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Age validation and growth function of Chilean jack mackerel (*Trachurus murphyi*) off Chile

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Abstract

The ageing of jack mackerel, *Trachurus murphy* of southern Pacific Ocean, was validated using three methods: 1) primary micro increment reading in 45 sagitta otolith of YOY to validate the first annulus; 2) modal progression of length frequency to validate the second annulus, and 3) bomb-radiocarbon trials of 15 otolith cores whose year of formation ranged from 1960 to 1972 to validate the absolute age in older fish over 38 cm FL. The result allowed the correction of the conventional ageing in order to estimate new vB growth parameters. The age (days) - fork length (cm) relationship fitted used Laird-Gompertz model of fishes between 3.4 and 23.0 cm FL and ages from 56 to 550 days. This allowed to estimate that the first annulus was formed when fish have in mean 22 cm FL. This estimation is larger compared with mean fork length estimated through conventional ageing whole otolith. The progression of first mode of length frequency distribution corresponding at the recruits of 2008 (age 0), was tracked through three-next years with quite accuracy. The mean lengths estimated by mixture analysis method showed that progression of jack mackerel mode from one to two years old was 23 and 27 cm FL, respectively. This result also shows a high growth rate for the second-year as compared to the conventional ageing method, confirming the result for first annulus estimated from otolith microstructure analysis. Bomb-radiocarbon analysis results suggest that some of the otolith ages appear to be older, because the cores formed before about 1964 should not have such high radiocarbon values. However, when the formation year was estimated from ageing corrected with result of validation for first and second annulus, the jack mackerel ages provide reasonable estimates. Finally, the results show high growth in juvenile and YOY of jack mackerel that suggest the possible age overestimation from conventional whole otolith ageing. This overestimation was not evident to fish over 8 years old from bomb-radiocarbon analysis. New validation studies are necessary to increase the accuracy in the determination of absolute age in order to develop a definitive reading protocol to this species.

Keys words: Chilean Jack mackerel, age validation, daily ring, modal progression radiocarbon analysis. growth model.

Introduction

Chilean jack mackerel (CJM), *Trachurus murphy,* is a very important commercial pelagic fish of the *Carangidae* family that inhabits the Southern Pacific Ocean. On the coast of Chile three fishing grounds for Chilean jack mackerel can be identified: north fishery (18°21'S-24ºS), Caldera-Coquimbo fishery (24°S-32°S) and south central fishery (32°S-43°30'S).

In the period 1960-1995 the capture of jack mackerel grew in ascending form arriving at a maximum of 4,6 million tons. later it began to decline until reaching 234,000 t in 2012 (Aranis et al. 2014). Jack mackerel is also exploited by foreign fleets outside the Chilean EEZ, mainly off the south-central area, by Russian, Cuban, Chinese and Vanuatu fleets. Fleets from Peru and Ecuador operate in their EEZ. It was a high priority for Chile in the negotiation process for the establishment of South Pacific Regional Fisheries Management Organization (SPRFMO), under which the exploitation of mackerel by different countries was ratified by member countries in 2013 (Canales et al. 2013).

The Chilean jack mackerel is a wide distributed species throughout the Southeastern Pacific, ranging from the Galapagos Islands and south of Ecuador to southern Chile. Its current distribution also extends from south-central Chile across the Pacific Ocean, to New Zealand and Tasmanian waters (Evseenko, 1987; Serra, 1991; Elizarov et al., 1993; Taylor, 2002) (Fig. 1).

The jack mackerel population can be characterized by a spawning area from 35º to 40ºS and to 90ºW; a coastal feeding habitat of adults in the central-southern area off Chile (33ºS-40ºS), where the juveniles are recruited, and a nursery habitat north of 30ºS in warm oceanic and coastal waters (Arcos et al., 2001).

Peru researchers suggest an isolated stock off Peruvian coasts, but the Jack mackerel scientific work group of SPRFMO considered the existence of a whole stock for the South Pacific and the 2012 have made the unite stock assessment with this stock definition.

The age composition, in the jack mackerel catch, has particularly been a relevant element for understanding the changes in the stock. The Fisheries Research Institute (IFOP) has been carrying out studies on ageing and growth since late 1970's, which have been used for developing size-age keys and catch-at-age matrix per zone in quarterly basis, that are input data for the stock assessment.

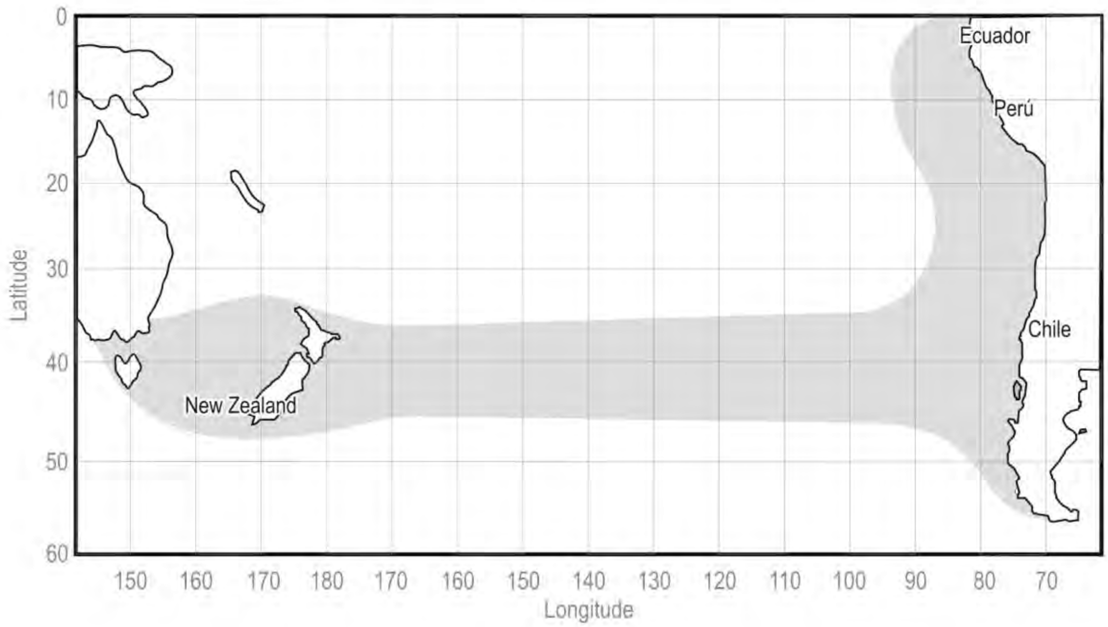

Figure 1. Distribution area of Chilean jack mackerel (*Trachurus murphyi*) in South Pacific Ocean.

