SImulatioN of TAGs (SINTAG) revisited: An updated model to estimate the number and size of tunas tagged by the RTTP-IO that are still alive in 2009.

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Abstract

During the 2008 meeting of the IOTC WPTDA it was suggested that a simple model should be devised to estimate the number and size of tuna tagged by the large scale Regional Tuna Tagging Programme in the Indian Ocean (RTTP-IO) for a projected period of time after the completion of tagging. This suggestion was made, as the RTTP-IO had reported a 16% return rate of the 168.000 tuna tagged between 2005 and 2007. Approximately 95% of these returns have been reported from the purse seine fishery. This has lead to speculation that the tagged tuna have not yet reached sizes at which they could be caught by longliners (bigeye and yellowfin) or by the baitboat fishery (skipjack). A simple exponential decay and growth model developed in 2008 indicated that this was probably not the case, and tagged individuals should have been available to these fisheries at that stage. The model presented in 2008 has been updated to include tag reporting and shedding rates and the latest recapture data has been included to clarify those findings. It would still appear that tagged tuna have not been fully reported by the longline and baitboat fisheries. Thus, an effort should be made to increase the level of tag reporting in those fleets as theoretically there may still be large numbers of tagged tuna at liberty and, therefore, still good prospects for their recovery in the future

1 Introduction

Tagging studies have been carried out on tuna populations for many decades (Anonymous 1993). Tag-recovery studies facilitate the collection of a variety of information on fish species, such as stock structure, growth rate, gear selectivity, migrations, survival/mortality and immediate mortality due to tagging (Beverton and Holt, 1957; Seber, 1973, Gaertner and Hallier 2004, Gaertner *et al.* 2004, Hallier *et al.* 2005). Consequently, conventional tagging is a research tool widely used by tuna commissions to increase the biological understanding of spatially structured populations and to gauge the effects of fishing activities on these populations (Gaertner *et al.* 2008).

In the Indian Ocean, tagging of tropical tuna has historically only been carried out targeting skipjack in the Maldives during the early nineties (Adam and Sibert 2001). As the Indian Ocean has increasingly become an important tuna fishing region, particularly for tropical tuna species (IOTC yearly statistics), it was strongly recommended in 2000 by the IOTC that a large scale tagging project be conducted as soon as possible in the region. The Regional Tuna Tagging Project – Indian Ocean (RTTP-IO) was requested by the Indian Ocean Tuna Commission (IOTC) scientists to implement a tagging program in order to address the issue of the state of the stocks of the three main tropical tuna species: yellowfin (*Thunnus albacores*), bigeye (*T. obesus*) and skipjack (*Katsuwonus pelamis*). The project was funded by the 9th European Development Fund (EDF) with technical Supervision of the Project provided by the IOTC, and was based in the Seychelles.

This large-scale tagging of tropical tuna species was carried out under the RTTP-IO between May 2005 and August 2007. During this time, 168,163 tuna with tags were released including 34,570 bigeye, 54,663 yellowfin and 78,324 skipjack. By September 2009, the RTTP-IO statistics indicate that it now has 27 300 reported recoveries in its database, indicating a 16.2% recovery rate. Hallier (2008) noted that the number of tuna tagged and the number of tags returned were very similar between species. The rate of return has not been similar between fishing gear groups.

This large discrepancy in tag reporting rates between fisheries has prompted the IOTC to request an investigation into its possible causes. In the 2008 meeting of the Working Party on Tagging Data Analysis (WPTDA) it was suggested that the reason for the lack of tag reporting from the longline fishery is due to the fact that the majority of bigeye and yellowfin tuna tagged, were and are below the size caught by this fishery. This was also suggested to be the case for the baitboat fishery with regards to skipjack tuna. As a result, the WPTDA decided to investigate the development of the three species tuna tagged, simply using a combined growth, exponential decay model in order to determine:

a) if the tagged tunas have grown to a size at which they may be available to the aforementioned fisheries, and

(b) if this is found to be the case, how many of these surviving tagged tunas could still be available to the aforementioned fisheries.

This information can be obtained from the SINTAG model, and these results can be analysed in conjunction with the comparison between catch at size and the numbers of recovered tags by species and size, for each gear. These estimated numbers of surviving tuna at given sizes are also estimated by Multifan-CL and other statistical models, but there are various benefits to estimating these parameters directly using ad hoc simulation models. These are: (1) to easily and quickly obtain the estimated numbers and sizes of tagged survivors, (2) to easily introduce or modify parameters assumed or used in the model (for instance growth, natural and fishing mortality)

2 Data and Models

The purpose of the initial SINTAG model presented at the 2008 IOTC working party on tropical tuna [WPTT] meeting (de Bruyn *et al.* 2008) was to simulate the decay and growth of cohorts of tunas tagged within a given period of time (in this case during 2 years), with each fish exhibiting an assumed growth, and each cohort suffering a natural and a fishing mortality, variable by size and season. In the present model, the simulated fishing mortality is simply driven by the number of recovered tags, although an alternate fishing mortality hypothesis, for instance vector of F at age estimated by an assessment model could of course be easily introduced as an alternate hypothesis. An alternate F assuming a low reporting rate by non purse seine gears could also be included, as the present estimated F (based solely on the high reporting level of the purse seine fishery) will tend to introduce a systematic bias by underestimating total F and overestimating the population of survivors for longline and baitboat fleets.

Data used in the model were provided by the RTTP-IO. All tag releases of bigeye, yellowfin and skipjack tuna were extracted from the RTTP-IO database released by the IOTC secretariat in September 2009. Any data for which there was missing information (such as release date, or release size), were excluded. The lengths and dates used for the recaptured data were those labelled as CAL_REC_FL and CAL_REC_DATE_AVG respectively in the RTTP-IOTC database.

