# **LIFE HISTORY PARAMETERS OF JACK MACKEREL (*Trachurus murphyi*, Nichols 1920) BASED ON THE NEW VALIDATED AGEING CRITERIONS**

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# **INTRODUCTION**

Age determination of jack mackerel (JM) a long time were supported on indirect validation of the age through marginal increment analysis, which indicate the annual translucent zone formation fish each winter (Serra & Gili, 1995; Castillo & Arrizaga, 1987). We currently have evidence of JM age validation that was curried out of the FIPA 2014-32 study "Protocol of jack mackerel ageing ". In this study the ages of jack mackerel were validated using three methods: 1) daily microincrement readings in sagittal otoliths of young-of-the year (YOY) fish to validate the first annulus; 2) modal progression of strong year-classes (PSYC) to validate the first, second and third annuli, and 3) bomb radiocarbon analysis of otolith cores to validate the absolute age in older >38 cm fork length (hereafter as L). A Laird-Gompertz (LG) model was fitted to fork length (cm) at age (days) relationship in ranging from 3.4 to 23.0 cm L and from 56 to 550 days in age. The LG model estimated a mean L of 22 cm at the end of the year of life, which was large compared with the mean L estimated through conventional ageing in whole otoliths. The comparison between daily age with annual growth bands from whole otoliths, showed a false increment formed at 185 ± 34 days and a second translucent increment formed at the 352 ± 79 days, corresponding to the annulus for with the mean L of 21.4 ± 1.8 cm. The PSYC coinciding with the recruits of 2008 (age 0), was tracked through three subsequent years with high accuracy, attaining 23, 27 and 30 cm L in 2009, 2010 and 2011, respectively. These modes identified as age 1, age 2 and age 3 in the PSYC, matched to the mean length of with 2, 4 and 5 translucent increments in sagittal otoliths. Results from Bomb radiocarbon analysis evidenced most the ages were correct, because the Δ14C content of adult otolith core matched the reference chronology. The absolute mean ages for the assayed otoliths, based on the comparison with the reference chronology, ranged from 7 to 13 years for sizes between 39 and 60 cm L (Cerna et al. 2016).

A second validation study (FIPA 2017-61 "Validation of the formation of daily growth rings of jack mackerel") allowed to validate the primary micro-increments of jack mackerel otoliths, confirming that these have a daily periodicity. The relationship between the daily micro-increments with the length of the fish and the radius of the otolith showed that the mean length and radius at 365 days was 21.3 cm L and 3 mm, respectively, confirming the high growth rate for the jack mackerel first year of life. These studies shows a high growth rate the two first year of life compared to estimates made up to that time.

Based on these validation results, the otolith reading criteria for jack mackerel age estimation were modified and the life history parameters were recalculated.

# **METHODOLOGY**

## **Reconstruction of maturity ogives at age.**

The maturity ogive at the age of females was estimated using histological maturity data on samples collected between September 2011 and January 2012. This was estimated by Leal *et al*. (2013). The age was estimated by reading whole otoliths from 179 females, based on historical age determination criteria. These otolith readings were modified by removing the first and third growth rings, which according to age validation correspond to false rings.

A logistic model was applied to describe sexual maturity as a function of jack mackerel age. This is described below:

$$P=\frac{1}{1+exp\left(β\_{0}-β\_{1}\*L,A\right)}$$

where P is the ratio of mature individuals to fork length (L) or age (A), β1 and β2 are the parameters that represent the position and slope of the curve, respectively. These parameters were obtained by maximum likelihood, assuming a binomial distribution (mature/immature) of the random variable. The log-likelihood estimation function is expressed as follows:

$$L\left(β\_{0},β\_{1}\right)=\sum\_{}^{}k ln\left(P\right)+\left(1-h\right) ln\left(1-P\right)$$

where k indicates the presence or absence of mature individuals, P is the previously described logistic function.

The fork length or mean age of maturity which is defined as that at which the fish has a 50% probability of being mature. It was estimated as the ratio between the parameters β0 and β1:

$$A\_{50}=\frac{β\_{0}}{β\_{1}}$$

All the specimens that presented stages II to V were considered mature, according to the microscopic table of jack mackerel maturity stages described by Leal *et al*. (2013).