The von Bertalanffy growth parameters of Chilean jack mackerel estimate by different authors through whole otolith analysis show similar result with L asymptotic between 65 to 80 cm fork length (FL), and K until 0.07 to 0.1 (Kochkin, 1994; Castillo and Arrizaga, 1987; Gili et al., 1996; Gang Li et al., 2011; Cerna and Bocic, 2011). These authors estimated that Chilean Jack Mackerel have medium longevity with maximum age observed between 9 to 17 years old. Other authors estimated a higher growth rate to the coast of Peru, with K = 0.155 and 0.165 and maximum age from 10 to 15 years old (Dioses, 2013; Goicochea et al. 2013).

The ageing of jack mackerel is supported in indirect age validation as periodicity of growth increment formation, which indicated the hyaline ring formation by year in winter seasons (Serra and Gili, 1994; Castillo and Arrizaga, 1987). Other studies permitted to confirm the ring identification criteria through comparison or precision analysis with senior research that shows high accuracy in most ages (1 to 10 years) and a slight underestimation of age by the IFOP reader from age 11, but in general concluded that the reading jack mackerel tests carried out have shown that the precision of the regular readers is high and adequate, while the variability between readers is considered acceptable and within normal limits of error (Morales-Nin, 1997).

The actual indirect validation of Chilean jack mackerel only considered the determination of the frequency of formation of a growth increment for fish sample, with edge analysis method, could be necessary but insufficient for obtaining an accurate age determination.

The prevalence and impact of inaccurate age determinations on the accuracy of population dynamics studies cannot be overstated. There are many instances in which ageing error has contributed to the serious overexploitation of a population species. The problem is often about age underestimation rather than overestimation, resulting in overly optimistic estimates of growth and mortality rate (Campana, 2001).

The objective this study is validate the annual ageing method for Chilean jack mackerel, used the daily microstructure reading, the progression analysis of length frequency and Bomb Radiocarbon method.

Materials and Methods

Validation of the first annulus

A total of 45 sagittae otoliths of jack mackerel ranged 3 to 23 cm FL, 35 juveniles fishes <20 cm FL were collected aboard a scientific vessel off west coast northern of Chile between December 2012 and February 2013 and 10 young-of-the-year fish (YOY) between 21 and 23 cm FL obtained from commercial purse seine fisheries vessel.

Whole otoliths were mounted in epoxy resin on slide glass and polished in sagittal planes using 30 and 1 µm-grit sandpaper (Plaza et al. 2005). Otoliths that showed a clear sequence of daily increments from primodium to postrostral tip were photographed with QImagen Evolution 5.0 camera on light microscopy at 400x magnification. The primary micro increment around the primordium was read using 1000X magnification.

The result was an image that contains a joint sequence of photos along the longitudinal plane of each otolith. The adult (27 cm FL) micro-increment formation in sagittae otoliths of *Trachuchus murphy* was validated in laboratory experiment indicated the result that micro-increment at formed with a daily frequency (Araya et al., 2003). A distinctive microstructural feature in the jack mackerel otolith was the presence of a secondary primordium (SP), which divided the sagittal plane of the otolith into a primary and secondary growth zone (PGZ and SGZ). In some areas of the otoliths, subdaily and double rings encompassed wider micro-increments and these were counted as PMs (Fig. 2) following the criteria of Campana (1992).

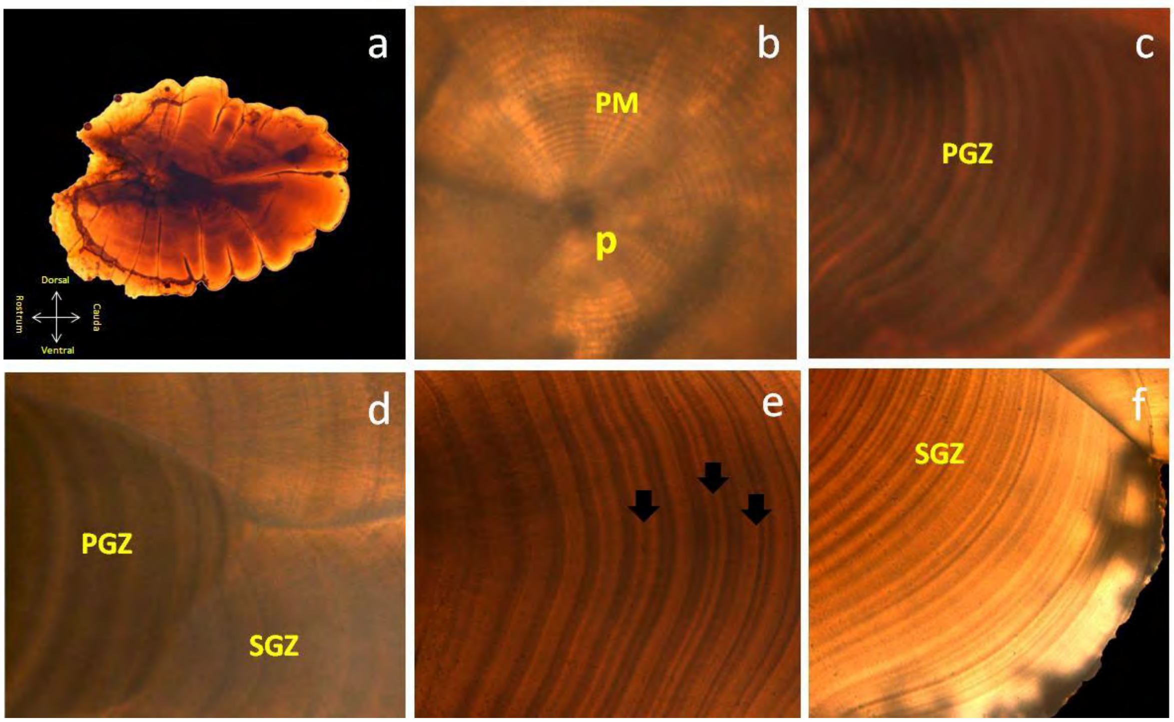

Figure 2. Sagittae otolith microstructure of *T. murphyi* with 10.7 cm FL. The pictures show the whole reading axis toward the post-rostrum. The picture a) shows the whole otolith; b) shows the initial primordium (p) and primary microincrement (PM); c) the middle area of Primary Growth Zone (PGZ); d) the end area of PGZ and start of Secondary Growth Zone (SGZ); e) corresponds to the middle area of SGZ where was observed the growth bands formed for two thin rings, the arrow indicated an possible sub-daily ring; f) shows the thin rings near to the edge of the otolith.

The primary micro-increment (Daily increment) was read three times by two independent readers in different time. The result of each reader was an overage of the three analyses. A comparison between readers was carried out applied Wilcoxon rank test for 32 otolith's reading in order to evaluate the precision on reading.