The first model presented at the 2008 WPTT (de Bruyn *et al* 2008) did not include tag reporting or shedding rates and thus may have over-estimated the number of surviving tunas. This has been corrected in the present model.

Initially, the model simulated the dynamics of the tagged individuals from the first month of tagging (May 2005) until the end of August 2007, the date at which the last tagged individuals were released. In all cases, intervals **t** of the model were measured in months. The dynamics of the model are described by the following equations:

For the Initial year of the model (May 2005):

$$N_{l,t=1} = T_{l,t=1} \qquad (1)$$

Where: $N_{l,t=1}$ is the number of tagged individuals of length l in the first time period of the model,

$T_{l,t=1}$ is the number of tagged individuals of length l released in May 2005.

Between June 2005 and August 2007:

$$N_{l,t} = N_{l-1,t-1} \times e^{(-M_l((t_1-t_2)/12)} + T_{l,t} - R_{l,t} \qquad (2)$$

Where: $N_{l,t}$ is the number of tagged individuals of length l at time t,

$N_{l-1,t-1}$ is the number of individuals from a smaller length class in time t - 1 calculated to have grown to length l by time t using the growth equations below,

M_l is the instantaneous natural mortality at length l,

$T_{l,t}$ is the number of newly tagged and released individuals of length l at time t,

$R_{l,t}$ is the number of calculated recaptures for all fisheries of tagged individuals of length l at time t.

In turn $R_{l,t}$ was calculated as follows:

$$R_{l,t} = (AR_{l,t} / P_t) / \lambda_t \tag{3}$$

Where: $AR_{l,t}$ is the actual number of tagged individuals reported of length l at time t

P_t is the proportion of tagged individuals who have not experienced tag-shedding at time t

λ_t is the tag reporting rate from the European Union purse seine fleet at time t

For the purposes of this model, Z was replaced with M in equation 2 (Table 1) as the number of tagged individuals removed from the population as a result of fishing (and thus F) was accounted for using the term $R_{l,t}$.This term takes into account tag reporting rates as well as the proportion of individuals experiencing tag shedding. M was assumed to be constant across years. P_t and λ_t are provided in Table 2.

From September 2007 until September 2009:

$$N_{l,t} = N_{l-1,t-1} \times e^{(-M_l((t_1-t_2)/12)} - R_{l,t} \tag{4}$$

Equation 4 was modified to reflect the fact that no new tagging occurred after August 2007, by removing (the $T_{l,t}$ term). The present final year and month included in the model was September 2009 (the month for which the most recent recapture data is available), but of course this date could easily be expanded in time.

Growth of the tagged individuals was modelled using the equations proposed by Eveson and Million (2008) but re-parameterized by Eveson (2008) subsequent to the IOTC working party on tagging data analysis meeting (WPTDA) in June 2008.

For skipjack tuna (Figure 1), a simple Von Bertalanffy growth function was assumed:

$$\Delta L = (66 - L)(1 - e^{-0.498\Delta t}) \tag{5}$$

For yellowfin (Figure 2) and bigeye (Figure 3) tuna, a VB log k growth function (Laslett *et al.* 2002) was assumed, where:

$$l(a) = L_\infty f(a - a_0; \theta) \qquad (6)$$

L_∞ is asymptotic length and *f* is a monotone increasing function with parameter set $\{a_0, \theta\}$ that equals 0 when $a = a_0$. θ and *f* can be defined as follows:

VB log k: $\theta = \{k_1, k_2, \alpha, \beta\}$ and

$$f(a - a_0; \theta) = 1 - \exp(-k_2(a - a_0))\left\{\frac{1 + \exp(-\beta(a - a_0 - \alpha))}{1 + \exp(\alpha\beta)}\right\}^{-(k_2 - k_1)/\beta} \qquad (7)$$

The parameter estimates included in equation 7 are presented in Table 3.

The simulated sizes of the tagged tunas have also been compared to the typical sizes caught by the two fishing sectors of interest and the catch at size data from the IOTC database were used to calculate the length classes targeted by the major gear types (Figures 4 to 6) and in particular the longline fisheries for yellowfin and bigeye tuna and the baitboat fishery for skipjack tuna. The catch at size data were averaged between 2006 and 2008. The size frequencies of the tagged tuna at release are also provided, and they are independent of release date. The numbers of tagged tuna released presented in the figures below are less than the official number of released tuna mentioned above, as all data entries that were judged to be unreliable were removed for the purposes of this study, as explained above.

3 Results

The projections for the tagged yellowfin tuna are presented in Figure 7. It is clear from these projections that in September 2009 the predicted lengths of the tagged yellowfin fell within the size distribution targeted by the longline fishery. The number of tagged tuna still at liberty is also currently estimated to be quite high and was even more so at the time of the 2008 IOTC WPTDA (17740) and WPTT (14626) meetings during which this study was first initiated. This is also the case for the tagged bigeye tuna (Figure 8). Again, considerable numbers of tagged tuna were calculated to be at liberty at the time of both WPTDA and WPTT meetings (14986 and 11647 respectively) while it is theoretically possible that in excess of 8000 are still currently at liberty. For skipjack tuna, the size distribution observed for the Maldivian baitboat fishery is bimodal. The predicted distribution of the tagged skipjack lies within the right modal distribution of the observed catch of skipjack by the baitboat fishery (Figure 9). As was the case with the other two species, the SINTAG model estimated that a large number of tagged skipjack tuna were at liberty on the dates of both the WPTDA and WPTT meetings in 2008 (19894 and 15238 respectively) and 7319 were calculated to still be at liberty.

