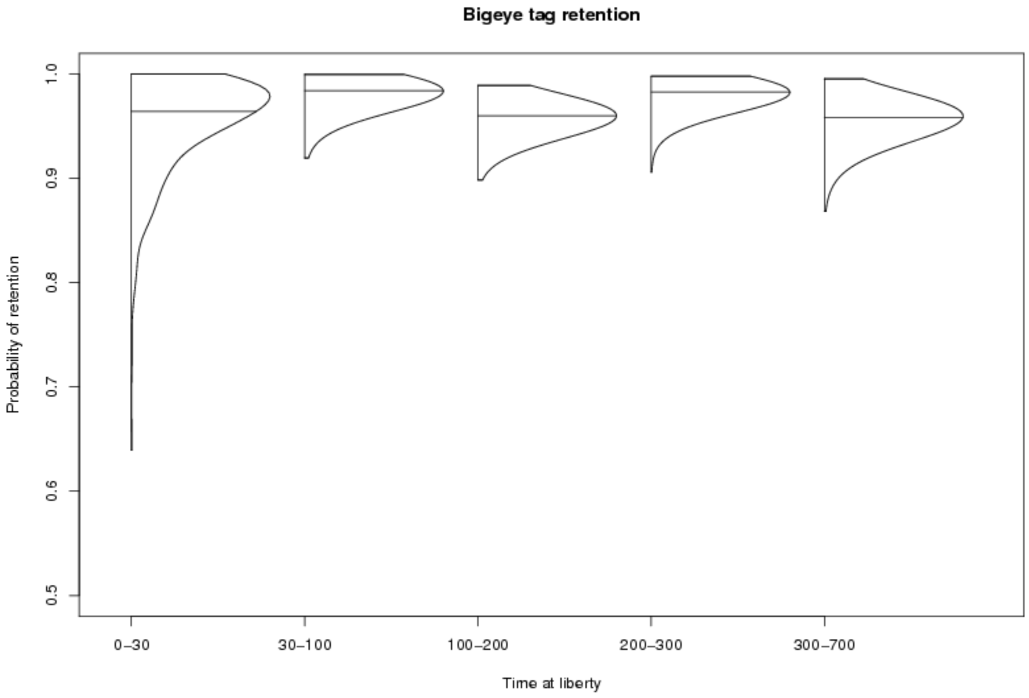
For the prior parameterisations for the retention probabilities, we chose $\alpha=\beta=1$ which corresponds to a uniform prior on the unit interval, chosen to be a quasi non-informative prior so that the information in the data should dominate the parameter estimates. Figure 1 (a) to (c) shows the resultant posterior distributions for the tag retention probabilities for each of the members of the time-at-liberty partition.

Figure 1 (a) yellowfin, (b) bigeye, and (c) skipjack tag retention posterior distributions for the time-at-liberty partition. The posterior density and the median (horizontal line) are displayed.