The daily age was subtracted from the date of catch (corresponding to the edge of the otolith) to calculate the exact date of hatch. In order to obtain a frequency distribution of hatch dates that should coincide with the date spawning distribution.

The profile of mean increment width to the age was estimated like proxy of growth rate. These analyses were only performed for juveniles because increment measurements could not be performed in adults.

The Laird–Gompertz model was used to estimate the age-at-length relationship for juveniles, because this model has been widely used to characterize early growth patterns in members of teleost fish. The function has three parameters: L_∞ is the asymptotic length; X_0 is the inflexion point of the curve; and α is the instantaneous growth rate at age X_0 (Campana and Jones 1992):

$$L_t = L_\infty\, exp[-\exp(-\propto \{X - X_0\})]$$

Modal-progression analysis of length frequency

A modal-progression analysis was performed to compare age classes with ages estimated from otolith to obtain a verification of ages 0–3 years in the jack mackerel. Length–frequency data were obtained from commercial captures of the fishery during 2008–2011. Length–frequency histograms were made with 1 cm intervals by year of sampling that included all months. Modes were identified from length–frequency distributions sampled by the mixture analysis method implemented through the mixdist package for R (Macdonald and Du 2004). The algorithm iteratively fits distributions to database on proportion, mean and standard deviation through a maximum likelihood approach to decompose a time series of length–frequency data into age classes (MacDonald and Pitcher 1979).

Radiocarbon absolute age validation

Bomb-radiocarbon assays were used to examine the accuracy of annual age estimation from whole and sectioned otolith (Kalish, 1993; Campana, 1997). The otolith cores for age validation of 15 jack mackerel adult with mean ±SE of fork length of 47±1.4 cm was collected from fishing area off the Chilean coast, from 1971 to 1982. Age estimates of the adult fish were available from examination of whole otolith by the Fisheries Research Institute (IFOP).

All ages of adult Chilean jack mackerel were based on counts of presumed annual growth increments that were visible in whole and transverse sections of the sagittal otolith. The sections of the otoliths to be aged were first embedded in a slow-drying hard epoxy (Araldite epoxy GY502 and hardener HY956 in a 5:1 weight ratio). Sections through the core (~450 µm thickness) were prepared with a single cut using twin blades separated by a spacer on an Isomet low-speed diamond-bladed saw. The sections were lightly polished to improve visibility. While under a binocular microscope at 16-40X magnification using reflected light, the growth increment sequence was digitally photographed at a resolution of 2048 x 2048 pixels, then digitally enhanced.

Otolith cores for bomb radiocarbon age validation were isolated from three adjacent 1-mm thick transverse sections of the otolith, polished lightly in order to view the growth sequence. Otolith cores were isolated from the central section as a solid piece with a Merchantek computer-controlled micromilling machine using 300-µm diameter steel cutting bits and burrs. Additional core material from the same otolith was isolated from the two adjacent sections, but restricted to the innermost two growth increments so as to allow for the offset of these lateral sections from the primordium. This procedure of obtaining material from multiple sections per otolith was necessary to maximize the amount of sample material available for assay from each otolith.

Even then, the mean weight of isolated core material was sometimes less than 3 mg. Therefore, otolith cores from 1-2 additional fish of the same age and collection year were extracted and pooled so as to bring the sample weight up to the minimum of 3 mg necessary for radiocarbon assay. The date of sample formation was calculated as the year of fish collection minus the age of the fish, plus one half the number of growth increments extracted in the core. After sonification in Super Q water and drying, the sample was weighed to the nearest 0.1 mg in preparation for ^{14}C assay with accelerator mass spectrometry (AMS). AMS assays also provided $\delta^{13}C$ (0/00) values, which were used to correct for isotopic fractionation effects and provide information on the source of the carbon. Radiocarbon values were subsequently reported as $\Delta^{14}C$, which is the per mil (0/00) deviation of the sample from the radiocarbon concentration of 19th-century wood, corrected for sample decay prior to 1950 according to methods outlined by Stuiver and Polach (1977). The mean standard deviation of the individual radiocarbon assays was about 50/00.

Chronology of reference

Since no juvenile otoliths were available to describe the Chilean reference chronology prior to 1964, the reference chronology based on juvenile Pacific halibut (*Hippoglossus hippoglossus*) (Piner et al. 2004) from the northwest Pacific Ocean was used as a basis for comparison.

We compared the halibut chronology, scaled to jack mackerel, with radiocarbon chronology of New Zeland and Australian *Trachurus declivis*.

To verify the accuracy of the age assignment, 15 fish ranging in age from 9 to 14 years were selected. The levels of $\Delta^{14}C$ to the reference chronology permitted to estimate the birth year.

Growth parameters estimation

The length and age data of 2,153 fish that included the result of age validation with methods of primary micro-increment, modal progression analysis, boom of radiocarbon, was modeled with the von Bertalanffy growth model (von Bertalanffy 1938).

Growth parameters were fitted in R by likelihood maximum (Kimura 1980; Haddon 2001), assuming normally distributed errors.

Results

Validation of first annulus

The reading error of micro-increments of jack mackerel between two independent readers was acceptable, with a mean of 176.6 ± 142.6 and 176.8 ± 111.6 for reader 1 and 2, respectively, for fish sizes range between 3.0 and 19.0 cm and ages between 51 and 550 days. The Wilcoxon rank test did not detect significant differences in the number of rings counted between the two readers (P=0.647).

Hatch dates extended from August to February with a maximum in October-November with similar distribution of spawning, at least for juvenile fish (Fig. 3).

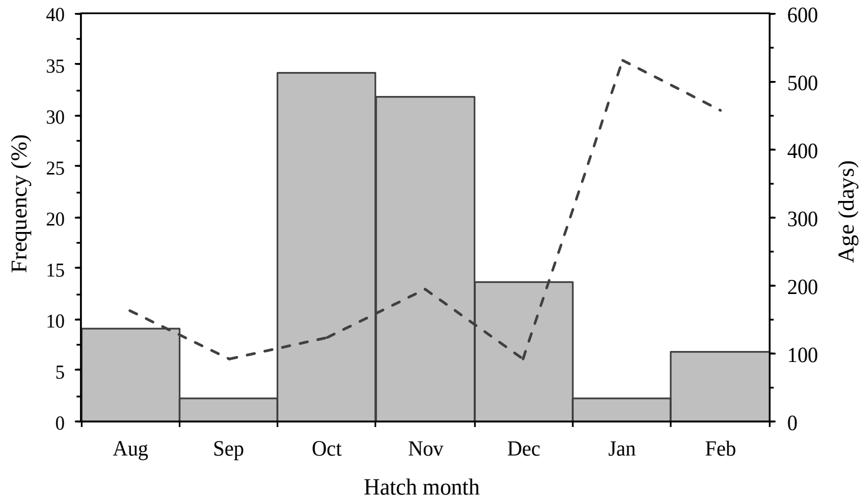

Figure 3. Frequency distribution hatch month of juvenile *Trachurus murphyi* collected between Arica and Coquimbo off the coast of Chile.

