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Analysis of the microincrements and the formation of the first annual ring in otoliths of Jack mackerel (*Trachurus murphyi*) from Chile and Peru through the Individual Mark Reading (IMR) and the Group Band Reading (GBR), with observations on the periodicity of the growth ring

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Analysis of the microincrements and the formation of the first annual ring in otoliths of jack mackerel (*Trachurus murphyi*) from Chile and Peru through the Individual Mark Reading (IMR) and the Group Band Reading (GBR), with observations on the periodicity of the growth rings - Working paper contributed to the Task Team on jackmackerel age and growth of the SPRFMO Scientific Committee

by

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SUMMARY

This study is based on the analysis of a total of 87 samples of otoliths of jack mackerel (*Trachurus murphyi*) from catches in northern Chile and in central-southern Peru and is divided in two parts. The first part examines the application of the two known criteria used for the analysis of the growth of microstructures in otoliths: the Individual Mark Reading (IMR) and the Group Band Reading (GBR). The first criterion (IMR) was applied in a parallel analysis of otoliths from northern Chile and central-southern Peru and it shown a great coincidence in the readings of microstructures in otoliths from the two areas, indicating that when completing the first year of age (365 rings read) jack mackerel reaches a total length of 19.5 to 20.8 cm. The second criterion (GBR) was only applied in the analysis of otoliths from central-southern Peru and these readings indicate that at one year of age (365 rings read) jack mackerel would have reached a total length of 28.4 cm. These results, and specially those with the GBR criterion suggest that at one year of age jack mackerel reaches a much larger total length than the 15.3 cm corresponding to the growth parameters currently in use. The second part of this study analyses the frequency in the formation of the growth rings after the first formed ring in otoliths from southern Peru. Two types of ring formation patterns were identified: a) rings with a narrow radio or a tight formation sequence (type I rings); and b) rings with wide or well separated radios (type II rings). It was found that in the type I rings the length of the increment from the first to the second ring was 0.519 mm and from the second and third ring was 0.407 mm, with age readings of 92.2 and 93.1 days respectively, suggesting a quarterly formation. In the case of type II rings, the length of the increment from the first to the second ring was 0.962 mm and from the second to the third ring was 0.660 mm, with age readings of 183.9 and 182.5 days respectively, which suggests a biannual formation periodicity. The occurrence of these quarterly type-I and biannual type-II growth rings in the otoliths of jack mackerel underlines the need to clearly distinguish and properly identify these two types of rings in the age determination process in order to avoid the overestimation or underestimation of the ages of jack mackerel. From these results it seems clear that the problems and uncertainties regarding the age determination of jack mackerel within the context of the SPRFMO are still not resolved and more in-depth analyses of the otolith microstructure and of the formation process of daily, seasonal and annual rings are still needed.

BACKGROUND

In 2013 the Peruvian journal “Revista Peruana de Biología” published a special issue on the ecology, fishery and conservation of jack mackerel (*Trachurus murphyi*) in Peru (Csirke et al, 2013) which includes three articles reporting on the most recent research work undertaken by the Instituto del Mar del Peru (IMARPE) on the age and growth estimation of this species. As highlighted by Csirke (2013), this special issue presents the results of several combined approaches to estimate the age and growth of *T. murphyi*, including the conventional interpretation of annual rings in the otoliths (Dioses, 2013; Goicochea et al., 2013); the validation of the annual growth rings by reading the microincrements and analyzing the growth of the radius of the otolith between the second and third ring following a cohort (Goicochea et al, 2013); and, the analysis of monthly length-frequencies to estimate the growth parameters (Diaz, 2013). The results of all these studies were consistent and confirm the estimates of the von Bertalanffy growth parameters being use for the Peruvian jack mackerel since the 1990's, where $L_{\infty} = 80.77$ cm in total length (TL), $k = 0.1553 \text{ year}^{-1}$ and $t_0 = -0.3562$ (Dioses 1995, 2013).

Preliminary results of the above research work were presented and discussed during the 11th meeting of the South Pacific Regional Fisheries Management Organization (SPRFMO) Science Working Group held in Lima, Peru, 15-19 October 2012 (IMARPE-PRODUCE, 2012), and the final published results were communicated and made available to the 1st meeting of the SPRFMO Scientific Committee held in La Jolla, U.S.A., 21-27 October 2013 (Csirke, 2013a; IMARPE-PRODUCE, 2013).