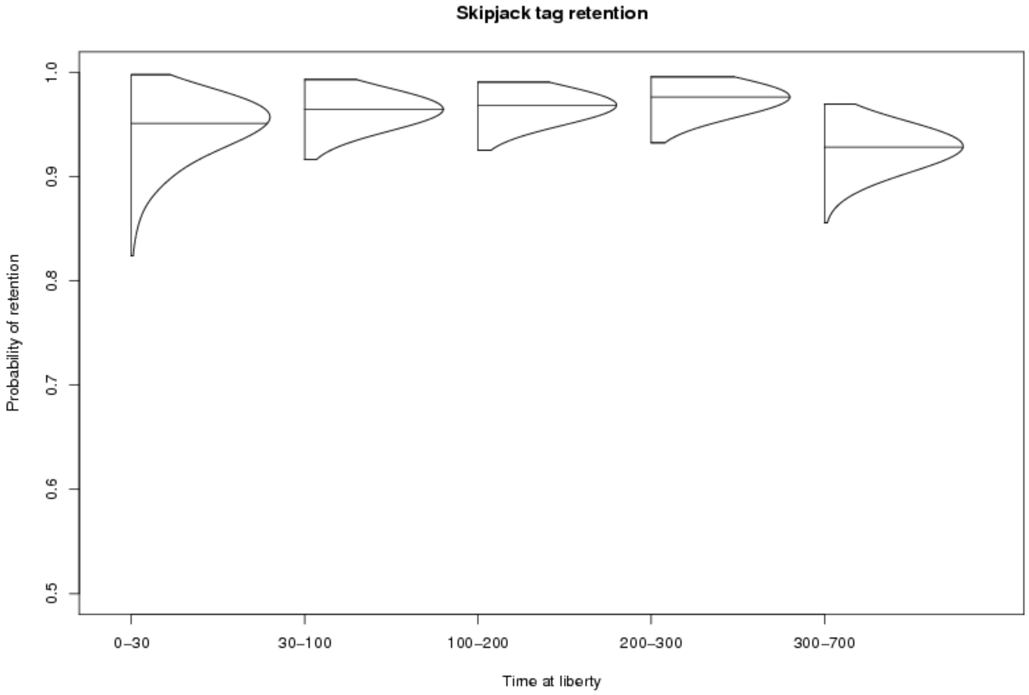
(a)



(b)



(c)



There are some general conclusions that can be made about the retention of tags, with respect to all three species: in all cases, the probability of tag retention in the first 30 days is lower than the retention probability at 30-100 days-at-liberty, suggesting that there is indeed type I shedding going on for all species. For yellowfin this effect seems strongest, but is also highly uncertain, given the small amount of samples; for bigeye there was no observed shedding of tags in this period, but there were only 19 recaptures of double-tagged fish so the posterior estimate has its mode very close to 1 but with a wide spread; for the skipjack, somewhat unsurprisingly, we had many more recaptures at this short time-at-liberty, with few observed shedding incidents and a high tag retention probability. At least for skipjack, we see a pattern whereby the probability of tag retention increases as we leave the type I 'period' and enter what would be assumed to be the type II shedding phase, only decreasing for the last period in the partition, which is over a year long. The mean probability of retaining a tag up to 1 year at liberty is around 0.85.

At least for skipjack, Adam and Kirkwood (2001) used a continuous time-at-liberty model and the exponential decay function seen in Eq. (1) to estimate the tag shedding dynamics for tagged animals caught in the Maldives pole-and-line fishery. Clearly, the initial exploratory modelling undertaken here for skipjack would not seem to support that choice of model (see Figure 1 (c)) but we can perhaps compare the magnitudes of tag loss expected between the two models. At least for the type I shedding probability, the estimate from Adam and Kirkwood (2001) was $\varphi = 0.97$ (0.91-1); from our work the median and 95% credible interval of the probability of retaining a tag from 0-30 days (our proxy for type I shedding) was $\pi^{ret}_{0-30} = 0.95$ (0.88-0.99). For 6 months at liberty, the estimates from Adam and Kirkwood (2001) suggest a probability of tag retention of 0.87; using our pooled probability of retention model we would predict a median and 95% credible interval of 0.89 (0.82-0.94). There seems to be good agreement, at least in terms of median predictions made here and MLE estimates from the previous work

For yellowfin and also for bigeye we see a similar increase in the retention probability as we move into the type II region but we see a noticeable decrease in the retention of tags at 100-200 days-at-liberty and then a subsequent increase for 200-300 days-at-liberty. For both yellowfin and bigeye we used a Kolmogorov-Smirnov test to assess the significance with which the posterior distributions differed in these two periods and the difference was highly significant ($p < 0.0005$) for both species, but not for skipjack. One can see this effect by simple inspection of the data in Tables 1 (a) and (b) where we see an increase in the proportion of single-tagged fish being recaptured in this 100-200 period that then decreases again at 200-300 days.