The increment width profile along the post-rostrum radius of sagitta showed the characteristic curve of fish on early stages. Increment width increased gradually from 3.4 µm of the first increment, peaked about of 20 um ranged 50 to 80 days, then became progressively narrow until they reached a value of 2.1 um at 170 days old (Fig. 4).

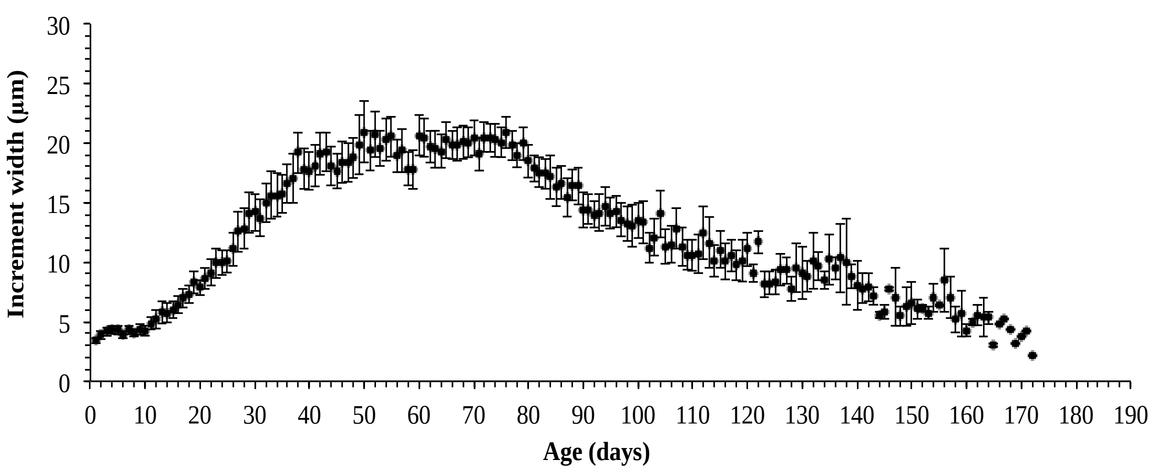

Figure 4. Increment width profile along the post-rostrum radius of sagittae otolith *T. murphyi*. Values are mean with standard error measurement in 21otoliths of juvenile fish, collected in the north coast (Arica to Coquimbo) off Chile.

The age-length relationship of juvenile and YOY of jack mackerel was based on otoliths collected from Arica to San Antonio, with length of fishes ranged between 3.4 and 23.0 cm FL and ages from 56 to 550 days. This relationship was explained significantly by the growth equation of Laird-Gompertz (Fig. 5). The adjustment presented a high coefficient of determination ($r^2 = 0.80$) and the parameters significant values (Table 1). The residuals of the fit present a normal distribution, according to the Shapiro-Wilk (W) normality test (SW=0.984; P=0.792).

The Laird-Gompertz parameters permitted to estimate the mean of fork-length at 365 days of age that correspond to 22.0 cm FH.

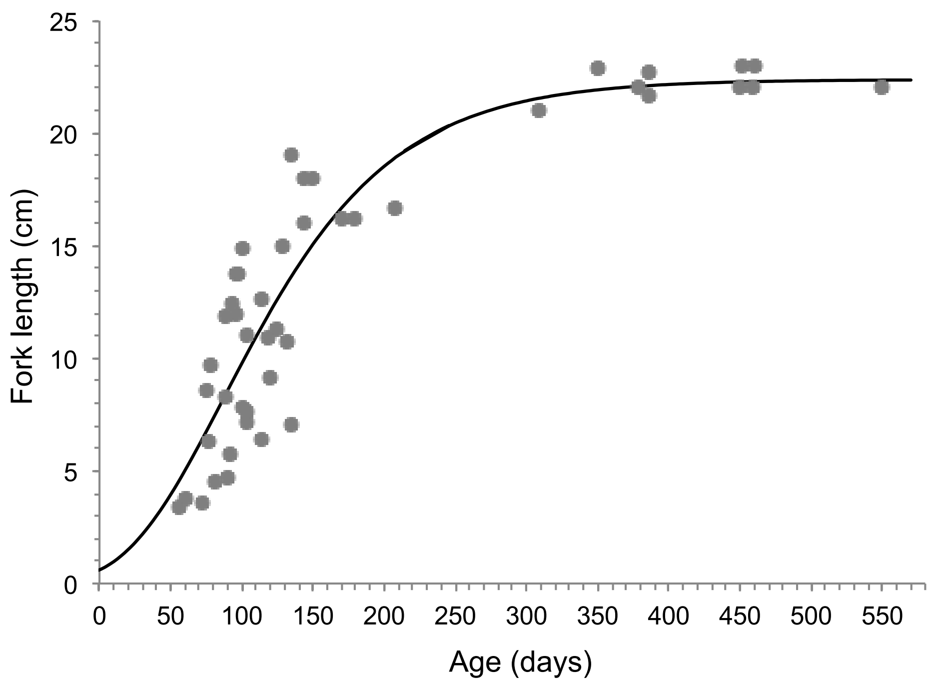

Figure 5. Laird–Gompertz model fitted to the age (daily) – fork length relationship of juvenile *Trachuru murphyi*, caught between Arica and San Antonio.

Table 1. Parameters derived from Laird–Gompertz models fitted to the age–length relationship of *Trachurus murphyi* from 3 to 23 cm fork length.

Parameter	Estimación	± E.E	t valor	P valor
L_∞	22.38	± 0.97	22.96	< 2E-16
G	0.015	± 0.003	5.28	4.2E-06
X_0	87.20	± 5.59	15.59	< 2E-16
R^2	0.80			
-LogLike	-108.36	(df=4)		
n	45			

Progression analysis of length frequency

The progression of the first length frequency mode, corresponding to the recruitment of 2008, could have been followed through next years because of the lack of recruitment from 2009 to 2011. The first mode of 14.6 cm FL corresponds to recruitment fish of age 0, confirmed with micro-increment analysis. This mode is identified the next year (2009) as mode of age 1 of 23.1 cm FL, the 2010 as mode of age 2 (27.0 cm FL) and the 2011 as mode of age 3 (30.0 cm FL) (Table 2; Fig. 5).

Table 2. Mean and standard deviation (s.d) of annual modal progression analysis of jack mackerel for period 2008 to 2011 to national fisheries of Chile.