In order to further highlight the disparity been tag reporting rates between the purse seine and longline fisheries, the number of large tuna (>1 m) and the number of reported recoveries for the same size class were compared for yellowfin and bigeye tuna caught in the western Indian Ocean (Table 4). It is clear that the number of reported tags per 1 million tuna caught is far higher for the purse seine fishery than for the longline fishery. The overall trends in catch recoveries by species are presented in figure 10. As would be expected, the number of reported returns increased rapidly after the initiation of the project. The number of returns peaked towards the middle of 2007 before decreasing until September 2009 although the decrease (apart from the final month) has been gradual and tag recoveries are still being reported for each species. The overall trend is generally similar between species

4 Discussion

The method used by SINTAG to estimate the present number and sizes of tagged tunas, taking into account their growth and mortality is clearly a quite simplistic approximation, but also a valid attempt to estimate this fundamental information. The model uses current M-at-age vectors used in the assessment for the three species. This may be improved in the future once more realistic vectors have been agreed upon for the Indian Ocean. The model does not include an F estimate, but rather subtracts recaptures directly from the simulated population, taking into account tag reporting rates for the purse seine fisheries (from whom the vast majority of reported tags have come) and potential tag shedding. This is not ideal, as the experiments have shown that the tag reporting rate from the purse seine fishery is high (Hillary *et al*. 2008a and b), and thus using this rate as a proxy across fisheries is almost certainly leading to a systematic bias in the calculation of survival amongst tagged individuals.

It is thus likely that less tagged individuals of each species are alive today than indicated in this study. As there is simply no information to determine what potential reporting rates are for other fisheries, it is not immediately clear how this could be rectified in the model. One potential step is to look at the numbers presented in table 4 and assume that the number of tags reported per million tuna caught should be the same for all fisheries and thus calculate the number of tags the longline fishery should “theoretically” have caught, and scale this against the number of tags actually reported in order to obtain a hypothetical catch reporting rate. This would, however assume that the tagged tuna are equally vulnerable to both fleets, and even should this be the case from a size selectivity point of view, it does not take into account the spatial dynamics of the different fleets. In fact as the majority of tuna were tagged and released in areas most commonly targeted by purse seine fisheries (Hallier 2008), this may partly explain the higher reporting rate from this fishery relative to the others. More complex models including tuna movement and times at liberty may clarify this issue somewhat

Since this study was initiated, there have been several tags reported from the other fisheries, however these still remain low (less than 5% of the total number of reported tags). The results of this model would clearly indicate that the size of the tagged individuals is not an explanation as to why the tag returns from the other fisheries have been low. There is, however, some debate as to what growth curves are most suitable for the different species. The growth curves utilised in this study may well not be optimal, but until a “definitive” growth curve is decided upon these models indicate that theoretically at least, tagged tuna should be available to these fisheries. In any case, the size distribution of the yellowfin catch is similar for the purse seine catch on free-schools and longline fisheries and this is again the case for the baitboat and purse seine fisheries for skipjack tuna. It is thus not clear from a biological aspect why there is such a discrepancy in tag reporting rates between fisheries. It would thus appear from the results of this study that there is systematic under-reporting of tag recaptures from the longline fishery. This is a problem when attempting to conduct meaningful evaluations on the status of the populations in the Indian Ocean region, given that it is important to have good estimates of tag reporting rates when inferring exploitation rates and natural mortality rates from tagging experiments (Cadigan and Brattey 2006) The RTTP-IO has resulted in a wealth of information being obtained on tuna in the Indian Ocean region, but every effort must be made to maximise its quality and usefulness in order to facilitate the use of this data in the management of tuna species in the region.

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Table 1: Natural mortality estimates for the three tuna species included in the model

Species	Instantaneous natural mortality	Reference
Yellowfin tuna	-0.2 x age + 0.8 (age < 1) and $0.6.y^{-1}$ (age ≥ 1)	Shono *et al.* 2007
Bigeye tuna	$0.8.y^{-1}$ (age < 2) and $0.4.y^{-1}$ (age ≥ 2)	Nishida and Shono 2006
Skipjack tuna	$0.8.y^{-1}$	Fonteneau and Pillarés 1999

Table 2: Tag retention proportion parameters (Hillary *et al.* 2008a) and tag reporting rate (Hillary *et al*. 2008a and b) included in the model. † Indicates values were averaged across species based on the recommendation by the IOTC tropical tuna working group (IOTC 2008) and *indicates values were averaged across quarters.

Species	Year	P_t	λ_t
Yellowfin tuna	2005	0.8	0.6†
	2006	0.8	0.8*
	2007	0.8	0.9*
	2008	0.8	0.9*
Bigeye tuna	2005	0.9	0.6†
	2006	0.9	0.8*
	2007	0.9	0.9*
	2008	0.9	0.9*
Skipjack tuna	2005	0.9	0.6†
	2006	0.9	0.8*
	2007	0.9	0.9*
	2008	0.9	0.9*

Table 3: Parameter estimates for VB log k model

Species	L_∞	k_1	k_2	α	β	a^0
YFT	146	0.1334	0.905	4.1228	10.9654	-1.42
BET	160	0.071	0.4207	5.6033	2.999	-3.09

Table 4: Comparison of tag returns by gear for large yellowfin and bigeye tuna

Yellowfin	Purse seine	Longline
Catch in IO of individuals >1 m	2229874	1081870
Recoveries > 1 m	2984	46
% of recoveries by gear	96.7	1.5
Number of tags recovered per million tuna caught	1338	43
Bigeye	**Purse seine**	**Longline**
Catch in IO of individuals >1 m	165254	1083515
Recoveries > 1 m	182	39
% of recoveries by gear	82.4	17.6
Number of tags recovered per million tuna caught	1101	36