Subsequently, during the 3rd meeting of the SPRFMO Scientific Committee held in Port Vila, Vanuatu, 28 September - 3 October 2015, the Chilean delegation presented a preliminary analysis of jack mackerel otoliths microstructure by Cerna and Moyano (2015) with the results of their examination and interpretation of microincrements of otoliths of juvenile jack mackerel caught off northern Chile. Cerna and Moyano (2015) indicate that they did not have major difficulties in reading and interpreting the microincrements in the primary growth zone (PGZ) of the otolith, nor in the interpretation of the microincrements formed after the first 80 rings. However, they report having some difficulty with the interpretation of the microincrements in the secondary growth zone (SGZ), between the increments 50 to 80, where they found groups of two or more increments in the form of packages.

Two different criteria could be applied in the interpretation of daily rings when this type of packages occurs. As described by Cermeño et al (2006), the first criterion is to interpret all clear microincrements as daily rings, independent of their appearance, in what is known as the Individual Mark Reading (IMR); while the second criterion is to identify the packages of two or more microincrements and interpret each package as a daily unit, in what is known as the Group Band Reading (GBR).

The difference between these two criteria is illustrated in Figure 1, where on the right hand side one can easily identify the primary growth zone (PGZ) in the center of the otolith, with the secondary growth zone (SGZ) next to it, to the left. In this secondary growth zone, occurring 50 to 80 microincrements after birth, one can note several rings that can be

individually identified and clearly illustrate the applicability of the first criterion (IMR). Then, to the left one can note groups of two or more microincrements that according to the second criterion (GBR) would be identified as a unit.

It is noted that Cerna and Moyano (2015) adopted the first criterion (IMR) in their readings, and conclude that in the case of the jack mackerel caught off northern Chile *"the growth curve in the interval of 3 to 16 cm (FL) length was similar to the one reported by Goicochea et al (2013) for jack mackerel captured off the Peruvian coast"*. However, they also mentioned that this similarity could only be verified up to 16 cm in length (FL) since the authors were not able to estimate the length at 365 days due to limitations in the samples they had available.

In this study we will apply and compare the results of both reading criteria (IMR and GBR) with an expanded length range sample.

