An Updated Analysis of Tag-Shedding by Tropical Tunas in the Indian Ocean

By Daniel Gaertner [(1)] and Jean Pierre Hallier [(2)]

[(1)] IRD – UMR EME, CRH, BP 171, 34203 Sete Cedex, France

[(2)] Regional Tuna Tagging Project - Indian Ocean (RTTP-IO), Victoria, Seychelles

Summary

Tag shedding experiment was conducted during the Regional Tuna tagging Project-Indian Ocean by double-tagging part of the tuna released (27,850 double tags with 4,650 recoveries) with the objective of assessing the tag shedding rate (type-1 shedding (immediate shedding and tagging-induced mortality) and tag-2 shedding (continuous shedding and tag-induced mortality)). This rate was assessed by estimating α and λ of the probability of tag retention equation $Q(t) = \alpha\ [\beta/(\beta+\lambda t)]^{\beta}$). For SKJ α = 0.987, λ (per year) = 0.015; for YFT α = 0.977, λ (per year) = 0.041 and for BET α = 0.996, λ (per year) = 0.024. These results are comparable to others obtained from large-scale tropical tuna tagging project.

Introduction

The objective of this paper is to provide an update of the preliminary analysis of tag-shedding by tropical tuna in the Indian Ocean (Gaertner and Hallier, 2008). Estimate of tag-shedding is required for an estimation of fishing and natural mortality rates from tagging data. Tag shedding is of two types (Wetherall, 1982):

-Type-1 shedding includes immediate tag shedding, immediate tagging-induced mortality and failure to report recovered tags

-Type-2 shedding includes continuous tag shedding/mortality attributable to the tag, emigration away from the fishing ground, etc

In general shedding rates cannot be estimated directly from tag-return data. As a consequence, different methods have been proposed for estimating shedding rates using data from double tagging experiments. The aim of this paper is to update the preliminary analysis on shedding-rates by tropical tunas conducted by Gaertner and Hallier (2008). Since it was not evidenced in the previous study that factors such as the length of the tag (e.g., 11 cm and 14 cm length) or the position of the inserted tag (in the right side or in the left side of the fish) for originally double tagged fish may influence the return rate, the present analysis is devoted on (1) a comparison between a constant-rate model and a time-varying model (the integration of longer-term recovery periods should have modified the selection procedure of the best tag shedding model) and (2) an attempt to account for a tagger*cruise effect on parameter estimates (i.e., in addition to a tagger effect, the distance between the area were the tagging cruise took place to the main fishing grounds could have influenced the return rate).

Data

Different types of tags have been used during the Regional Tuna Tagging Project – Indian Ocean (RTTP-IO). However, only conventional « spaghetti » tags are considered in this study (i.e., red and white tags indicating archival tags and injection of oxy-tetracycline for growth studies, respectively, were omitted). In the case of double tagging experiments (conducted alternatively with simple tagging operations) tags originally inserted in the right side of the fish were identified by even numbers and tags inserted at the left side were coded with odd numbers. The updated tagging data set concerns recaptured fish reported until august 2009 for double tagging experiments conducted since 2006 (27,850 double-tagged tuna released, 4650 recovered so far including 313 having lost one of their tags.

Because recapture dates are needed to calculate days at sea, when the exact date was lacking from the tagging data set, the date of recapture was estimated by averaging the dates of the most plausible sets from which the recaptured tag is assumed to have been caught.

Method

Modelling the shedding rate

A simple analysis of the proportion of tags lost over time can be conducted as:

$$P.Obs_t = \frac{n_t^{ds}}{(n_t^{ds} + 2\, n_t^{dd})}$$, Chapman et al, (1965),

with n^{ds} and n^{dd} = numbers of recoveries of originally double tagged fish retaining one (ds) or two tags (dd), respectively, and t time at the middle of the k th time period since release. A simple plot of the proportion of tags lost over time gives insight of form of the relationship between the shedding rate and the time at liberty but due to the low sample size for some classes of time at liberty the corresponding value of the proportion of tags lost may be biased. It seems more appropriate to model this process with individual time at liberty. Thus, for modelling the proportion of tags lost: $P.Fit_t = 1 - Q_t$

with different potential models for the probability Q_t of a tag being retained at time t after release e.g.:

$Q_t = \alpha\, e^{-(L t)}$, (Hampton, 1997; Adam and Kirkwood, 2001),

$$Q_t = \alpha \left[\beta / (\beta + \lambda t) \right]^{\beta}$$, (Kirkwood, 1981, Hampton and Kirkwood, 1989)

α = type-1 retention probability (i.e., 1 - immediate type_1 shedding rate),
L = continuous type-2 shedding rate,
λ and β = gamma parameters of L allowing a time-varying shedding rate

Under the assumption that all tags not immediately shed have independent and identical probabilities, the probabilities of 2, 1 and no tags being retained at time t after release are, respectively:

$P_t(2) = Q_t^2$;
$P_t(1) = 2\, Q_t\, [1 - Q_t]$;
$P_t(0) = [1 - Q_t]^2$

Since identifiable recaptures consist only of fish retaining either one tag or two tags, conditional on retention of at least one tag, the probability of capturing a fish retaining 2 tags at time t is:

$P_t(2) / (1 - P_t(0))$,

and retaining only one tag at time t is:

$P_t(1) / (1 - P_t(0))$.