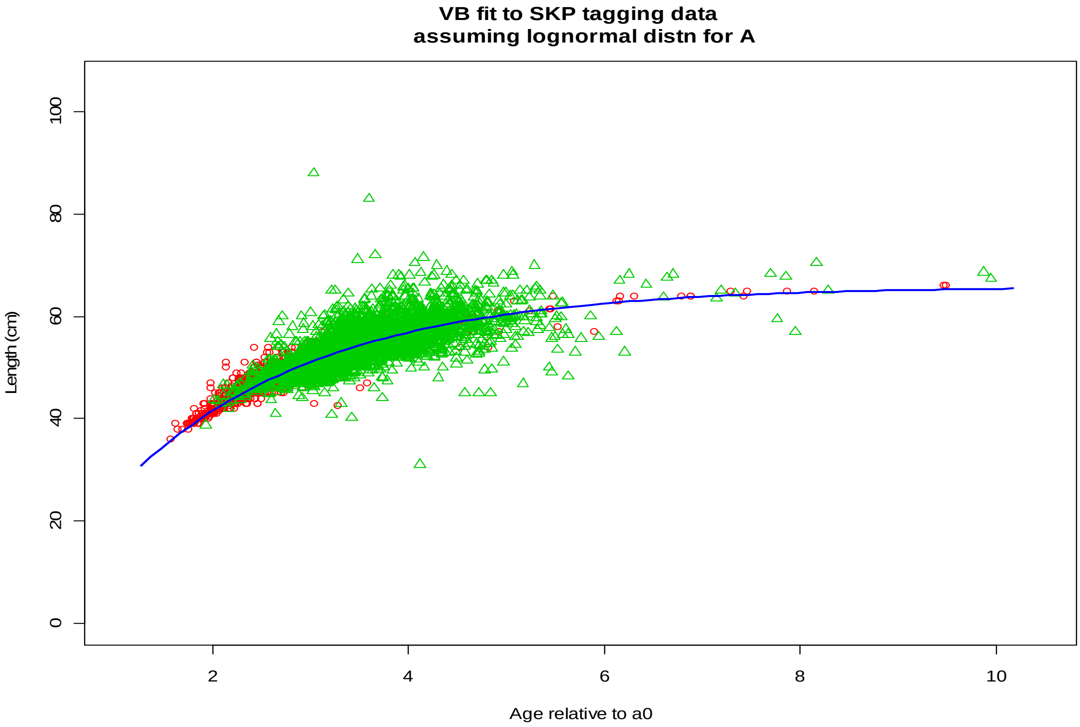

Figure 1: Growth function used for skipjack tuna tuna

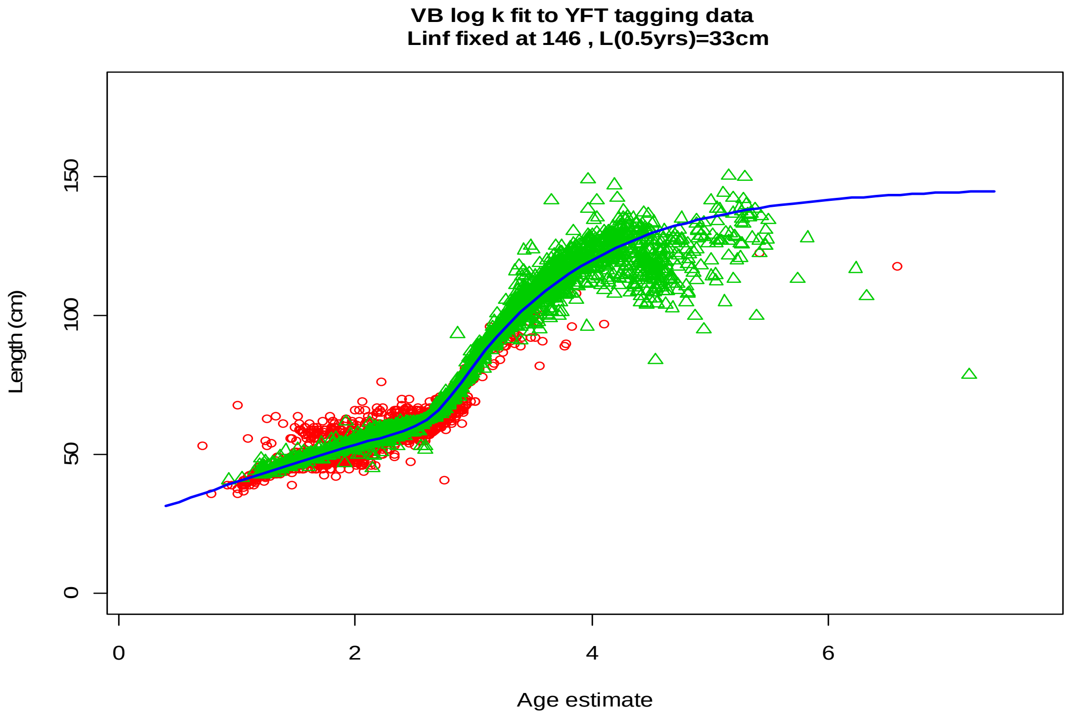

Figure 2: Growth function used for yellowfin tuna (Eveson 2008)