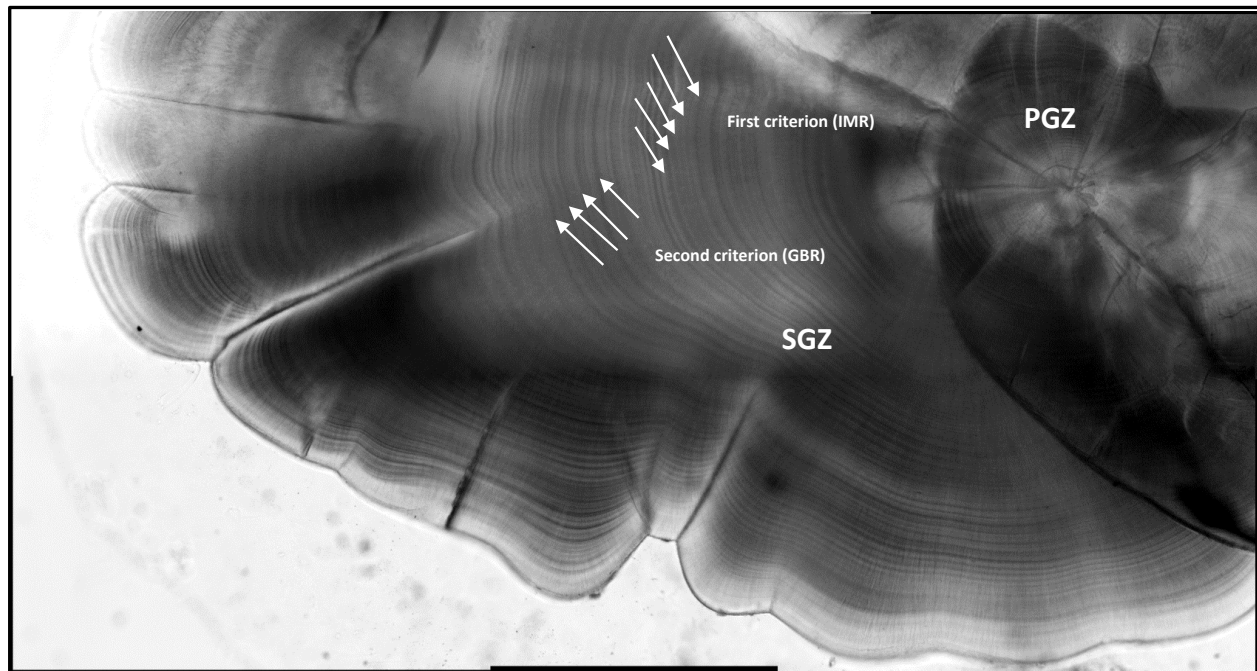


Figure 1. Microincrements in an otolith of a jack mackerel showing the primary growth zone (PGZ) and the secondary growth zone (SGZ), with an illustration of the two reading criteria examined in this study: the IMR (first criterion) and the GBR (second criterion)

MATERIAL AND METHODS

The readings and interpretation of the microincrements were made in two parts by reading of a total of 87 jack mackerel otoliths (Table 1). 41 otoliths were analyzed in the first part, including: 20 otoliths of jack mackerels of 40 to 260 mm of total length captured in northern Chile, and 21 otoliths of jack mackerels of 40 to 320 mm of total length captured in summer-fall 2014 in central-southern Peru. In addition, the microincrements readings of 31 otoliths jack mackerels of 35 to 210 mm of total length caught in central-southern Peru in the summer of 2011 made by Goicochea et al (2013) were also included in this study. In

the second part we analyzed 15 otoliths of jack mackerels between 31 and 38 cm of total length captured in January 2007 in southern Peru.

Table 1. Jack mackerel otolith samples used in the microstructure analyses

Origin of samples	Number of otoliths	Total body length range (TL, mm)	Type of analysis
Northern Chile	20	40 - 260	IMR (1st criterion)
Central-southern Perú	21	40 - 320	GBR (2nd criterion)
Central-southern Perú*	31	35 - 210	IMR (1st criterion)
Southern Perú	15	310 - 380	Periodicity

* from Goicochea et al (2013)

The two known reading criteria used in the analysis of microstructures in the otoliths were applied in the first part of this study. That is, the IMR (Individual Mark Reading) and the GBR (Group Band Reading), as described above.

The 20 otoliths from northern Chile were analyzed according to the first criterion (IMR), which is the same criterion applied by Goicochea et al (2013) in the reading of the 31 otoliths from central-southern Peru. As already noted, this was also the criterion applied by Cerna and Moyano (2015) in a sample of 21 jack mackerel otoliths of 38 to 192 mm of fork length caught in northern Chile.

Then, 21 otoliths from central-southern Peru were analyzed following the second reading criterion (GBR), where packages of two or more rings were interpreted as a unit. Limitations in the available samples did not allow the application of the second criterion (GBR) to read otoliths from northern Chile, although packages of two or more rings similar to those found in the otoliths from central-southern Peru were also observed in some otoliths from northern Chile. Therefore, given the great similarities in the readings observed when applying the first criterion (IMR) it is likely that readings following the second criterion (GBR) would also be similar.

Another 15 otoliths of jack mackerels of 31 to 38 cm of total length from southern Peru were analyzed in the second part of this study to determine the frequency of formation of the growth rings after the first well-formed ring. These 15 otoliths were a sub-sample that was selected based on the observed clarity or sharpness of the growth rings from a sample of 204 otoliths collected during IMARPE biological surveys in January 2007 in southern Peru. Due to sample limitations it was not possible to extend this type of analysis to otoliths from Chile, although, as indicated above, it is very likely that the observations based on the otoliths from southern Peru could be extended to northern Chile.

Two distinct patterns in the formation of the growth rings were found in this second part of our analyses, which are described as formation patterns type I and type II, where:

Pattern type I - when the rings are formed with a narrow radius, or with a tight formation sequence (Figure 2A); and,

Pattern type II - when the rings are formed with large or loose radius (Figure 2B).