Length modes	1		2		3		4	
Ages	0		1		2		3	
Year	mean	s.d	mean	s.d	mean	s.d	mean	s.d
2008	**14,6**	± 1,5	18,2	± 1,9	30,0	± 3,2	39,0	± 4,1
2009			**23,1**	± 2,4	32,9	± 3,4	37,9	± 4,0
2010					**27,0**	± 3,1	38,3	± 4,4
2011							**30,0**	± 3,1

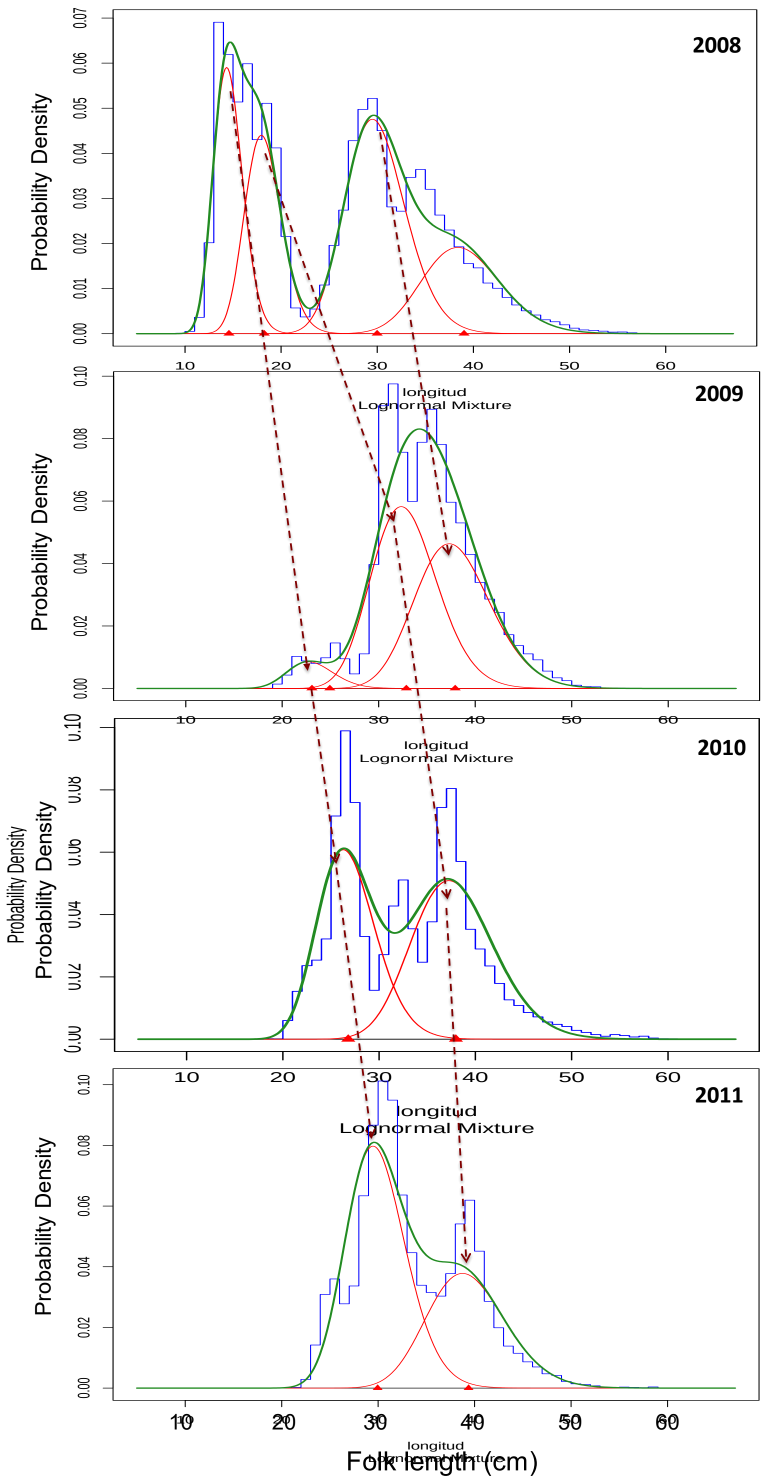

Figure 5. The length–frequency distributions (bars), principal modes estimates (red curve) and total fit (green curve) found with the modal-progression analysis for jack mackerel, collected during 2008 to 2011 from the waters off Chile. The dotted line that cross the graphics indicated the annual mode progression.

Bomb Radiocarbon method

Reference chronology

The comparisons between halibut radiocarbon chronology with radiocarbon chronology of New Zeland and Australian *Trachurus declivis*, showed a similar pattern that Pacific halibut in the postbomb, the values of radiocarbon increased between 1958 and 1971, and Australian *Trachurus* Chronology is similar to Pacific Halibut between 1974 and 1983, when the radiocarbon level is asymptotic. The similitude of South Pacific *T. declivis* and North Pacific halibut (*Hippoglossus hippoglossus*) in the postbomb period suggests that the use of the Pacific halibut chronology to validate age of Chilean jack mackerel (*Trachurus murphy*) is correct. The halibut chronology represents adequately all radiocarbon patterns in contrast with *T. declivis* chronology that presents no data in the prebomb period (Fig. 6).

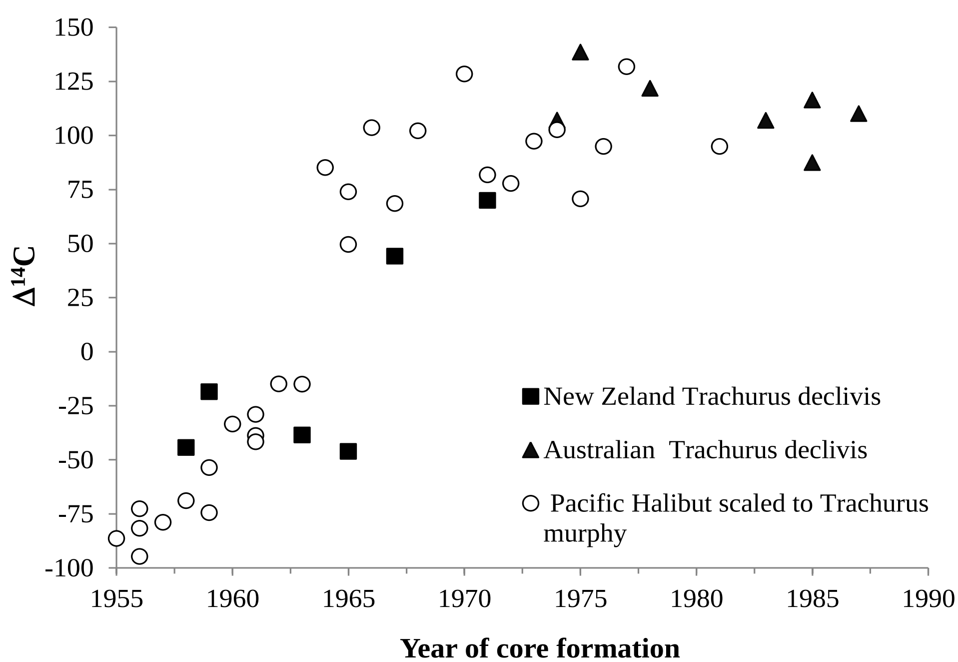

Figure 6. Bomb Radiocarbon reference chronology of New Zealand and Australian *Trachurus declivis* and Pacific halibut scaled to *Trachurus murphyi*.