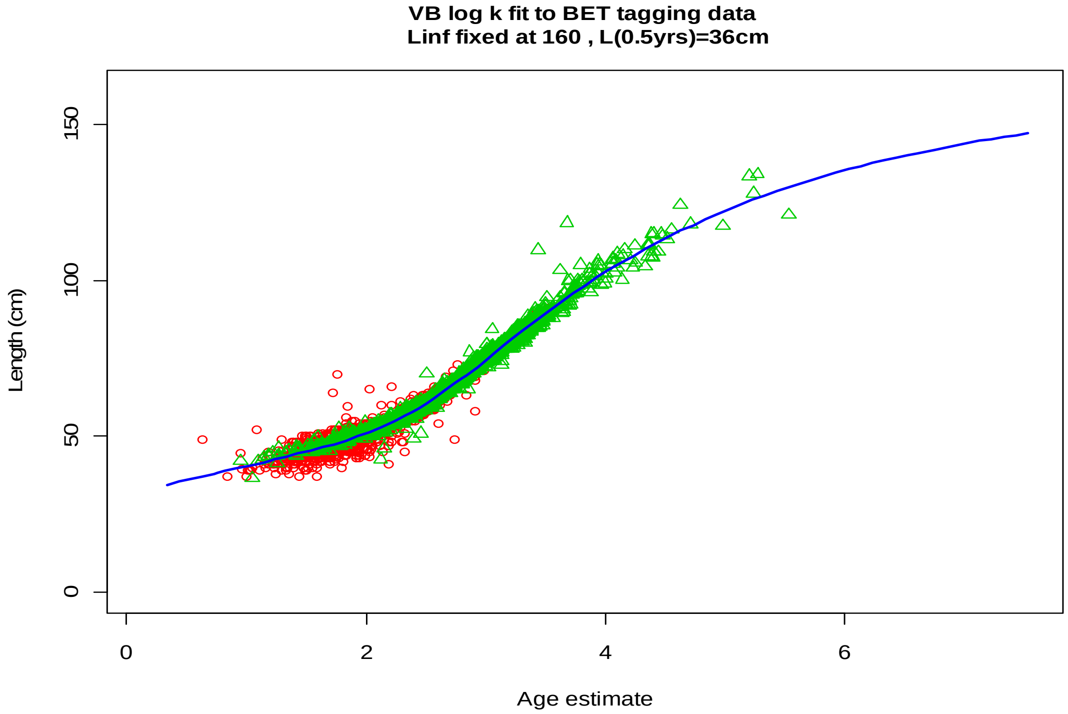

Figure 3: Growth function used for bigeye tuna (Eveson 2008)