We cannot, as yet, offer any satisfactory explanation as to why this might be happening – we lack the data to really look at potential issues such as tagger effects and length/location/season-at-release effects. It is unlikely to be a tagger effect, given its appearance so clearly in the yellowfin and bigeye but no the skipjack data – there was no obvious difference between the taggers used when tagging the different species. If it is a spurious result, driven by a combination of effects as described then we really lack the available data with which to both identify the cause and account for its presence in the current scheme. If it is not a spurious result then it is a very confusing one. None of the species exhibit the continuous (monotonic) decrease in tag retention with time-at-liberty – indeed for skipjack retention actually seems to increase on the whole from 0-300 days-at-liberty.

Estimating the reporting rate of tags in the Seychelles recaptures

Materials and methods

During a tagging experiment, once a tagged fish is recaptured, it can be either:

- detected and reported,
- detected and not reported or
- not detected.

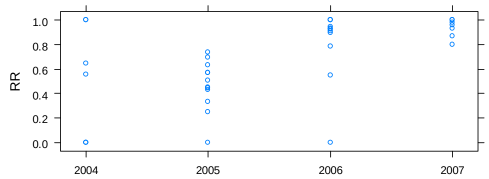
And this could influence greatly the total number of fish being recapture. In order to estimates this number, the number of recoveries being reported to the project needs to be corrected with a Reporting Rate for a particular recovery plateform.

To estimate the tag reporting rate for a specific tag recovery platform is a key issue to be able to analyse tagging data in assessing the real number of fish recaptured by the said platform. Unfortunately, estimating the tag reporting rate is not always trivial and cannot be done for all the fisheries. Tag reporting rate can be estimated from tag seeding experiment (Youngs, 1974 ; Green *et al.*, 1983 ; Campbell *et al.*, 1992, Hampton, 1997) ; by comparison of the tag return rate for a platform with those of a control group reporting *a priori* all recoveries – such as observers , or finally by observations of recoveries at different stage of catch handling or processing (Hillborn, 1988).

Within the framework of the IOTTP, the IOTC has conducted since 2004 a tag seeding experiment onboard the Purse-Seine fleet based in Seychelles, during which tuna caught by those Purse-Seiners were discreetly tagged by fisheries observers or voluntary skippers before the fish were placed in the brine wells. The tag used were almost similar to the ones used for the tagging and release of live fish. In order not to alter the dectection by the stevedores unloading the boat, or the workers processing the fish, the leader of the tag was strictly the same as for the other tag with the same printing. The only difference resides in the attachment of the tag which differes fomr the plastic barb used on the normal tags. Seeding tags are implanted on dead fish, as a result the anchorage of the tag within the pterigyophores is not secure by the healing of the fish around the attachment. To avoid rapid shedding, metal attachments were used, securing a better anchorage within the flesh of the fish. The tags were implanted in the same location on the fish, at the basis of the second dorsal fin. During each trip, 15 tags and one applicator was provided to the tagger who was asked to tag the three species in different wells and to spread the tag within different size categories. As a result, since 2004, 1102 SKJ, 1178 YFT and 226 SKJ have been seeded within the fleet. In This paper, only the one reported by stevedore in Seychelles have been accounted for, in order to have an estimation of the reporting rate for the recovery platform “purse-seiner unloaded in Seychelles”. Differences of reporting rate per year, per size category and per tagger - observers and skippers- were investigated through a Generalized Linear Model (Nelder, J. And Wedderbum, R. 1972) for the tags unloaded in Seychelles.

Estimating tag reporting

For the three species, the trend of the reporting rate since the implementation of the tag seeding experiment seemed to have increased every year (figure 1).