## **Estimation of the growth parameters**

This report uses the 2008 reading database in a preliminary way, transformed according to the validation criteria, which indicate that the first and third rings are false. The 2008 database was used mainly because it was the year used for age validation, based on the microstructure analysis of juvenile otoliths, as well as the method of progression of the size distribution of a strong year class.

The length-age relationship of data at the time of capture was fitted to the von Bertalanffy (vB) growth model for combined sexes, whose function is as follows

$$L\_{t}=L\_{\infty }\*\left(1-e^{-K\left(t-t\_{0}\right)}\right)$$

where: Lt is the fork length of the fish at age t, L∞ is the maximum asymptotic length, K is the speed growth coefficient, t is the age, t0 is the hypothetical age when the length of the fish is zero.

The model was fitted using the R-project "FSA" package, developed by Ogle (2016). The adjustment included the estimation of the confidence interval at 95% of the parameters calculated by bootstrapping, using the nlsBoot() function of the nlstools package (Baty et al. 2015)

**Estimation of natural mortality (M)**

Estimates of M using empirical models using the parameters for growth (L∞, K and t0), longevity and length and mean age at maturity (L50, A50) are presented in this report. Both growth parameters and the L50 correspond to those estimated in this study.

For the estimation of M, the Hoening\_nls and Pauly\_nls-T estimators recommended by Then et al. (2015) were used. In addition, the method of Rikhter & Efanov (1976), which considers the average age of maturity, and that of Zhang & Megrey (2006), which includes the K and t0 of the growth model vB and the longevity or maximum age, were used.

* Hoening\_nls model.

$$M=4.899t\_{max}^{-0.916}$$

Maximum age of this equation uses (Tm) observed which corresponds to 17 years.

* Pauly\_nls-T method.

$$M=4.118k^{0.73}L\_{\infty }^{-0.33}$$

* Rikhter & Efanov method (1976).

This method shows the relationship between M and the average age of sexual maturity (E50) according to the following expression:

$$M=\left(\frac{1.521}{E\_{50}^{0.72}}\right)-0.155$$

where: M is the natural mortality and E50 is the maturity age, which is going to be estimated in this study.

* Zhang & Megrey method (2006) calculated using the Cope platform <http://barefootecologist.com.au/shiny_m>

$M=\frac{βK}{e^{K\left(t\_{mb}-t\_{0}\right) }-1}$ $t\_{mb}=C\_{i}\left(t\_{max}\right)$

where: M is the natural mortality, L∞ and K are parameters of the von Bertalanffy model, tmax is the maximum age recorded, β is the slope of the length-weight relationship and Ci is a constant for ecological group i, in pelagic it is equal to 0.38 (Zhang & Megrey 2006).

# **RESULTS**

## **Reconstructed mature-at-age ojives**

Jack mackerel individuals captured in 2011 reached the mean age of maturity (A50%) at 0.99 years of life (~1), lower than that reported by Leal et al., (2013), who estimated, with the histological age reading criterion, 2.5 years (**Figure 1**).



**Figure 1.** Sexual maturity ogive estimation at age (**A50%)** of female jack mackerel, based on the histological analysis of samples collected during the 2011 reproductive period (Leal *et al*. 2013).

## **Estimation of the growth parameters**

The growth adjustment made with the von Bertalanffy model was adequate for the 2008 age-length data distribution, with low standard error and high significance of the three model parameters (**Table 1**). Data show a significant number of specimens of age zero and a maximum age of 16 years (**Figure 2**).

**Table 1**

Growth parameters with their standard error, confidence interval at 95% and significance, estimated with the von Bertalanffy model, for jack mackerel age-length data collected in 2008 in the national fishing ground off Chile.

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
|  |  |  | Confidence interval 95% |  | Statistical significance |
| Parameters | Value | Est. Error | Lim. Inf. | Lim. Sup. |  | t value | Pvalue | -LogVeros. | R2 |
| L∞ | 68.96 | 0.9636 | 67.16 | 70.78 |  | 71.56 | <2e-16 | -7550.1 | 0.74 |
| K | 0.088 | 0.0025 | 0.083 | 0.092 |  | 35.17 | <2e-16 |  |  |
| t0 | -3.18 | 0.0598 | -3.30 | -3.08 |  | -53.21 | <2e-16 |  |  |
| n | 3176 |  |  |  |  |  |  |  |  |

**Figure 2**. Growth curve of the von Bertalanffy model for jack mackerel for the age-length data collected in 2008 in the national fishing zone off Chile. The curve shows the 95% confidence interval as a dashed line.