Estimates of the model parameters are obtained by minimizing the negative log-likelihood of the data conditional on recapture times:

$$LL = - \Sigma \, Ln \, [P_t(2) / (1 - P_t(0))] - \Sigma \, Ln \, [P_t(1) / (1 - P_t(0))]$$

It should be noted that other approaches that take into account differences in reporting rate (i.e., including detection rate) between double and simple tags, differences in continuous tag loss depending on the position/side of the fish where each double tag is inserted, etc have also been proposed (Barrowman and Myers, 1996; Xiao, 1996; Cadigan and Brattey, 2006, among others).

Preliminary analysis of the return rates suggested that, in addition to the tagger effect, the distance from the area where the tagging cruise took place to the main fishing grounds may influence the probability to recover a tagged fish. Consequently, in addition to the base case model (i.e., no cruise effect on type-1 and on type-2 shedding rates), cruise-varying type-1 shedding and cruise-varying type-2 shedding models were considered as follow:

Model A $Q(t) = \alpha \, e^{(-L t)}$ base case model;
Model B $Q(t) = \alpha_i \, e^{(-L t)}$ type-1 shedding rate (i.e., α) varies by cruise *i* ;
Model C $Q(t) = \alpha \, e^{(-L_i t)}$ type-2 shedding rate (i.e., L) varies by cruise *i*.

To account for the uncertainty into the model selection procedure, the results are presented within the framework of a Bayesian model averaging approach. Accounting for small-sample bias correction, the conventional AIC criterion is modified as (Anderson *et al.* 1994):

$$AICc = -2 \log \left[L \left(\hat{\beta} / data \right) \right] + 2K + \frac{2K(K+1)}{n - K - 1}$$

where n = number of observations,
K = number of parameters of the model,
$L\left(\hat{\beta} / data\right)$= value of the maximized log-likelihood over the unknown parameters, given the data and the model.

However, AICc values are sometimes nearly equal, making the choice of one specific model problematic. Consequently, to account for model selection uncertainty, the normalized quasi-likelihood Akaike weights (W_i) are calculated for each candidate model i, as:

$$W_i = \left[\exp\left(\frac{-\Delta \, AICc\,i}{2} \right) \right] \Big/ \sum_i \left[\exp\left(\frac{-\Delta \, AICc\,i}{2} \right) \right]$$

where $\Delta \, AICc\,i = AICc_i - \min AICc$ (Anderson *et al.* 2000).

The model with the greatest W_i will have the highest probability to be the best model for the data, given the candidate set of models.

Results

The results concerning the comparison between constant-rate and time-varying models developed to estimate tag-shedding rates with exact time at liberty from double tagging experiments are showed in tables 1. Compared with the preliminary study of Gaertner and Hallier (2008), the integration of longer-term recovery periods in the tagging data allow one to assess whether time-varying shedding rate may be an alternative to the constant-rate shedding. However, results showed that the addition of an additional parameter (i.e., in the time-varying model) does not improve the fit. Consequently we endorsed the constant-rate model for characterizing tag-shedding by tropical tunas (Figure 1).

Based on Akaike' weights, it was evidenced that the simplest model was the most plausible among the 3 formulations considered for the different species of tropical tunas (Table 2). Since we give a credibility of 100%, 86% and 98% to model A for skipjack, yellowfin and bigeye respectively, there is no needs of averaging the estimates among the different models.

In general, the low values of the tag shedding parameters found in our study are of a similar order to those previously reported by different authors (Hampton, 1997; Adam and Kirkwood, 2001). In contrast, the relative high value (0.22) reported by Adam and Kirkwood (2001) for skipjack in Maldivian waters, and not supported by our data, may reflect in part some emigration away the fishing ground (Table 3). The present study confirms that, in spite a “frenetic” behavior during the tagging operation, skipjack does not depict a larger type-1 shedding rate than yellowfin or bigeye (one could expect a larger immediate mortality and/or a larger immediate tag loss for skipjack than for the other two species of tropical tuna which in contrast of skipjack stay relatively quiet during the tagging).

Confidence intervals at 95% (for the constant shedding rate model only) were performed by bootstrapping.