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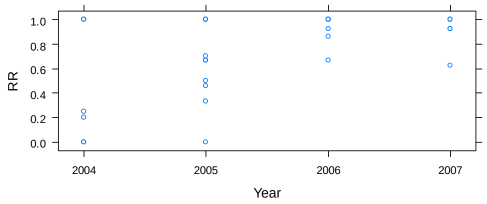

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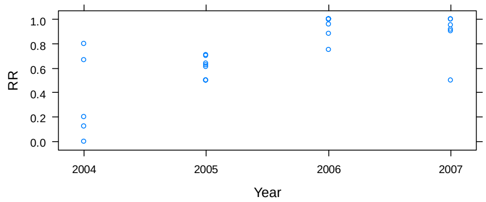

c

Several parameters could influence this trend such as the size of the fish which will influence their handling at unloading, the time as the reporting rate will be influenced by the publicity campaigns which have been developed since 2005. Also, there was a need to verify that the reporting rate was not depending on the type of tagger (skipper or observer). To measure these effects on the reporting rate, an analysis through a GLM has been implemented.

The model selected for the analysis of the data was as follow:

$$\ln(RR/(1-RR)) \sim Year + Size\_cat + Tagger$$

Three size categories were chosen close to the different commercial category used for the catch of the purse-seine fleet. The fish were categorized as less than 50cm (less than 3kg), between 50 and 80cm (between 3 and 10kg) and more than 80cm (more than 10kg). In fact, all the fish less than 3.4kg (54cm for skj, 56cm for yft and 53cm for BET) are commercialised under the same size category as skj. Only the larger fish are separated per species and might be sorted during the unloading. The analysis was done only on the unloading realised in Seychelles and all other unloading in Mombasa or Antsiranana were removed, in order to have the best estimate possible of the reporting rate for the catches of the purse-seine fleet unloaded in Seychelles.

The results of the GLM for both yellowfin and skipjack shows a significant effect of only one factor, the Year factor (Table 1 and 3). The bigeye analysis shows at first a significant effect of the tagger (Table 2a) which is probably due to the low number of samples being seeded by observers (25 bigeye being seeded by observers while 169 have been seeded by skippers). The same GLM analysis in which the factor Tagger is removed will also show a significant effect of the Year on the reporting rate for this species (Table 2b.).

Table 1. GLM results for the reporting rate of the seeded yellowfin

	Estimate	Std.Error	tvalue	Pr(>|t|)	
(Intercept)	-5257.6594	2452.9069	-2.143	0.0393	*
Year	2.6188	1.2236	2.140	0.0396	*
Size_cat	0.3416	1.5226	0.224	0.8238	
Tagger	4.4400	2.5028	1.774	0.0850	.

Table 2. GLM results for the reporting rate of the seeded bigeye for the three factors Year, size_cat and tagger (a) and for only two factors Year and Size_cat (b)

a.	Estimate	Std.Error	tvalue	Pr(>|t|)	
(Intercept)	-3076.256	3211.700	-0.958	0.3470	
Year	1.527	1.603	0.953	0.3495	
Size_cat	2.818	1.831	1.539	0.1359	
Tagger	7.608	3.467	2.194	0.0374	*

b.	Estimate	Std.Error	tvalue	Pr(>|t|)	
(Intercept)	-6635.903	2961.083	-2.241	0.0334	*
Year	3.308	1.476	2.241	0.0335	*
Size_cat	2.862	1.956	1.463	0.1550	

Table 3. GLM results for the reporting rate of the seeded skipjack

	Estimate	Std.Error	tvalue	Pr(>|t|)	
(Intercept)	-8460.8671	2120.9455	-3.989	0.000481	***
Year	4.2226	1.0578	3.992	0.000478	***
Size_cat	-0.8791	1.6565	-0.531	0.600129	
Tagger	-1.5131	2.2074	-0.685	0.499121	

From this analysis, only the year has a significant influence on the reporting rate of the tagged fish being unloaded in Victoria harbour. This could be explained by the fact, that since 2005 an extensive publicity campaigns have been implemented in Seychelles, targeting mainly the stevedores. Obsviously this campaign increased the awareness of the potential recoveres and in the same time increase the detection and the reporting of the tags.

Table 4. Reporting Rate per Species and per Year, estimated for the catch unloaded by the PS fleet in SeychelleS.

	RR2004	RR2005	RR2006	RR2007
YFT	61%	57%	89%	94%
BET	40%	56%	91%	95%
SKJ	37%	67%	92%	96%

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