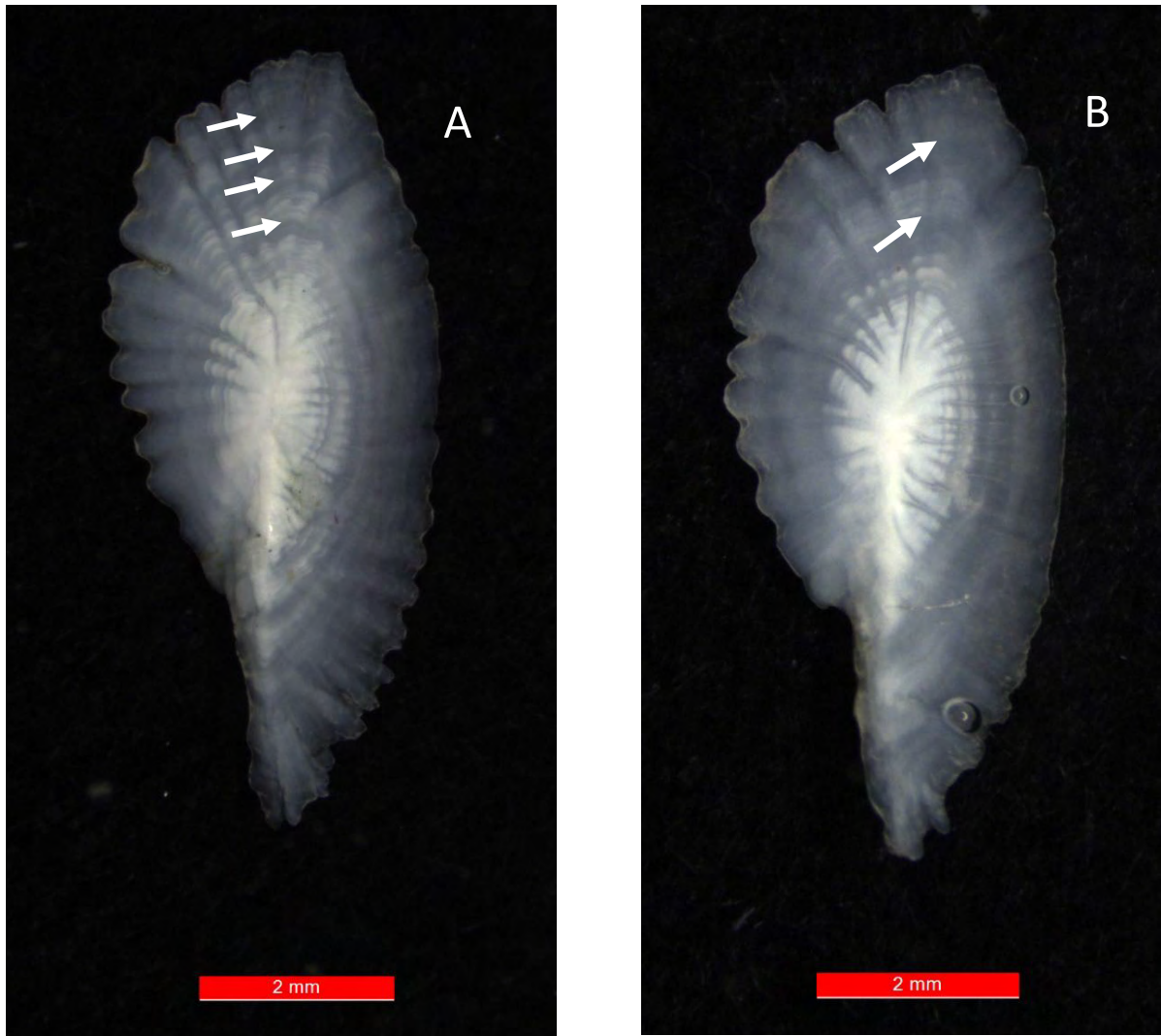


Figure 2. Jack mackerel otoliths at 10x magnification showing two types of growth rings formation pattern: (A) Pattern type I, in otolith of jack mackerel of 32 cm TL; (B) Pattern type II, in jack mackerel of 33 cm TL

In this second part of the analyses the growth rings of the 15 selected otoliths were measured and then polished in the frontal plane from the internal and external faces until the microincrements were visualized. The count of the microincrements was carried out starting from the first to the second growth ring and from the second to the third growth ring in the back of the otolith. For comparative purposes, 5 otoliths were used to analyze the type I formation pattern and 10 to analyze the type II formation pattern. We used the annual rate of increase in length from the first to the second ring and from the second to the third ring estimated by Goicochea et al (2013) and interpreted each microincrement as a day according to Araya (2003).