The main conclusion of this updated shedding analysis is that the estimated proportion of tags lost was very low for the 3 species of tropical tunas. For instance, the largest shedding rate was observed for yellowfin, which reached around 10% only after 2 years after release (Table 4).

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Table 1. Comparison between parameter estimates for the time varying shedding rate model (i.e., the probability of retention $Q(t) = \alpha [\beta / (\beta + \lambda t)]^{\beta}$) and the constant rate model from double tagging experiments for the 3 main tuna species in the Indian Ocean. Ndd=number of fish double tagged and caught with the two tags; Nds=number of fish double tagged and caught with only one tag; Nll= Negative log-likelihood.

Species	Model	α	λ (per year)	β	Ndd	Nds	Nll
SKJ	constant	0.987	0.015		1450	64	259.59
	time varying	0.987	0.015	997.77			259.59
YFT	constant	0.977	0.041		1760	203	630.81
	time varying	0.977	0.041	29019.15			630.81
BET	constant	0.996	0.024		1094	46	183.01
	time varying	0.996	0.024	42657.45			183.01

Table 2. Model selection for estimating shedding rates in tropical tunas using data from double tagging experiments. Model A = base case model (i.e., constant-rate model with 1 type-1 shedding parameter and 1 type-2 shedding parameter), Model B = model accounting for different type-1 shedding by cruise; Model C = model accounting for different type-2 shedding by cruise; K = number of parameters, Nll = negative log-likelihood, QAICc = Akaike corrected information criterion for small-sample sizes, W*i* = Akaike's information criterion weight.

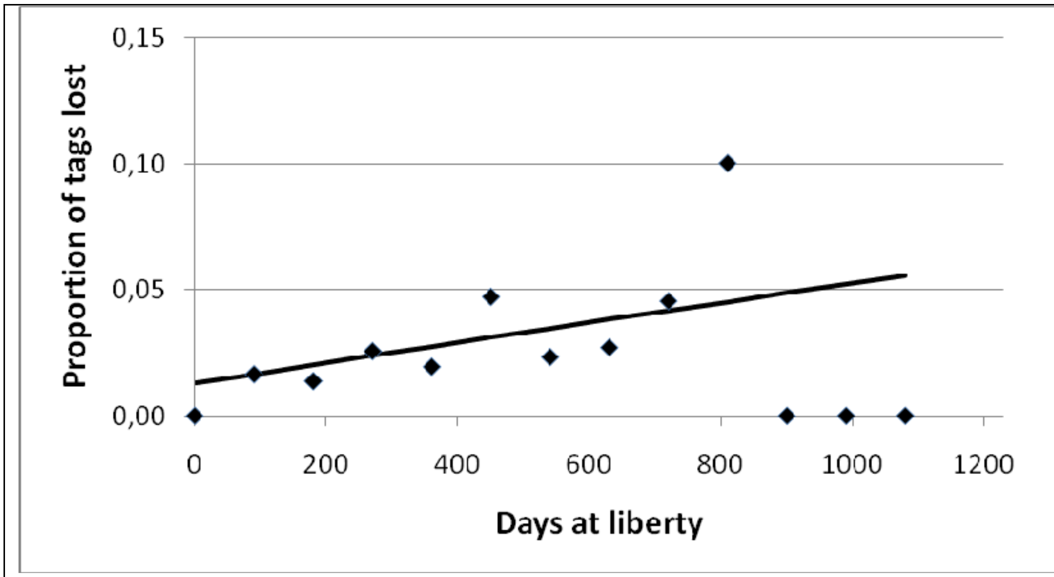
Species	Model	K	Nll	QAICc	Wi
	A	2	259.595	523.198	1.000
SKJ	B	18	255.292	547.041	0.000
	C	18	255.151	546.760	0.000
	A	2	592.787	1189.580	0.864
YFT	B	20	576.416	1193.272	0.136
	C	20	585.367	1211.176	0.000
	A	2	183.014	370.039	0.984
BET	B	14	176.715	381.804	0.003
	C	14	175.111	378.594	0.014

Table 3. Parameter estimates with bootstrapped confidence intervals (B.C.I.) for the constant shedding rate model (i.e., the probability of retention $Q(t) = \alpha \exp^{(-\lambda t)}$) from double tagging experiments for the 3 main tuna species in the Indian Ocean.

