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FIRST ESTIMATE OF TAG-SHEDDING FOR YELLOWFIN TUNA IN THE ATLANTIC OCEAN FROM AOTTP DATA

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SUMMARY

An objective of the AOTTP was to estimate Type-I (immediate) and Type-II (long-term) tag-shedding rates for Atlantic yellowfin tuna from double-tagging experiments (4,518 double tags released with 1,061 recoveries). Accounting for the insertion point of the tag according to the body side of the fish, by introducing a tag-location effect in Type-1 (i.e., 1- α) and in Type-II tag-shedding, in the constant-rate model did not improve significantly the fit. Type-I and Type-II tag shedding estimates (0.026 and 0.031, respectively) are close to the values obtained in the Indian Ocean (0.028 and 0.040, respectively). On the basis of these results, the shedding rate is about 6% the first year at sea and reaches 17% after 5 years at sea. Preliminary results suggested that tag loss could differ according to the size at release but additional factors must be analysed before drawing a definitive conclusion. This study showed that tag shedding rate should be taken into account with other sources of uncertainty such as the reporting rate in order to estimate exploitation and mortality rates derived from tagging data.

RÉSUMÉ

Un objectif de l'AOTTP était d'estimer les taux de perte des marques de type I (immédiat) et de type II (à long terme) apposées sur l'albacore de l'Atlantique dans le cadre d'expériences de double marquage (4.518 marques doubles remises à l'eau avec 1.061 récupérations). En tenant compte du point d'insertion de la marque en fonction du côté du corps du poisson, l'introduction d'un effet de localisation de la marque dans le taux de perte des marques de type I (c'est-à-dire, 1- α) et de type II, dans le modèle à taux constant n'a pas amélioré de manière significative l'ajustement. Les estimations de perte de marques de type I et de type II (0,026 et 0,031, respectivement) sont proches des valeurs obtenues dans l'océan Indien (0,028 et 0,040, respectivement). Sur la base de ces résultats, le taux de perte est d'environ 6% la première année en mer et atteint 17% après cinq ans en mer. Les résultats préliminaires suggèrent que la perte des marques pourrait différer en fonction de la taille à la remise à l'eau mais des facteurs supplémentaires doivent être analysés avant de tirer une conclusion définitive. Cette étude a montré que le taux de perte des marques devrait être pris en compte avec d'autres sources d'incertitude telles que le taux de déclaration afin d'estimer les taux d'exploitation et de mortalité dérivés des données de marquage.

RESUMEN

Un objetivo del AOTTP era estimar las tasas de desprendimiento de marcas Tipo I (inmediata) y Tipo II (a largo plazo) para el rabil del Atlántico a partir de experimentos de doble marcado (4.518 dobles marcas colocadas con 1.061 recuperaciones). Teniendo en cuenta el punto de

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inserción de la marca de acuerdo con el lado del cuerpo del pez, introducir un efecto de ubicación de la marca en el desprendimiento de marcas del tipo I (es decir, 1- α) y del tipo II no mejoraba significativamente el ajuste en el modelo de tasa constante. Las estimaciones de desprendimiento de tipo I y tipo II (0,026 y 0,031, respectivamente) están cerca de los valores obtenidos en el océano Índico (0,028 y 0,040, respectivamente). Basándose en estos resultados, la tasa de desprendimiento es de aproximadamente el 6 % el primer año en el mar y alcanza el 17 % tras 5 años en el mar. Los resultados preliminares sugerían que la pérdida de marcas podría diferir según la talla en el momento de la liberación, pero deben analizarse factores adicionales antes de sacar alguna conclusión definitiva. Este estudio demostró que la tasa de desprendimiento de marcas debería tenerse en cuenta junto con otras fuentes de incertidumbre, como la tasa de comunicación, para estimar las tasas de explotación y de mortalidad derivadas de los datos de marcado.

