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An update of the Indian Ocean skipjack growth curve parameters with tagging data. Some new evidences on area-specific growth rates.

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Abstract – In order to assess the growth of the Indian Ocean skipjack (*Katsuwonus pelamis*), recaptures of conventional tagging data released during the Regional Tuna Tagging Project of the Indian Ocean (RTTP-IO) between May 2005 and August 2007 were reanalyzed using the von Bertalanffy-Fabens growth model. Our results (ie, K = 0.282 and L_∞ = 76.876 cm) are consistent with the range of growth estimates obtained in different parts of the World's oceans and alternative model such as Gompertz equation was not supported by the data. However our findings suggest that growth of skipjack exhibits phenotypic plasticity among regions of the Indian Ocean which should be taken into account to assess the responses of skipjack to exploitation.

Résumé – Dans le but d'évaluer la croissance du listao (*Katsuwonus pelamis*) dans l'océan Indien, les données de recapture des marques traditionnelles relachées durant le marquage traditionnel réalisé par le Programme Régional de Marquage des Thonidés de l'Océan Indien (RTTP-IO) entre mai 2005 et aout 2007 ont été réanalysées à l'aide du modèle de croissance de von Bertalanffy-Fabens. Nos estimations (K = 0.282 et $L_{\infty =}$ 76.876 cm) sont consistantes avec les estimations des paramètres de croissance obtenus dans différentes parties de l'océan mondial et il n'y a pas d'évidence que d'autres modèles de croissance comme le modèle de Gompertz ajuste mieux les données. Toutefois, nos travaux indiquent que la croissance du listao montre une variabilité phénotypique en fonction des régions et que cet aspect doit être pris en compte lors des évaluations des stocks de listaos.

Introduction

Tagging studies are essential in stock assessments studies because of the variety of information on the species under study, such as stock structure, growth rate, gear selectivity, migrations, survival/mortality, immediate mortality due to tagging, etc. Consequently, conventional tagging is one of the research tools 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. Between May 2005 and August 2007, around 79,000 skipjacks were tagged with conventional "spaghetti" tags within the framework of the Regional Tuna Tagging Project of the Indian Ocean (RTTP-IO). The aim of this paper is to update previous findings on skipjack growth (de Bruyn and Murua, 2009) with the most complete and updated tagging data set. Bearing in mind the relative short life duration of this species, it can be reasonably assumed that the quasi totality of recaptures has been reported yet.

Material and methods

Data

Measurements of the fish were taken, with callipers, from the tip of the snout to the fork of the tail to the nearest centimeter or half-centimeter. Only fish with accurate species identification at release, good fork length reliability at release and at recapture, exact known date at tagging and at recapture and with time at sea larger than 20 days were used in the present study. From a subset of 5087 data, recaptures of fish with growth rate outside the 0.025 and 0.975 growth rate quantiles have been omitted (reducing the data set to 4696 individuals). The limitation concerning days at sea larger than 20 days is to take into account possible stress of the fish that will disrupt the growth and slight measurement errors as tuna were measured directly on the tagging cradle. The attempt to eliminate suspicious growth rate is directly related to measurement errors that can be done negatively or positively. From an explanatory analysis based on Fabens' equation, 4 outliers were detected by visual inspection and omitted for the statistical analysis.

Method

Growth was modelled using the translation of the von Bertalanffy curve formalized by Fabens (1965) to account for the sort of information obtained from tagging programmes (i.e., tag release and recapture lengths and time at liberty data):

$$\Delta L = (L_\infty - L_t)(1 - e^{-K\Delta t})$$
$$\Delta L = L_{t+\Delta t} - L_t$$

where the increment in length ΔL through the period Δt (i.e., the time at liberty) is calculated as the difference between the size at recapture $Lt+\Delta t$ and the size at tagging Lt ; K and L_∞ are the conventional growth rate coefficient and the asymptotic average maximum length of the von Bertalanffy curve, respectively (Haddon 2001).