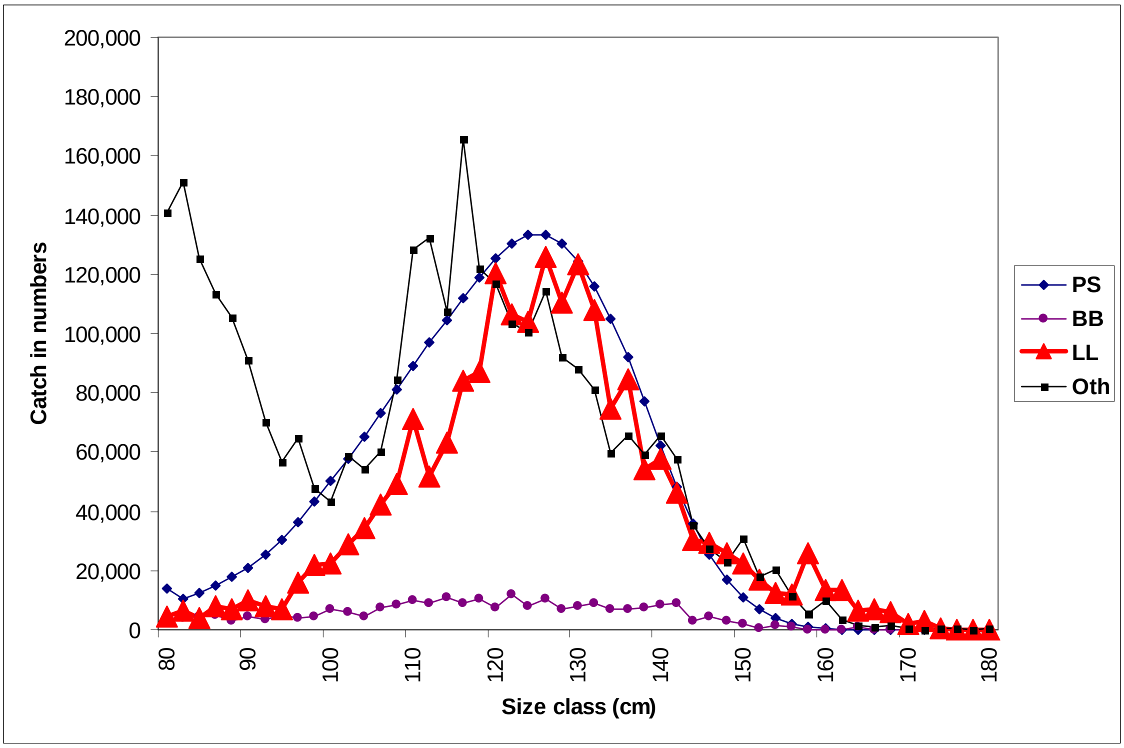

Figure 4: Size frequency of yellowfin catches in the Indian Ocean by gear type

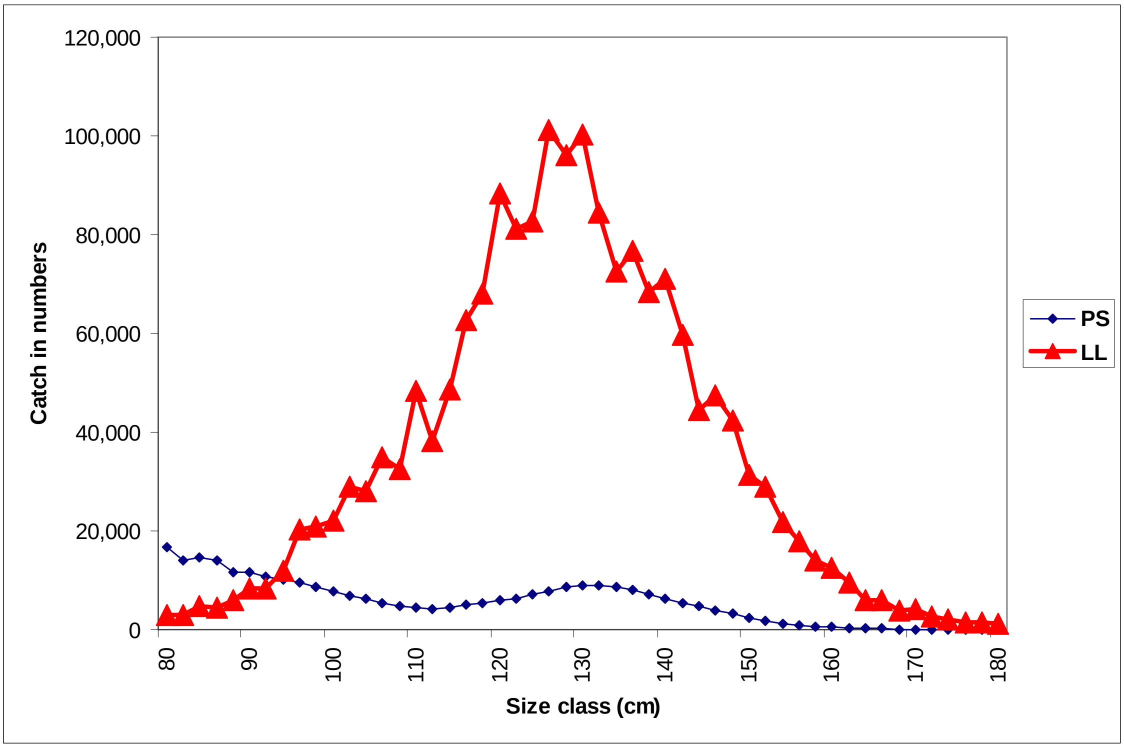

Figure 5: Size frequency of bigeye catches in the Indian Ocean by gear type.

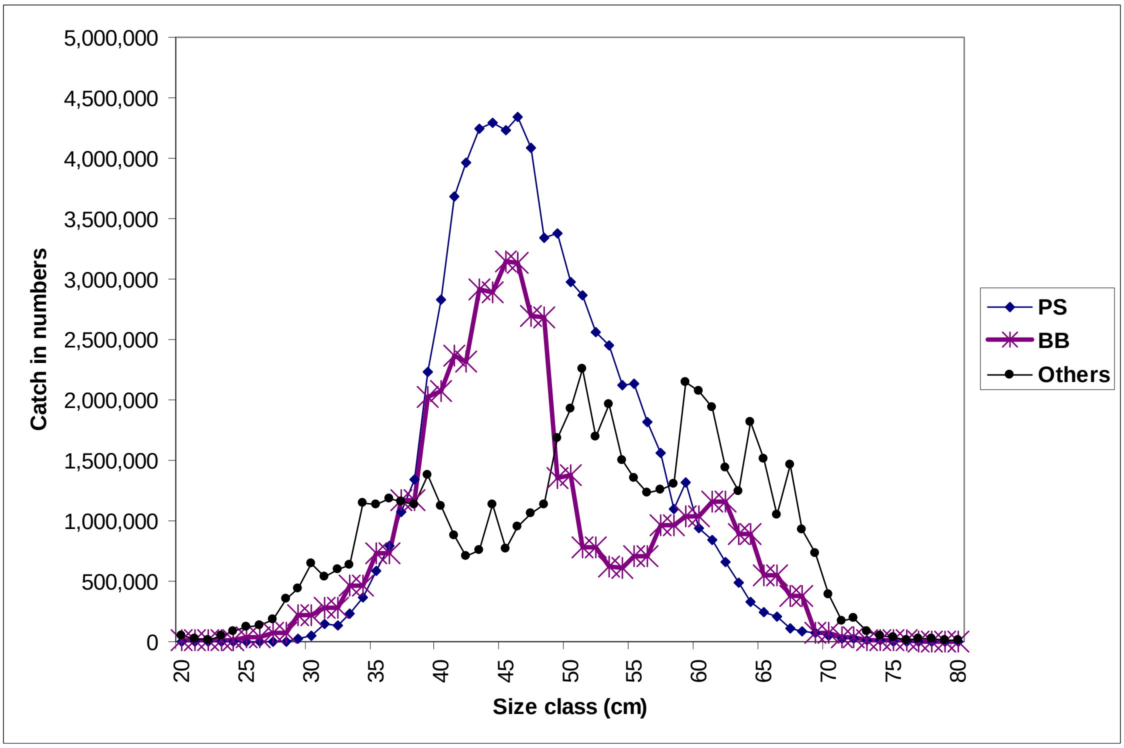

Figure 6: Size frequency of skipjack catches in the Indian Ocean by gear type.