RESULTS

The reading results of the 20 otoliths of jack mackerel from northern Chile analyzed according to the IMR criterion (1st criterion, where all clear microincrements are interpreted as daily rings) are presented in the Table 2, while Table 3 presents the readings

Table 2. Total body length (mm) and daily increment readings following the IMR criterion in 20 otoliths of jack mackerel (*T. murphyi*) caught in northern Chile

Otolith number	Total body length (mm)	Age (days)	Daily increment readings (\cong age in days)			CV %
			Reading 1	Reading 2	Reading 3	
1	40	64	65	66	63	2.36
2	50	93	87	92	99	6.50
3	60	99	104	98	95	4.63
4	70	143	138	150	140	4.51
5	70	134	136	137	128	3.69
6	80	169	164	171	173	2.79
7	80	174	176	176	169	2.33
8	80	132	130	131	135	2.00
9	90	139	134	143	141	3.39
10	90	209	211	202	215	3.18
11	100	139	135	138	144	3.30
12	100	146	145	140	152	4.14
13	100	148	151	151	143	3.11
14	120	211	205	218	209	3.16
15	130	243	239	238	251	2.98
16	140	263	253	270	265	3.33
17	140	259	250	254	272	4.53
18	230	375	388	365	371	3.18
19	250	397	385	395	410	3.17
20	260	481	480	472	490	1.88

Table 3. Total body length (mm) and daily increment readings following the GBR criterion in 21 otoliths of jack mackerel (*T. murphyi*) caught in central-southern Peru

Otolith number	Total body length (mm)	Age (days)	Daily increment readings (\cong age in days)			CV %
			Reading 1	Reading 2	Reading 3	
1	40	55	55	54	56	1.82
2	50	78	78	79	77	1.28
3	60	82	80	82	84	2.44
4	60	80	82	83	75	5.45
5	60	40	40	39	41	2.50
6	70	80	77	81	83	3.82
7	80	96	96	90	102	6.25
8	80	100	98	100	102	2.00
9	80	103	100	106	103	2.91
10	130	124	124	120	128	3.23
11	140	115	116	120	110	4.38
12	160	202	200	205	200	1.43
13	170	200	212	195	192	5.40
14	170	210	209	212	210	0.73
15	180	202	195	204	206	2.91
16	190	196	195	204	190	3.61
17	260	323	323	320	326	0.93
18	270	372	367	365	384	2.81
19	290	392	380	406	390	3.35
20	300	377	379	367	384	2.32
21	320	426	445	432	400	5.44

of the 21 otoliths from central-southern Peru which were analyzed according to the GBR criterion (2nd criterion, where packages of two or more rings are interpreted as a unit). In addition, reference is made to Table 2 in Goicochea et al (2013) for the reading results of the 31 otoliths of jack mackerel from central-southern Peru that analyzed according to the IMR criterion (1st criterion). The results of all these readings have been plotted in Figure 3.

It is worth noting that the age readings following the 1st criterion (IMR) in the 20 otoliths from northern Chile were between 64 and 481 days for jack mackerels in the size range of 40 to 260 mm total length, while in the case of the 31 otoliths from central-southern Peru read by Goicochea et al (2013) the ages were between 59 and 437 days for jack mackerels in the size range of 35 to 210 mm of total length. On the other hand, the age readings following the 2nd criterion (GBR) in the 21 otoliths of jack mackerel from central-southern Peru were between 55 and 426 days for specimens in the size range of 40 to 320 mm of total length.