Gompertz growth curve formulation for tagging data was also explored:

$$\Delta L = \left(L_\infty \left({}^{L_t}\!/_{L_\infty} \right)^{e^{-K\Delta t}} \right) - L_t$$

In both cases, assuming normal random errors, the likelihood function $L(\theta)$ can be represented by:

$$L(\theta) = \prod \left(\frac{1}{\sigma\sqrt{2\pi}} e^{-\frac{(\Delta L - \Delta \hat{L})^2}{2\sigma^2}} \right)$$

The maximum likelihood estimates of L_∞ and K, are obtained by minimising the negative logarithm of $L(\theta)$: (LL), which is :

$$LL = -\sum Ln \left(\frac{1}{\sigma\sqrt{2\pi}} e^{-\frac{(\Delta L - \Delta \hat{L})^2}{2\sigma^2}} \right)$$

where σ is the standard deviation which can be obtained analytically (as in the present study) or estimated as a free parameter in the likelihood function.

Confidence intervals (95% C.I.) of the parameters of interest were estimated by bootstrapping the residuals (B = 1000).

We used the Akaike's information criteria (AIC) as an objective means of model selection from a set of candidate models. The model j with the smallest AIC (the parsimonious model) is used for estimating growth rate by length at release, such as:

$$AIC_j = -2Log\left[L(\theta)_j\right] + 2k_j$$

with $L(\theta)$ is the maximum likelihood estimates of the model parameters (θ) and k is the number of parameters for model j.

Results

Conventional regression diagnostic plots were used to identify outliers and influential observations (Figure 1). Whatever the growth model used there is not any strong evidence of strange pattern or unusual values and the models fit relatively well the data.

Using the Akaike information criterion as the tool for model selection, the Fabens' model with the highest weight of evidence was deemed the most plausible given the data and set of candidate models (Table 1). Consequently the corresponding estimates of the asymptotic length (L_∞ = 76.88 cm), the growth rate coefficient (K = 0.28 cm/year) and the corresponding bootstrapped C.I. (74.98-79.19 and 0.26-0.31, respectively) provided by the Fabens' model are shown in Table 2 (while Gompertz's parameters were estimated at 72.70 and 0.41). It may be stressed that one of the limits of tagging data is the lack of an associated age estimate for each capture-recovery data. However since growth rate is at about 16 - 20 cm/year for skipjack close to 30 - 35 cm (fork length) at release (Figure 2) it may be assumed that these juveniles were plausibly 1 – 1.5 year old.

Discussion and conclusion

Our results reinforce previous analyses conducted with a reduced tagging data set (de Bruyn and Murua, 2009) but show some discrepancies with historic studies conducted on Indian Ocean skipjack growth (Table 3). In opposite, these estimates are in agreement with the estimates of the growth parameters obtained from skipjacks tagged in the eastern Atlantic (Gaertner et al 2008), in the Gulf of Guinea (Chur and Zharov 1983; Bard and Antoine 1986), in the western Atlantic (Vilela and Castello 1991; Pagavino and Gaertner 1995), as well as in other parts of the world's oceans (Table 3; Figure 3).

It should be stressed however that phenotypic plasticity exhibited by growth of skipjack among latitudinal regions has been evidenced in different parts of the world ocean (Bard and Antoine 1986; Bayliff 1988, Gaertner et al, 2008). In the case of Indian Ocean skipjack, the bimodal structure depicted by the bootstrapped distributions of the growth parameters of interest (Figure 4) suggests that growth rate may vary between large distance regions and consequently that further studies on area-specific growth rate are essential to better understand the growth of this species, as well as to integrate its spatial variability into accurate stock assessment methods.

References

Adams M.S., 1999, Population Dynamics and Assessment of Skipjack Tuna (*Katsuwonus pelamis*) in the Maldives. PhD dissertation, Renewable Resources Assesment Group. Centre for Environmental Technology, T.H. Huxley School of Environment, Earth Sciences and Engineering, Imperial College of Science Technology and Medicine, Univ. of London.