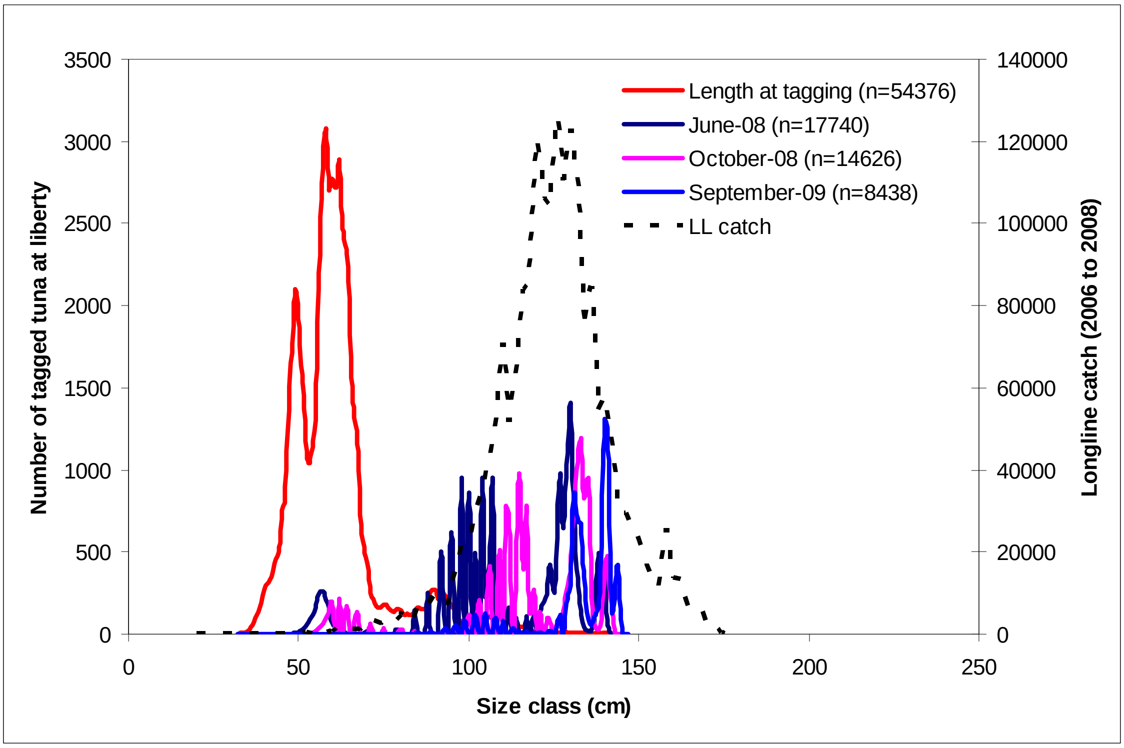

Figure 7: Numbers and size frequency of **yellowfin** tuna tagged by the RTTP-IO and observed size distribution of yellowfin tuna caught by the longline fishery in the Indian Ocean between 2000 and 2006. Solid lines are plotted on the primary y axis, while the dotted line is on the secondary y axis.

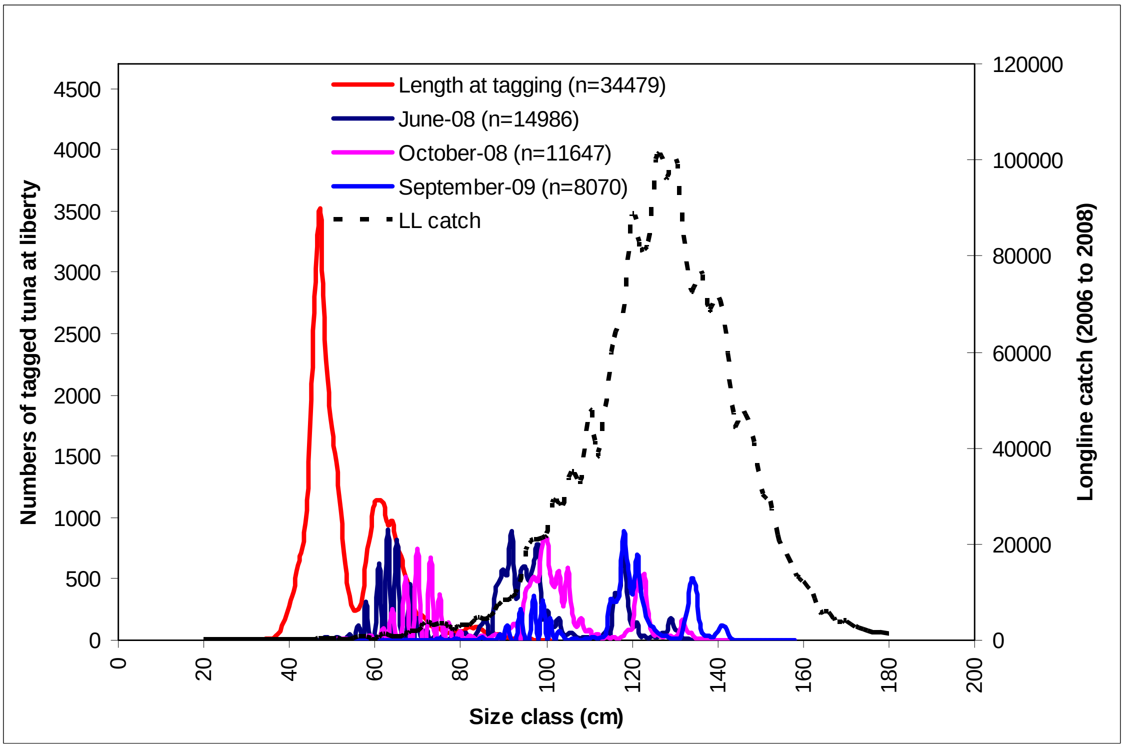

Figure 8: Numbers and size frequency of **bigeye** tuna tagged by the RTTP-IO and size distribution of bigeye tuna caught by the longline fishery in the Indian Ocean between 2000 and 2006. Solid lines are plotted on the primary y axis, while the dotted line is on the secondary y axis.