Radiocarbon age validation

Age validation plots were prepared to compare the bomb radiocarbon content of the Pacific halibut reference chronology with that of otolith cores of adult JM fish. This indicates that some of the otolith ages appear to be too old, because the cores formed before about 1964 should not have such high radiocarbon values (Fig. 7A). However, when birth date is estimated from ageing corrected, with result of validation for first and second annulus, it is observed that some of the JM ages are correct, at least on average. This result is confirmed with the closest of $\Delta^{14}C$ LOESS Smoothing of jack mackerel adult and Pacific Halibut reference chronology scaled to JM (Fig. 7B).

Table 3. Summary of adult jack mackerel otolith cores analyzed for radiocarbon ($\Delta^{14}C$). Year Core is the mean year of formation of the otolith material in the core.

Number	Samples Year	Zone	Fork length (cm)	Whole Otolith Age original	Whole Otolith Age corrected	Assay	Year Core age original	Year Core age corrected	$d^{13}C$	$D^{14}C$
21	1974	Centro	39	9	7	14077	1965.0	1967.0	-5.45	76.8
27	1976	Centro	42	10	8	14079	1966.0	1968.0	-5.05	52.8
5	1980		45	11	9	14826	1969.0	1971.0	-4.75	118.3
11	1971	Norte	48	10	8	14819	1961.0	1963.0	-5.85	75.8
25	1975	Centro	48	10	8	14078	1965.0	1967.0	-4.83	96.8
28	1976	Centro	43	10	8	14080	1966.0	1968.0	-5.28	97.7
10	1971	Norte	48	10	8	14818	1961.0	1963.0	-4.4	12.0
12	1971	Norte	47	11	9	14820	1960.0	1962.0	-2.78	-39.3
12	1982		42	12	10	14830	1970.0	1972.0	-4.86	76.7
13	1982		47	12	10	14831	1970.0	1972.0	-4.88	76.7
9	1971	Norte	47	11	9	14817	1960.0	1962.0	-5.23	70.2
20	1973	Sur-Austra	54	11	9	14823	1962.0	1964.0	-5.05	-44.7
24	1975	Norte	47	11	9	14824	1964.0	1966.0	-4.40	92.3
15	1982		49	12	10	14832	1970.0	1972.0	-4.82	112.3
16	1972	Norte	60	14	12	14821	1958.0	1960.0	-4.78	-36.6

The exact mean ages for the otoliths analyzed according to the observation of the reference chronology ranged from 7 to 12 years for sizes between 39 and 60 cm LH. That is, the reference chronology of the radiocarbon of the Pacific halibut, used for the validation of the absolute age of jack mackerel suggests, for the range of sizes studied, that the maximum age should reach at least 12 years (Table 3).