Amarasiri C., Joseph L., 1987, Skipjack tuna (*Katsuwonus pelamis*) - aspects on the biology and fishery from the western and southern coastal waters of Sri Lanka. IPTP. Coll. Vol. Work. Doc. 2, 1–10.

Bard F.X., Antoine L., 1986, Croissance du listao dans l'Atlantique Est. In: Symons P.E.K., Miyake P.M., Sakagawa G.T. (Eds.), Proc. ICCAT conference on the international skipjack year program, Madrid, pp. 301–308.

Bayliff W.H., 1988, Growth of skipjack, *Katsuwonus pelamis* and yellowfin, *Thunnus albacares*, tunas in the Eastern pacific Ocean, as estimated from tagging data. Inter-Am. Trop. Tuna Comm. Bull.19, 311–358.

Brock V.E., 1954, Some aspects of the biology of the aku (*Katsuwonus pelamis*) in the Hawaiian Islands. Pac. Sci. 8, 94–104.

Brouard F., Grandperrin R., Cillaurren E., 1984, Croissance des jeunes thons jaunes (*Thunnus albacares*) et des bonites (*Katsuwonus pelamis*) dans le Pacifique tropical occidental. ORSTOM de Port-Vila, Notes Doc. Océanogr. 10.

Cayré P., Diouf T., Fonteneau A., 1986, Analyse des données de marquages et recaptures de listao (*Katsuwonus pelamis*) réalisés par le Sénégal et la République du Cap-Vert. In: Symons P.E.K., Miyake P.M., Sakagawa G.T. (Eds.), Proc. ICCAT conference on the international skipjack year program, Madrid, pp. 309–316.

Chi K.S., Yang, R.-T., 1973, Age and growth of skipjack tuna in the waters around the southern part of Taiwan. [Summ. in Chin.] Nat. Taiwan Univ. Sci. Rep. Acta Oceanogr. Taiwanica 3, 199–221.

Chur V.N., Zharov, V.L., 1983, Determination of age and growth of the skipjack tuna, *Katsuwonus pelamis* (Scombridae) from the southern part of the Gulf of Guinea. J. Ichthyol. 23, 53–67.

De Bruyn P., and Murua H., 2009, Two simple alternative growth models for skipjack tuna (*Katsuwonus pelamis*) in the Indian Ocean, as estimated from tagging data. IOTC-2008-WPTDA-09, 12p.

Fabens A.J., 1965, Properties and fitting of the von Bertalanffy growth curve. Growth 29, 265–289.

Gaertner, D., Delgado de Molina, A., Ariz, J., Pianet, R., and Hallier, J.-P., 2008, Variability of the growth parameters of the skipjack tuna (*Katsuwonus pelamis*) among areas in the eastern Atlantic: Analysis from tagging data within a meta-analysis approach. Aquat Living Resour. 21: 349-356

Haddon M., 2001, Modelling and quantitative methods in fisheries. Chapman and Hall/CRC, Boca Raton.

Hafiz A., 1987, Skipjack fishery in the Maldives. IPTP. Coll. Vol. Work. Doc. 2, 11–22.

Joseph J., Calkins T.P., 1969, Population dynamics of the skipjack tuna *Katsuwonus pelamis* of the Eastern Pacific Ocean. Bull. Inter. Am. Trop. Tuna Comm. 13.

Josse E., Le Guen J.C., Kearney R., Lewis A., Smith A., Marec L., Tomlinson P.K., 1979, Growth of skipjack. South Pacific Commission, Noumea, Occas. Pap. 11.

Marcille J., Stéquert B., 1976, Etude préliminaire de la croissance du listao (*Katsuwonus pelamis*) dans l'ouest de l'océan Indien tropical. Cah. ORSTOM Sér. Océanogr. 14, 139–151.