## **Estimation of the natural mortality (M)**

Estimation of natural mortality, estimated by three empirical models showed significant differences in its results, with values ranging between 0.25 with the Zhang & Megrey model up to 1.37 with the Rikhter & Efanov model (**Table 2**).

**Table 2**

Estimation of the natural mortality (M) applying four empirical models

|  |  |
| --- | --- |
| **Method** | **M** |
| Zhang & Megrey | 0.25 |
| Hoening | 0.37 |
| Pauly | 0.92 |
| Rikhter & Efanov | 1.37 |

**DISCUSION**

## **Reconstruction of the maturity ogive**

In the update of the estimation of the mean maturity age (A50%), used the same age reading transformation criterion applied to update the readings of the historical series was used, that is, considerate the first and third ring as false. The new mean age is 1.5 years lower than that estimated by Leal et al. (2013), for the same sample collected in 2011. In other words, according to the current age reading, 50% of the jack mackerel population begins to spawn when they are one year old. Although a more adequate calculation of this parameter should be made by reading each of the otoliths, the preliminary result shown in this report should be an accurate approximation. Although there are species of the genus *Trachurus* with a mean maturity age between 2 and 4 years such as Trachurus picturatus (García et al. 2015), *Trachurus trachurus* (Abaunza et al. 2003), in *Trachurus mediterraneus* it has been estimated between 1 and 2 years (Păun et al. 2019) and in Trachurus japonicus 1 year (Yoda et al. 2014).

**Estimation of growth parameters**

The jack mackerel age-length data distribution from the national area (Arica to Guaitecas) from 2008 shows a range of ages between 0 and 16 years for sizes that ranged between 9 and 63 cm of fork length, which can be considered a good distribution of sizes and ages of this species, to estimate growth parameters. The preliminary estimation presented in this progress report is based on age estimates that were transformed, according to the same procedure used to prepare the new age structure matrices of the catches.

Although the validation background shows that jack mackerel growth is faster in the first two years of life, the vB model parameters estimated in current study, such as L∞ (68.96 cm L) and K (0.088) are similar estimated by Gili et al. (1996), with back-calculated length-at-age data from the central-southern zone of Chile, with an L∞ of 70.80 cm L and a K (0.094). That is, although the mean size of the fish at early ages in current study is greater than reported by Gili et al. (1996), this difference decreases in older fish (>9 years), reaching both estimations, a similar asymptotic length.

Other studies, for similar asymptotic lengths, show higher growth coefficients (Kochkin 1994; Dioses 2013; Goicochea et al. 2013) or lower than this study (Castillo & Arrizaga 1987; Gili et al. 1996). Although our estimates are preliminary, because the validated age-length data must be obtained from new readings and not ageing old transformed. However, the parameters estimates in current study, are more reliable than obtain in previous studies, because it's supported by age validation studies.

## **Estimate of natural mortality**

The natural mortality, estimated by empirical methods using growth parameters, have been reported by Arcos *et al*. (1995), that show a range of estimations between 0.10 and 0.33 years-1. In the jack mackerel stock assessment model, a value of 0.23 years-1 has been used (Canales & Serra, 2008 non-published report). The current study includes empirical methods of Hoening\_nls and Pauly\_nls-T adjusted by Then *et al*. (2015), Rikhter & Efanov (1976), Zhang & Megrey (2006) with values ranging between 0.25 and 1.37 years-1. The highest value corresponded to the method of Rikhter & Efanov that uses in its estimation the maturity mean age. The lowest value corresponded to the method of Zhang & Megrey that uses growth parameters (L∞ y K) and also the maximum age. This last estimate is close to the value currently used in the stock assessment model, could be consider more appropriate because the equation combines the growth parameters, which reflect the current higher growth rate, with the maximum age that show a accuracy longevity of JM. In other words, the estimate of M using this combination of parameters could be to better characterizes the life history of this species.

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