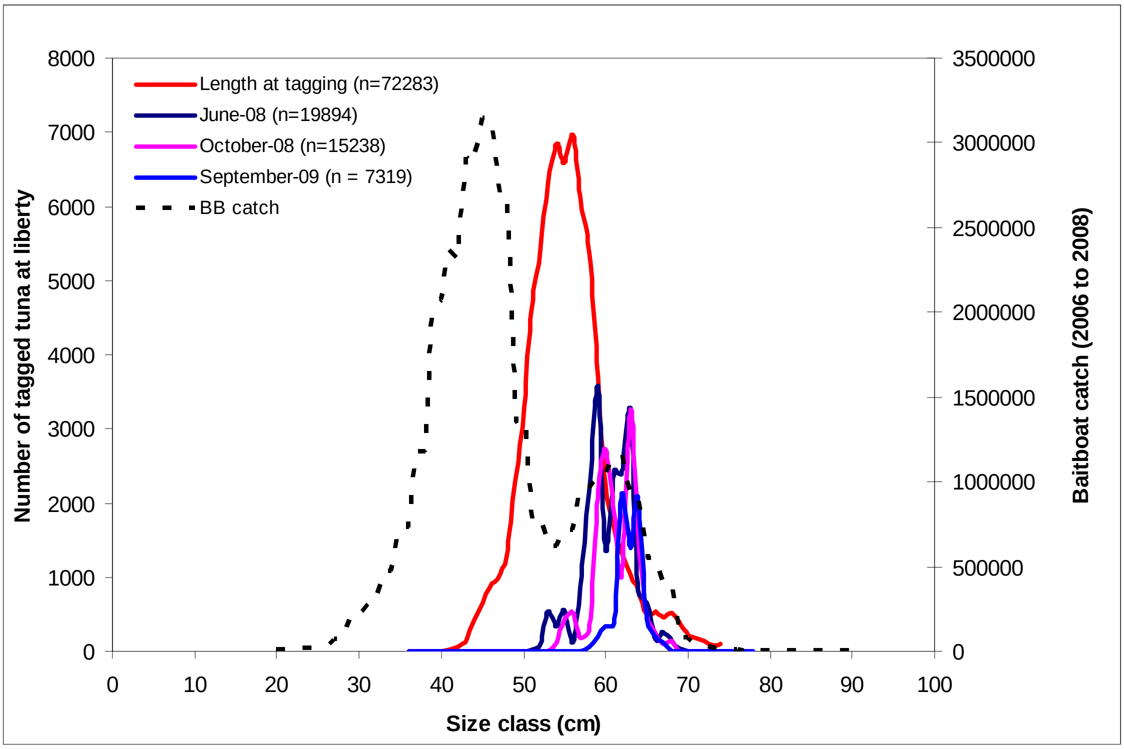

Figure 9: Numbers and size frequency of skipjack tuna tagged by the RTTP-IO and observed size distribution of skipjack tuna caught by the baitboat fishery in the Indian Ocean between 2006 and 2008. Solid lines are plotted on the primary y axis, while the dotted line is on the secondary y axis.

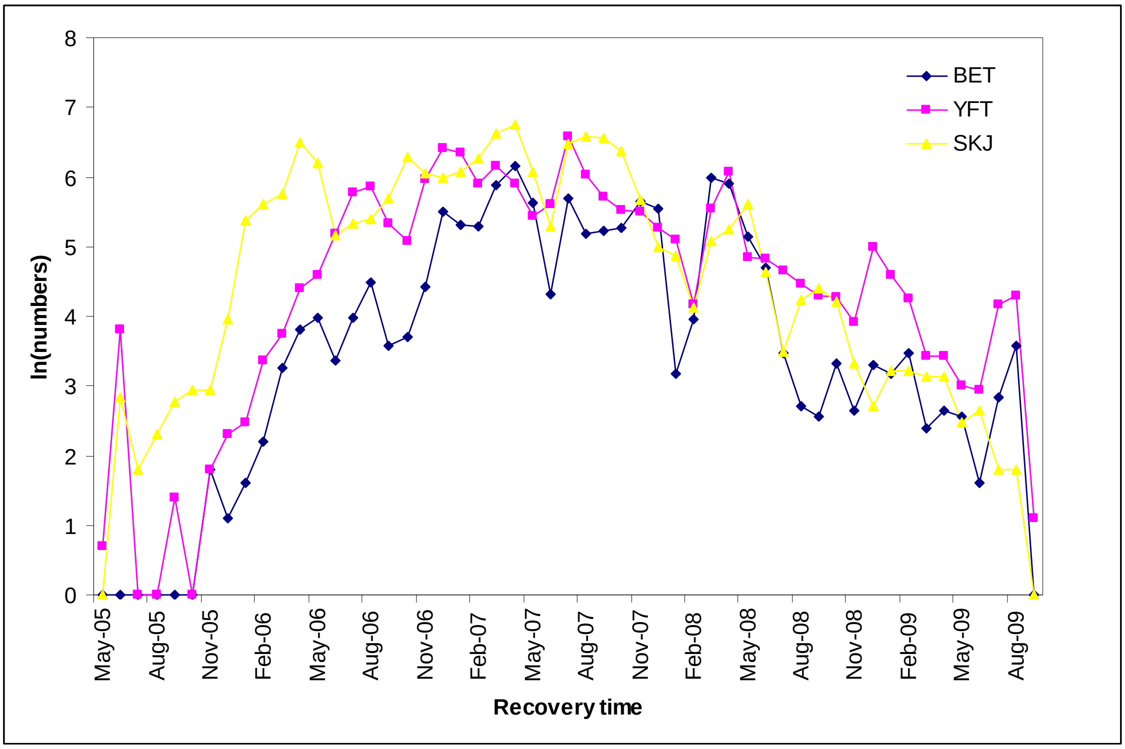

Figure 10: Overall trends by species of reported recoveries