Mohan M., Kunhikoya K.K., 1985, Age and growth of *Katsuwonus pelamis* (Linnaeus) and *Thunnus albacares* (Bonnaterre) from Minicoy waters, In: Silas E.G (Ed.) Tuna Fisheries of the Exclusive Economic Zone of India: Biology and Stock Assessment 36, CMFRI 143.

Pagavino M., Gaertner D., 1995, Ajuste de una curva de crecimiento a frecuencias de tallas de atun listado (*Katsuwonus pelamis)* pescado en el Mar Caribe suroriental. Col. Vol. Sci. Pap. ICCAT 44, 303–309.

Sibert J.R., Kearney R.E., Lawson T.A., 1983, Variation in growth increments of tagged skipjack *Katsuwonus pelamis*. Tuna and Billfish Assessment Programme. South Pacific Commission, Noumea, Tech. Rep. No. 10.

Sivasubramaniam K., 1985, Tunas and their fishery in the EEZs of Maldives and Sri Lanka. BOBP/WP/31, Bay of Bengal Programme (BOBP), Madras.

Tanabe T., Kayama S., Ogura M., 2003, An outline of the growth study on skipjack tuna (*Katsuwonus pelamis*) in the Western Pacific. Doc. IOTC WPTT-03-17.

Uchiyama J.H., Struhsaker P., 1981, Age and growth of skipjack tuna *Katsuwonus pelamis*, and yellowfin tuna, *Thunnus albacares*, asindicated by daily growth increments of sagittae. Fish. Bull. 79, 151–162.

Vilela M.J.A., Castello J.P., 1991, Estudio de la edad y del crecimiento del barrilete *Katsuwonus pelamis*, en la region Sur y Sudeste de Brasil. Frente Marit. 9, 29-35.

Wankowski J.W.J., 1981, Estimated growth of surface schooling skipjack tuna, *Katsuwonus pelamis*, and yellowfin tuna, *Thunnus albacares*, from the Papua New Guinea Region. Fish. Bull. 79, 517–532.

Wild A., Hampton, J., 1994, A review of the biology and fisheries for skipjack tuna, *Katsuwonus pelamis*, in the Pacific Ocean. FAO Fish. Tech. Pap. 336, No. 2.

Yao M., 1981, Growth of skipjack tuna in the western Pacific Ocean. Bull. Tohoku Reg. Fish. Res. Lab. 43, 71–82.

Table 1 Model selection for determining growth curve model from tagging data for Indian Ocean skipjack with (Nll) negative log-likelihood, (N. par.) number of parameters, (AIC) Akaike Information Criterion, (ΔAIC) Delta AIC, (W_i) Akaike's information criterion weight.

Model	Nll	N. par	AIC	ΔAIC	W_i
Fabens	10640,49	2	21284,98	0	0,999
Gompertz	10654,52	2	21313,04	28,06	8,07E-07

Table 2. Summary of bootstrapped statistics for the von Bertalanffy-Fabens model from Indian Ocean tagging data

Estimate	K	L_∞
mean	0.282	76.897
median	0.282	76.876
C.I.	0.256-0.306	74.978-79.187

Table 3. Estimates of growth parameters from different studies for skipjack in the world's oceans.