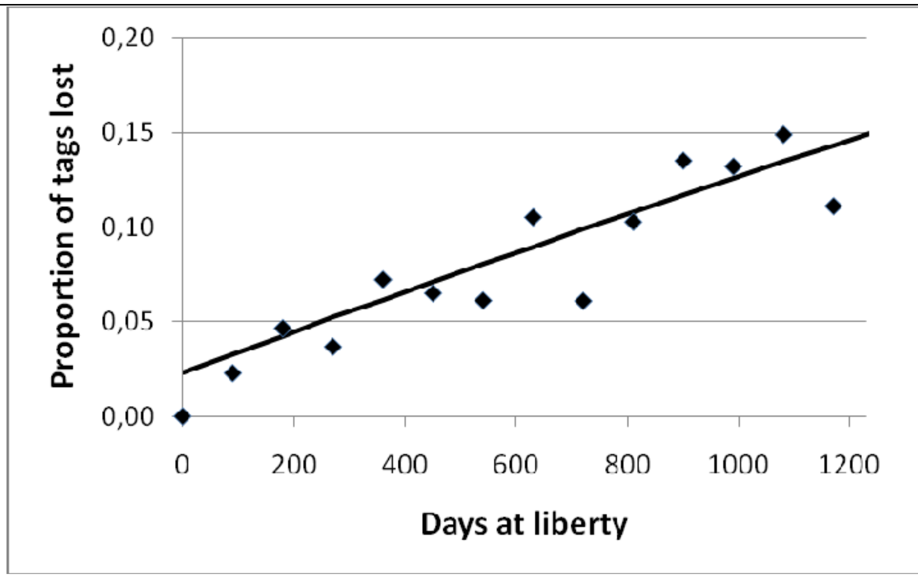
Species	α	95% B.C.I.	λ (per year)	95% B.C.I.	
SKJ	0.987	(0.980 - 0.995)	0.015	(0.002 – 0.029)	present study
	0.97	(0.94 - 1.00)	0.22	(0.09- 0.35)	Adam-Kirkwood 2001
	0.965		0.086		Hampton 1997
YFT	0.977	(0.966 - 0.985)	0.041	(0.027-0.053)	present study
	0.934		0.018		Hampton 1997
BET	0.996	(0.989 – 1.000)	0.024	(0.014- 0.030)	present study
	0.953		<0.001		Hampton 1997

Table 4. Estimated proportion of tags lost, immediately after release and after one and two years at liberty, respectively, from the constant shedding rate model for the 3 main tuna species in the Indian Ocean.

	Years		
Species	0	1	2
SKJ	0,013	0,027	0,042
YFT	0,023	0,062	0,099
BET	0,004	0,027	0,050


0,15
0,10
0,05
0,00
Proportion of tags lost
0
200
400
600
800
1000
1200
Days at liberty

SKJ


0,20
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Proportion of tags lost
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200
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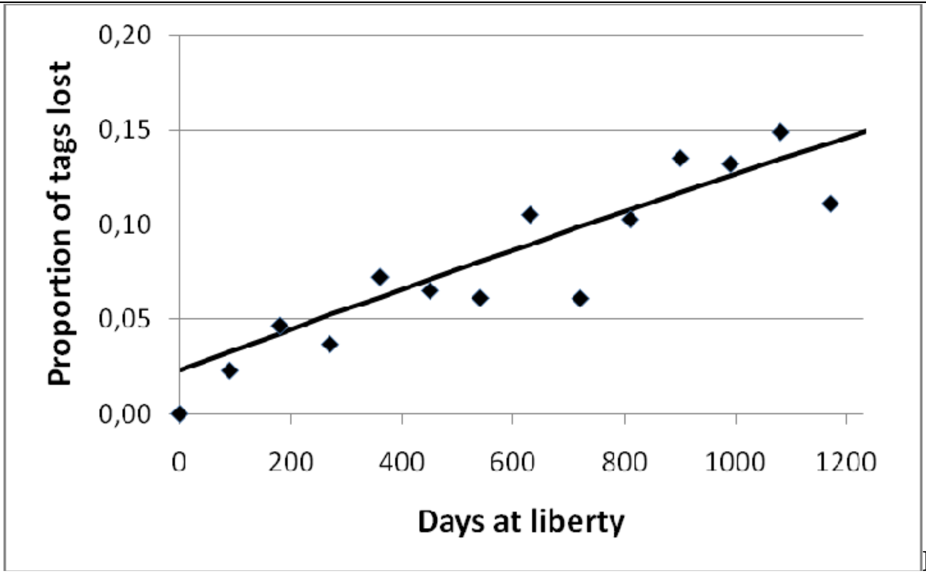
Days at liberty

YFT



BET

Figure 1. Proportion of tags lost per days at sea for the fish originally double tagged for the 3 main species of tropical tunas in the Indian Ocean: Skipjack (upper part), Yellowfin (median part) and Bigeye (lower part). Solid line = constant type-2 shedding rate model. The apparent lack of fit is due to the fact that models were fitted with exact days at liberty but observed shedding rates are represented by time periods of 90 days.