KEYWORDS

Yellowfin tuna, Atlantic Ocean, tagging, tag shedding

1. Introduction

The 5-years Atlantic Tuna Tagging Programme (AOTTP), funded mainly by the DG Devco of the European Commission and by other ICCAT CPC and partners, has been design to improve the estimates of the key parameters commonly used as inputs in the stock assessments of the 3 main species of tropical tunas (skipjack, yellowfin and bigeye tunas). To date, more than 60,000 tropical tunas have been marked and released in different places in the Eastern Atlantic (e.g., Azores, Madeira, Canary Islands, Senegal, Gulf of Guinea, South Africa) and in the Southwest Atlantic (Brazil) and approximately 20% of the released fish have been recaptured (Beare et al, 2018).

Tag-return models are commonly used when the focus of the study is on estimating mortality rates. Integral to the use of tagging data are standardization models, such as tag-attrition models for single release events (Kleiber *et al.*, 1987; Hampton, 1997) or Brownie models (derived from bird-banding studies) for multiyear studies (Brownie *et al.*, 1985; Hoenig *et al.*, 1998; Polacheck *et al.*, 2010). The results of tagging studies can, however, be compromised if tags or data are lost (i.e., through tag shedding and non-reporting). Both occurrences can lead to underestimations in tag-return rates, which create a negative bias in fishing mortality estimates, rates of fishery interactions, and tuna movements (Gaertner and Hallier, 2015). Ultimately, this leads to biased estimates of stock status. Thus, the objective of this paper is to use AOTTP double-tagging experiments (i.e., experiments in which a fish is tagged with two tags simultaneously) to conduct a preliminary estimate of tag-shedding rates for yellowfin tuna in the Eastern Atlantic Ocean.

There are two types of tag losses (Wetherall, 1982; Hampton and Kirkwood, 1990): Type-I losses, which reduce the number of tags initially put out (immediate tag shedding, immediate tagging mortality, and non-reporting), and Type-II losses which occur steadily over time (natural mortality, fishing mortality, permanent emigration, and long-term tag shedding). The current paper is only estimating the Type I and II tag shedding components of total losses.

2. Material and Methods

Data

The data set analysed in this paper was cleaned by the AOTTP staff and after omitting dubious data included a total of 4,518 double-tagged release records from which 1061 were recaptured (21.9%), which includes 1.54% of fish that have lost one of their tags (**Table 1**).

Method

Calculations to estimate tag-shedding rates from double-tagging experiments make the assumption that the first and second tags are shed at the same rate, independently of one another (e.g., Kirkwood, 1981; Wetherall, 1982; Kirkwood and Walker, 1984).

The most appropriate approach to model the tag-shedding process is using individual exact times-at-liberty that account for differences in the reporting rates of double and single tags (including differences in detection rates). This approach also accounts for differences in tag loss driven by the choice of insertion point (i.e., left side or right side) of each double tag (e.g., Barrowman and Myers, 1996; Xiao, 1996; Lenarz and Shaw, 1997; Cadigan and Brattey, 2006; Smith *et al.*, 2009). Exact time-at-liberty tag-shedding models are formulated by constant-rate model as follows. Assume that the probability $Q_A(t)$ of a tag-type A being retained at time t after release can be expressed as:

$$Q_A(t) = \alpha_A e^{-(L_A t)}$$ (Hampton, 1997; Adam and Kirkwood, 2001),

where α is the retention probability of the immediate Type-I shedding rate, L is the continuous Type-II shedding rate. Given this assumption, the probability of observing a tagged fish at time t after release is a combination of the reporting rate γ, and the probability of tag $Q(t)$ being retained, which can be expressed as:

$$P_A^A(t) = \gamma_A Q_A(t)$$

A similar expression can be used to determine differences in the proportion of tags returned over time for fish that have been tagged with a different type of tag or at a different insertion position. For non-permanent double-tagging experiments, the only recapture information available is whether a fish has retained one or both its tags. If reporting rates for double- and single-tagged fish are assumed to be equal the possible tag combinations at recapture are two tags (RL), right-tag only (R), and left-tag only (L), which can be expressed as the following outcomes:

$$P_{RL}^{RL}(t) = Q_R(t)\ Q_L(t)$$
$$P_R^{RL}(t) = Q_R(t)\ \left[1 - Q_L(t)\right]$$
$$P_L^{RL}(t) = Q_L(t)\ \left[1 - Q_R(t)\right]$$ respectively.