Area	L_∞	K	Method	Reference
E. Atlantic G. of Guinea	80	0.32	Tagging	Bard and Antoine, 1986
E. Atlantic N. trop	80	0.60	Tagging	Bard and Antoine, 1986
E. Atlantic G. of Guinea	86.7	0.31	Spines	Chur and Zharov, 1983
E. Atlantic Senegal	62	2.08	Tagging	Cayré et al, 1986
E. Atlantic Cap Vert	60	1.54	Tagging	Cayré et al, 1986
E. Atlantic North 10°N	91.82	0.35	Tagging	Gaertner et al, 2008
E. Atlantic South 10°N	85	0.22	Tagging	Gaertner et al, 2008
W. Atlantic Caribbean sea	94.9	0.34	Length-freq	Pagavino and Gaertner, 1995
W. Atlantic Brasil	87.12	0.22	Spines	Vilela and Costello, 1991
Indian Ocean	60.6	0.93	Length-freq	Marcille and Stequert, 1976
Indian Ocean Maldives	64.3	0.55	Tagging	Adams, 1999
Indian Ocean Maldives	82	0.45	Length-freq	Hafiz, 1987, in Adams 1999
Indian Ocean Sri Lanka	85	0.62	Length-freq	Amarasiri and Joseph, 1987
Indian Ocean Sri Lanka	77	0.52	Length-freq	Sivasubramanium, 1985; in Adams, 1999
Indian Ocean Minicoy	90	0.49	Length-freq	Mohan and Kunhikoya, 1985; in Adams, 1999
E. Pacific	75.5	0.77	Tagging	Sibert et al, 1979
E. Pacific	79	0.64	Tagging	Josse et al, 1979
E. Pacific N	96.3	0.52	Tagging	Bayliff, 1988
E. Pacific S	66.5	1.81	Tagging	Bayliff, 1988
E. Pacific	73	0.82	Tagging	Joseph and Calkins, 1969
E. Pacific	107	0.42	Length-freq	Joseph and Calkins, 1969
W. Pacific	61.3	1.25	Tagging	Sibert et al, 1979
W. Pacific	65.5	0.95	Tagging	Josse et al, 1979
W. Pacific Vanuatu	60	0.75	Length-freq	Brouard et al, 1984
W. Pacific Trop. & Jap.	93.6	0.43	Otolith	Tanabe et al, 2003
W. Pacific Japan	76.6	0.60	Length-freq	Yao, 1981; in Wild and Hampton, 1994
W. Pacific Taiwan	103.6	0.30	Vertebrae	Chi and Yang, 1973; in Wild and Hampton, 1994
Central Pacific	102.2	0.55	Otolith	Uchiyama and Struhsaker, 1981
Central Pacific	80	0.95	Grouped L-freq	Brock, 1954; in Adams, 1999
Central Pacific West	74.8	0.52	Length-freq	Wankowski, 1981

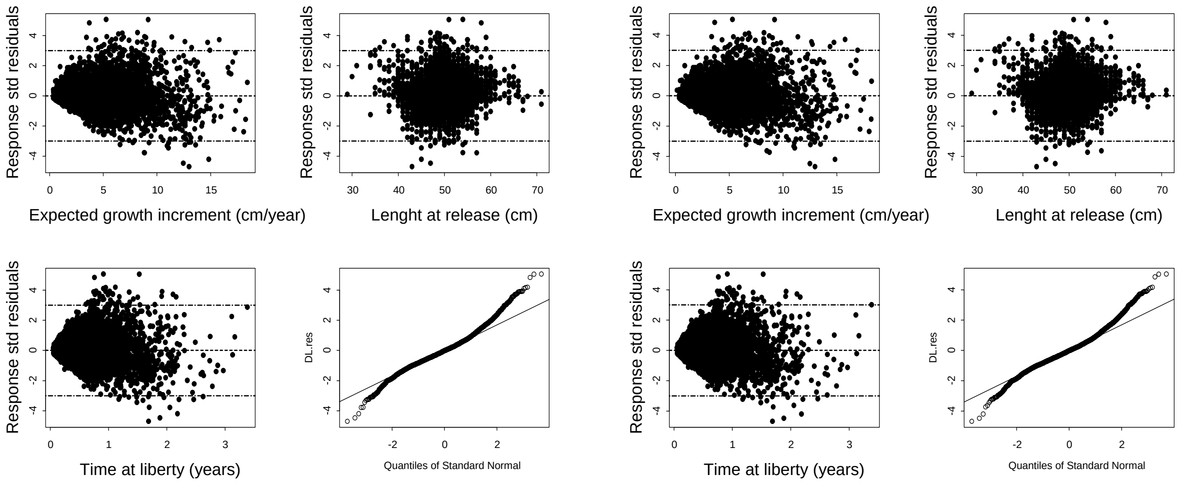

Figure 1. Diagnostic plots for skipjack growth rate from the Fabens' model (left) and from the Gompertz model (right)