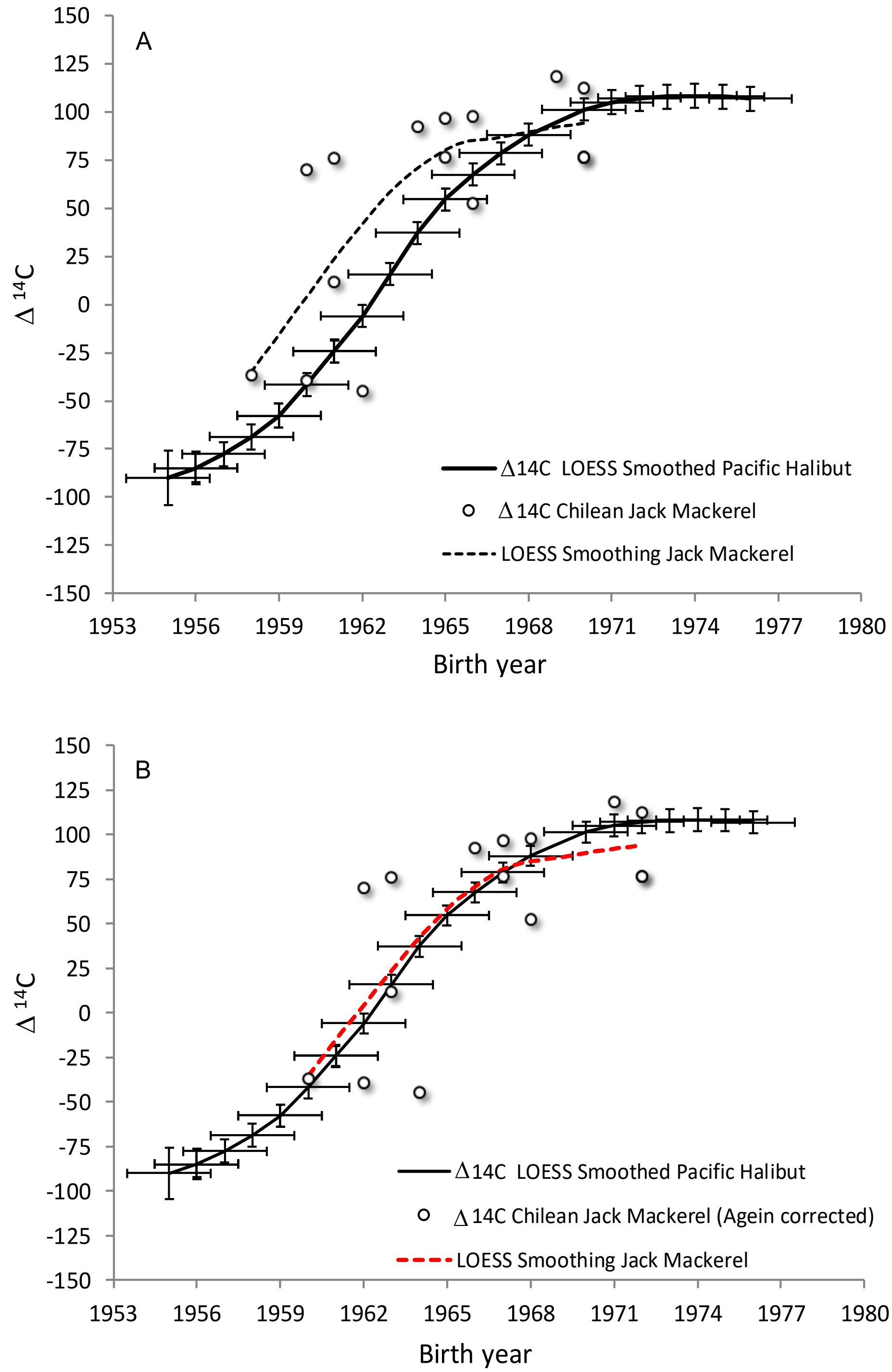

Figure 7. Radiocarbon reference chronology for Pacific halibut and Δ14C in otolith's cores of jack mackerel adult versus year of formation (Birth year) inferred from counts of the growth increment from: A) whole otolith reading (historical ageing criteria) and B) whole otolith reading with ageing criteria corrected from validation of first and second annulus with other methods.

Growth parameters estimation

The data corresponding to jack mackerel conventional reading of 2008 with changes accord to each new evidence of validation, were the macro-rings one and three were considered checks or false and discarded of conventional ageing. The rest of rings could be confirmed with radiocarbon validation method considered the new assignation age after the discard of the false rings already mentioned.

The von Bertalanffy growth model produced a satisfactory relationship with the age-length data, with low standard errors for each parameter (Table 4) and the plot of ageing together length-age data resulted of validation method applied are consistence (Fig. 8).

Table 4. Von Bertalanffy growth parameters and standard error estimated for jack mackerel Southeastern Pacific off Chile. Included statistical of significance of parameters and model. n corresponds to the number of otolith analyzed.

			Statistical significance			
Parameters	Value	Std. Error	t_{value}	P_{value}	-LogLike	R^2
L_∞	68.10	1.210	56.3	< 2e-16	-5073.16 (df=4)	0.92
k	0.09	0.004	24.9	< 2e-16		
t_0	-2.96	0.104	-28.6	< 2e-16		
n	2153					

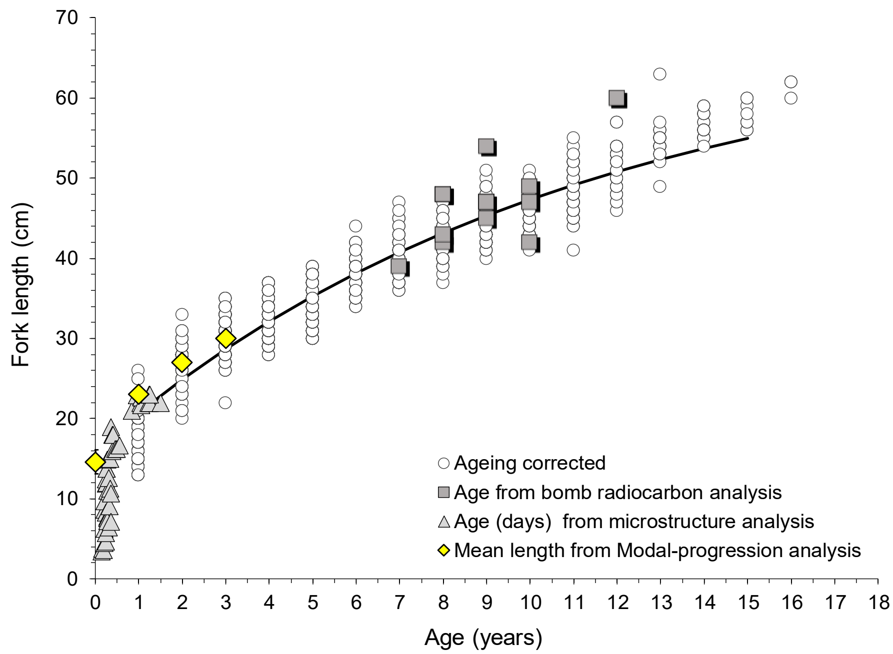

Figure 8. von Bertalaffy growth curves of jack mackerel from the Southeastern Pacific off Chile. The data correspond to whole otolith reading with ageing criteria corrected from validation of first and second annulus. On curve is shown the plot of length-age data from three validation methods (Bomb-radiocarbon, otolith microstructure reading and modal-progression analysis).

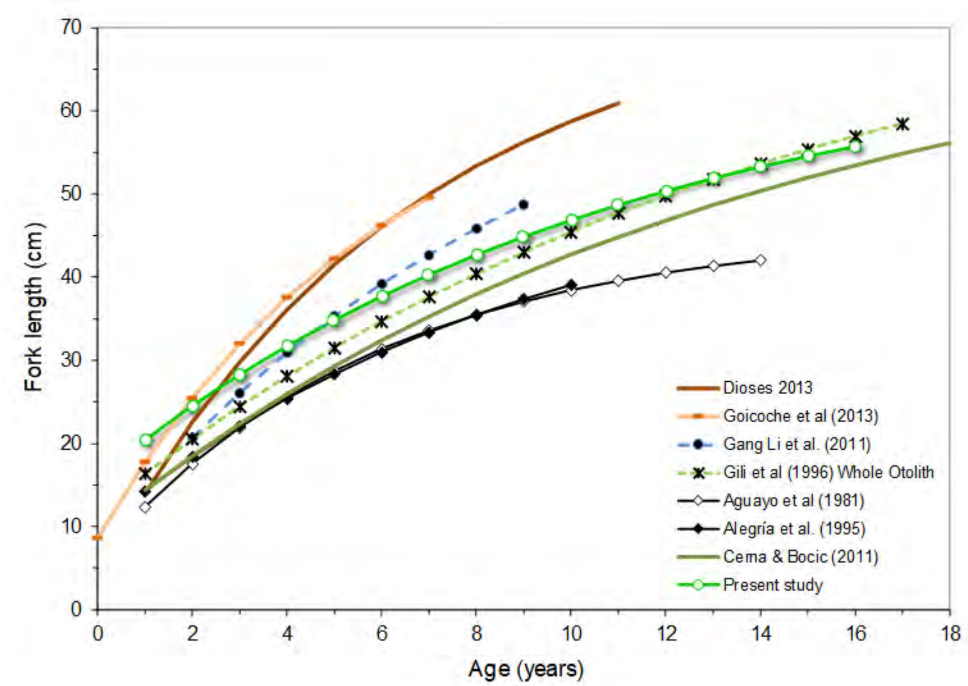

Figure 9. von Bertalaffy theoretical growth curves of jack mackerel from the Southeastern Pacific estimated by different authors.