The probability of observing the outcome i, for a fish captured at time t, for each of these three possible outcomes is given by:

$$P_i^{RL}(t) \Big/ \sum_{i=1}^{3} P_i^{RL}(t)$$

Estimates of the model parameters are obtained by minimizing the negative log-likelihood of the data conditional on recapture times (Barrowman and Myers, 1996):

$$LL = -\sum_{i=1}^{3} \sum_{j=1}^{n_i} Ln\left(P_i^{RL}(t_{ij}) \Big/ \sum_{i=1}^{3} P_i^{RL}(t_{ij}) \right)$$

The Bayesian information criterion (BIC) was used to objectively select a model from the set of candidate models considered. Each model had different explanatory variables; some, but not all, assumed a constant precision parameter.

$$BIC = -2\log\left[L\left(\hat{\beta},\hat{\gamma}/data\right)\right] + K\log(n)$$

where n is the number of observations, K is the number of model parameters, and $L\left(\hat{\beta},\hat{\gamma}\ /\ data\right)$ is the value of the maximized log-likelihood over the unknown parameters, given by the data and the model. The lowest BIC value identifies *a posteriori* which is the most probable model.

However, it is problematic to choose the most probable model when the BIC values are nearly equal. To account for any uncertainty associated with model selection, a Bayesian posterior model probability ($\Pr_i$) was calculated for each candidate model i as:

$$\Pr_i = \left[\exp\left(\frac{-\Delta BIC_i}{2}\right)\right] \Big/ \sum_i \left[\exp\left(\frac{-\Delta BIC_i}{2}\right)\right]$$

where

$$\Delta BIC_i = BIC_i - \min BIC \quad \text{(Burnham and Anderson, 2002).}$$

It is noteworthy that the inferential model weights from the BIC selection have the same formula as the Akaike weights, but may be interpreted as probabilities of the model (given the data, model set, and prior model probabilities of each model). Therefore, the model with the largest Pr_i is the one with the highest probability of being the best model for the data set.

3. Results

To investigate the effects of tag position on the tag-shedding rate for yellowfin tuna, we assessed four different models in which tag-retention parameters were varied according to the position of the tag.

- Model 1 (A1) assumed that tag position had no effect on tag loss;
- Model 2 (A2; three model parameters) allowed both L_R and L_L to vary as a descriptor of position effect in the instantaneous rate of long-term tag loss (α is assumed unique);
- Model 3 (A3; three model parameters) assumed a position effect in the probability that a fish retained its tag immediately after tagging (α_R and α_L can differ, but L is assumed to be independent of the insertion point(s));
- Model 4 (A4) assumed a specific position estimate for all four parameters (α_R, α_L, L_R, and L_L).

To reflect the uncertainty associated with ranking and selecting the most plausible model to depict the probability of observing the various combinations of right- and left-tagged releases possible, we used both the Akaike information criterion corrected for small sample sizes (AICc) and BIC.

Although the AIC and BIC are both penalized-likelihood criteria, they reflect subtle theoretical differences: AIC focuses on the best variance-bias tradeoff in a set of candidate models (i.e., the parsimonious model in terms of a frequentist approach), while the BIC identifies the "quasi-true" model. Consequently, the type of criteria used can drive some differences in which model is selected. In this analysis, the BIC-selected model (A1) suggests that tag position did not affect tag-shedding. For the AICc, except for the full model which has the less evidence, neither model dominate the others (**Table 2**). It should be noted that the study conducted in the Indian Ocean showed that the tag position affected Type-1 shedding for bigeye and yellowfin (Gaertner and Hallier, 2015). Accounting for this aspect can be relevant as in single-tagging experiments, tags are most-commonly inserted into the right side of the fish.