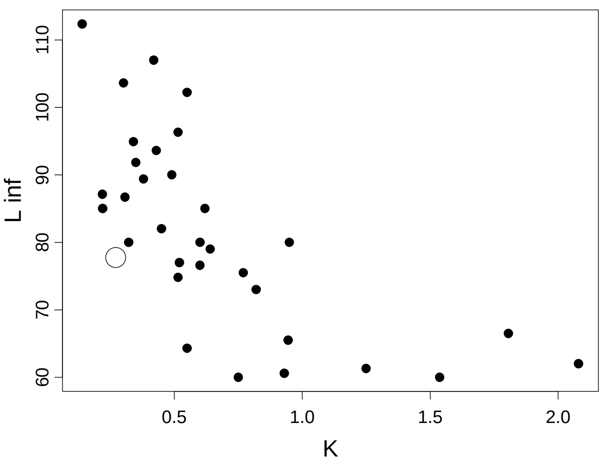

Figure 2. Distributions of skipjack growth parameters L_{∞} and K estimated from existing studies in the world's oceans (see, Table 1). The updated joint median estimate is represented by an empty circle.

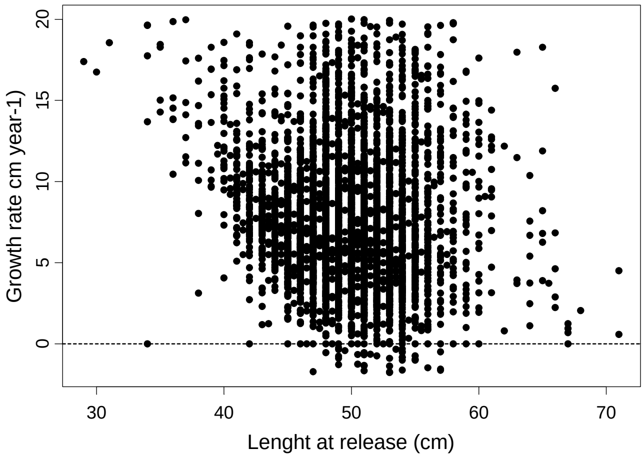

Figure 3 Growth rate by length at release for the Indian Ocean Skipjack from tagging data

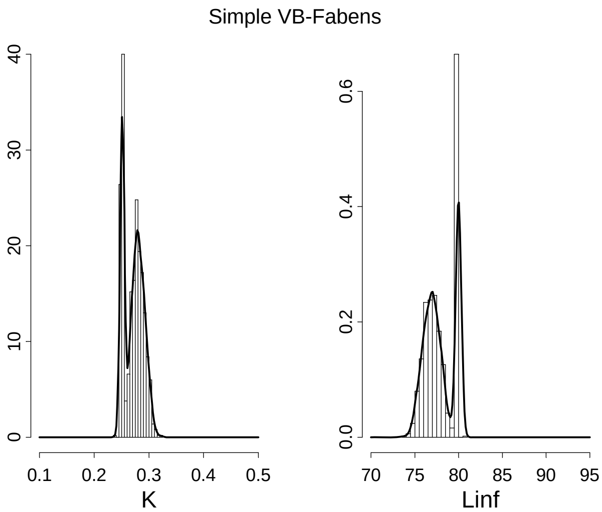

Figure 4. Bootstrapped values of the growth parameters K and L_∞ for Indian Ocean skipjack based on the conventional von Bertalanffy-Fabens model. The bimodal structure suggests area-specific growth rates as observed in other oceans.