DISCUSSION

The otolith microstructure of jack mackerel has distinctive features as: the occurrence of three microstructural zones in sagittal otoliths of immature fish: a first zone where primary increments were more homogeneous and easy to identify; however, the otolith has an initial primordium and variable numbers of secondary primordium (SP) that begin to form around 20 or 25 days after hatching. In jack mackerel, it is observed between 2 and 8 SPs, slightly different to Japanese jack mackerel with range 2-15 SPs (Xie et al.2005). It has been proposed that SPs form because of habitat shift (Campana 1984; Sogard, 1991), ontogenetic dietary shift (Marks & Conover, 1993) and because physiological changes (Hare & Cowen, 1994). A second zone where double rings and other perturbations predominated, and a third zone where the width primary microincrements are narrow but with a good resolution. The analysis of juvenile otolith of *Trachurus murphyi* shows the same general pattern of microstructure observed in *Trachurus japonicus* (Xie et al., 2005; Xie & Watanabe, 2005; Kanaji et al., 2010).

It is known that daily periodicity of microincrements was validated in adult of *T. murphyi* in fishes over 27 cm FL (Araya et al., 2003) but not in juvenile. However, our hatch date distributions analysis, between August and February with maximum in October-November, coincides at least for juveniles, with the spawning months that are verified between October and December according to Leal et al. (2013). The hatch date distributions are normally used to determine spawning times and inter spawning locations (Campana and Jones 1992). However, they can also be used as an indirect assessment of ageing accuracy in absence of experimental validation (Campana pers. com.).

The increment width profile along the post-rostrum radius of *T. murphyi* sagittae showed a characteristic curve comparable to *Trachurus japonicus* (Xie & Watanabe, 2005; Kanaji et al., 2010) and *Trachurus trachurus* (Waldron & Kerstan, 2001). The Peak of increment is similar al *T. japonicus* with increments over 20 µm between 40 and 100 days depending on hatching date (Xie & Watanabe, 2005). These authors suggest that 40 days correspond to the ending of metamorphosis and the high growth rate of jack mackerel could be associated with trophic shift.

The similar patterns of width micro-increment of juvenile jack mackerel with species that have been validated the microincrements as *T. japonicus* (Xie et al. 2005), allow us to verify correct identification of microincrements performed in our study and supports our assumption of these rings could have daily periodicity and our reading could be accurate.

The Laird-Gompertz model fit well at the data to fishes between 3 and 23 cm FL, with high significant of parameters and a model that explained the 92% of total variability. The growth curve in the length interval of 3 to 16 cm was similar to the reported for Goicochea *et al.* (2013) to jack mackerel catch off the Peruvian coast. However, the length to 365 days was different, while we estimated 22 cm FL, Goicochea *et al.* (2013) estimated 17.7 cm FL. Other estimation made by Gretchina et al. (2017) reported a mean fork length of 21.4 cm to 365 days. These results show a high growth in juveniles and the young-of-the-year (YOY) of jack mackerel of the Southeastern Pacific and the length at year of life is closer to the length-at-maturity (L_{50}) of 22.7 cm FL (Leal et al. 2013) and considering our result we might suggest that age-at-maturity (A_{50}) is reached at one year of life. . This age, 365 days, is closer to the second macro-ring of the conventional whole otolith ageing and suggest that the first macro-ring with a mean of 200 days of age was formed in the first winter of their life.

The progression of first mode of length frequency distribution that corresponds to the recruits of 2008 was possible followed for the three-next year because of the absence of recruitment, condition that facilitated tracking of modes progression in the next years. The following of recruitment pulse of 2008 (age 0) allows to obtain a mean of length to the first mode of 2009, whose value (23 cm FL) is close to the mean length of the first year derived from the microstructure analysis. The consistency between the two validation results reinforces both analyzes and confirm the high growth in the first year. The first mode of length distribution for 2010 is representative of mean length of age 2 (27 cm FL) and 2011 age 3 (30 cm FL).

This analysis of modal progression, that permitted to follow the strong year classes (recruitment pulse) through three years, it is considered acceptable because it meets the requirement of following a well-defined recruitment pulse and there is no appreciable age structure migration (Beamish &McFarlane 1995). Although the jack mackerel is known for oceanic migratory to spawning area, we believe that the YOY and perhaps important number of the fish of two years stay in the coastal area, at least this is shown in the length structure analyzed.

The reference chronology of Pacific halibut was used to validate the age of jack mackerel otolith because it has a greater amount of data for the entire period of radiocarbon change and it was not possible to construct a reference chronology of the Pacific southeast off Chile due to the lack of known age calcarean structures that would allowed to correctly identify the pre-bomb radiocarbon period. However, to know if our choice was correct, the Pacific halibut reference chronology was compared with *Trachurus declivis* of Australia and New Zealand radiocarbon data and the three species show the same tendency of radiocarbon level to increased and asymptotic period of reference chronology. This confirms that the levels of radioactivity of the North and South Pacific seem to be similar.

Although the bomb derived radiocarbon from nuclear testing provides one of the best age validation approaches available for long-lived fishes (Kalish, 1993, 1995a, b; Kalish et al., 1996,1997; Campana, 1997, 1999; Campana & Jones, 1998), to jack mackerel, that is a species of middle longevity, it was possible to obtain a good approximation of absolute age to fishes over 40 cm FL, and combined with result of other validation method, as otolith microstructure and modal progression analysis to identify the first and second annulus, respectively, have allowed to improve the level of prediction of the radiocarbon for the whole otolith reading.

Finally, the microincrement analysis results show high growth in juvenile of jack mackerel and show a possible ageing overestimation from conventional whole otolith ageing at least on juveniles and YOY specimens. The same result was obtained to the second year of live from the modal progression analysis, because the mean length of first mode to 2010, that comes from the recruitment of 2008, is higher than conventional ageing. Moreover, the correction of the year of formation of otolith core, subtracting two years from the conventional reading, allowed to obtain a better relationship between the radiocarbon level of the whole otolith core and this year formation, suggesting that the validation of the first and second annulus are correct and so, the ageing of jack mackerel was overestimated at least two years.

The conventional ageing made by IFOP was corrected, specifically the data of 2008 which was outlined in the past report (Cerna & Bocic 2011), in order to obtain a new von Bertalanffy growth parameters. The biggest differences of growth with the previous parameters are observed for ages less than 8 years old; older ages have a smaller difference in mean length (Fig. 9). Our new growth estimation to jack mackerel considered the validation result, still shows important differences in respect to the estimation made by other authors, including Peruvian studies, because it shows a lower growth.

We consider that an important step has been taken in the validation of the young of the year, which can be improved with the validation study of the primary microincrements, but we also believe it is necessary new validation studies to improve the accuracy in the determination of absolute age in order to develop a definitive reading protocol to this species.

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