The estimates of the Type-I (0.026) and Type-II tag shedding (L (per year) = 0.031) are very close to the values obtained from the Indian Ocean Tuna Tagging Program (0.028 and 0.040, respectively). By way of comparison, the estimates of α and L from AOTTP double tagging data for the Atlantic bigeye tuna were 0.989 and 0.044 (per year), respectively (Gaertner et al, 2018). On the basis of these results, the Atlantic yellowfin shedding rate is about 6% the first year at sea and reaches 17% after 5 years at sea (**Table 3**).

With the aim to assess potential differences in terms of tag-shedding according to the size (FL) at release, the double tagging dataset was divided in 3 size categories: yellowfin at release <= 45 cm, > 45 cm and <= 65 cm and > 65 cm. Preliminary results presented in **Table 4**, suggests than Type-I decreases for larger fish at-release (from 0.037 to 0.019) while the opposite trend is observed for Type II (from 0.01 to 0.07 per year). The combination of both types of shedding could have a large impact on larger individuals (31% of tag loss after 5 years). However, special attention should be paid before drawing definitive conclusions such as additional factors, e.g. the effect of different release teams and tagging experiments conditions, have not been taken into account in the analysis.

This study suggests that tag shedding rate should be taken into account with other sources of uncertainty such as the reporting rate in order to estimate exploitation and mortality rates derived from tagging data.

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Table 1. Number of double-tagged yellowfins by the AOTTP and the percentages of recaptures made with two tags (Both) and one tag (Tag 1, assumed to be Left or Tag 2 assumed to be Right).

	Released		
	4,518		
	Recaptured		
Total		(%)	
	Both	Right	Left
1,061	21.93	0.71	0.84

Table 2. The different parameterizations of the constant-rate shedding model (A1, A2, A3, and A4) considered to determine how tag position (Tag1 and Tag2, assumed to be inserted in the left or right side of the fish, respectively) differentially affects shedding rates, where *K* is the number of model parameters; nll is the negative log-likelihood; BIC is the Bayesian information criterion; Pr_i is the Bayesian posterior model probability, AICc is the small-sample-size corrected version of Akaike information criterion, and W_i is the AICc weight.

Model	α	α_R	α_L	L	L_R	L_L	K	nll	BIC	Pr_j	AICc	W_j
A1	0.974	NA	NA	0.031	NA	NA	2	304.382	622.699	0.929	612.776	0.482
A2	0.974	NA	NA	NA	0.037	0.026	3	304.306	629.513	0.031	614.635	0.190
A3	NA	0.971	0.977	0.031	NA	NA	3	304.081	629.063	0.039	614.184	0.239
A4	NA	0.970	0.977	NA	0.027	0.033	4	304.065	635.997	0.001	616.167	0.089

Table 3. Yearly estimated breakdown of proportions of the Atlantic yellowfin in tags lost, beginning immediately post-tagging until five years-at-liberty, by the constant-rate shedding model.

Year after release	0	1	2	3	4	5
Proportion Lost	0.026	0.056	0.085	0.112	0.140	0.166

Table 4. Yearly estimated breakdown of proportions of the Atlantic yellowfin in tags lost for 3 size categories at release, beginning immediately post-tagging until five years-at-liberty, by the constant-rate shedding model.

Size categories	Year after release	0	1	2	3	4	5
at release	Proportion Lost						
<= 45 cm		0.037	0.047	0.056	0.065	0.075	0.084
>45 and <=65 cm		0.027	0.049	0.071	0.092	0.113	0.133
> 65 cm		0.019	0.085	0.147	0.205	0.259	0.309