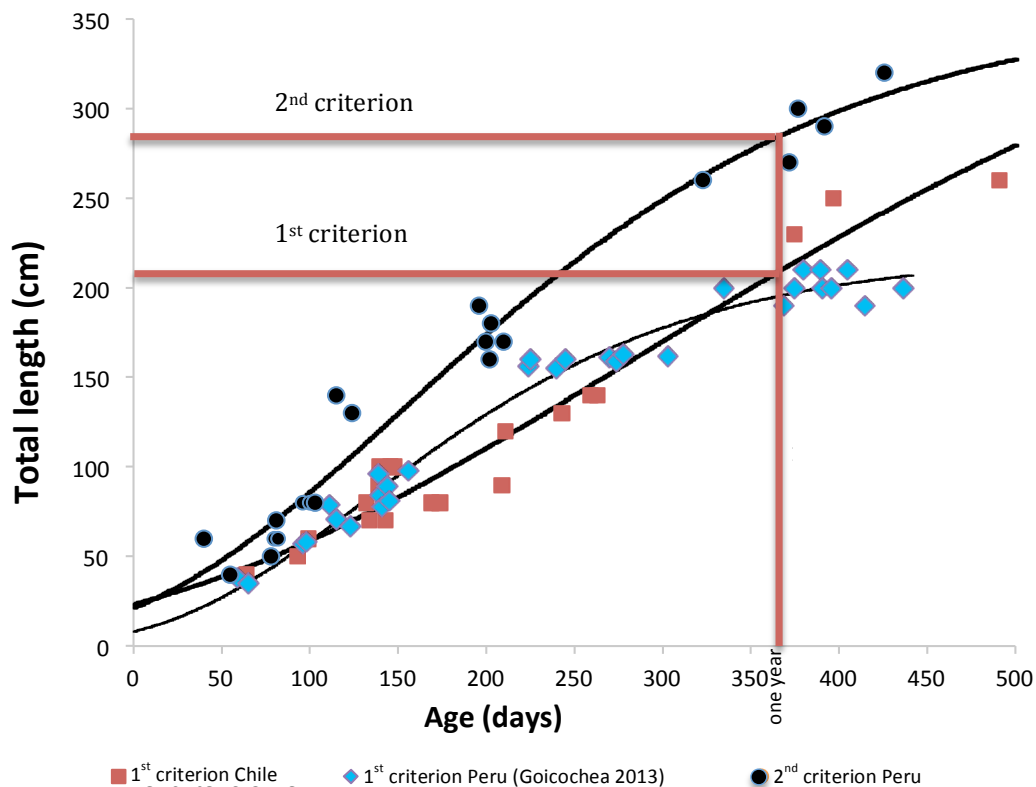


Figure 3. Microincrements reading results in three groups of otoliths of jack mackerel (*T. murphyi*) using two different reading criteria: (a) otoliths analyzed following the first criterion (IMR), from northern Chile (red squares) and from central-southern Peru (blue rhombus); and, (b) otoliths from central-southern Peru analyzed following the second criterion (GBR) (black circles). The continuous lines represent the Laird-Gompertz curves fitted to each group

As can be noted in Figure 3, when the 1st criterion (IMR) is applied in reading the microincrements in otoliths from Peru (blue rhombus) and Chile (red squares) the results obtained are very similar, reaffirming what was found by Goicochea et al (2013) and Cerna and Moyano (2015). While when the 2nd criterion (GBR) is applied (black circles), the estimated body lengths for the same ages are much larger, suggesting a much faster growth rate than estimated until now.

The fit of the Laird-Gompertz growth model (length-age relationship) to the observed data of central-southern Peru using the 1st reading criterion (IMR) (data from Goicochea et al, 2013) was significant ($p < 0.001$) and estimated the parameters $a = 216.25$ mm, $b = 0.00917$ and $c = 129.68$ days. While the same model fitted to the data of northern Chile (Table 2) also using the 1st reading criterion (IMR) was significant ($p < 0.001$) and estimated the parameters $a = 432.68$ mm, $b = 0.0038$ and $c = 281.02$ days. On the other hand, the fit of the same model to the observed data of central-southern Peru obtained using the 2nd reading criterion (GBR) (Table 3) was also significant ($p < 0.001$) and estimated the parameters $a = 359.9$ mm, $b = 0.00678$, and $c = 152.49$ days. Depending on the data set being used, the fitted Laird-Gompertz model predicts that a one year old (365 days) jack mackerel would have a total length of 19.5 cm in central-southern Peru or 20.8 cm in northern Chile if the 1st reading criterion (IMR) is applied, while the same one year old (365 days) fish would have a total length of 28.4 cm if the 2nd reading criterion (GBR) is the one to be applied.

In this respect, it is worth stressing that if the 2nd reading criterion (GBR) is to be applied, jack mackerel would reach its first six month of age with a total body length of 16 to 20 cm having the first growth ring in the otolith already formed (Figure 4), and would reach its first year of age with a total length around 28.4 cm and two growth rings in the otolith (Figure 5).



Figure 4. Otolith of a jack mackerel (*T. murphyi*) of 19 cm TL with the first growth ring already formed



Figure 5. Otolith of a jack mackerel (*T. murphyi*) of 32 cm TL with the second growth ring already formed

Therefore, jack mackerels which according to the 2nd reading criterion (GBR) would have one year of age (365 days) with a body length of 28.4 cm TL would be assigned to the two-year-old group if the 1st reading criterion (IMR) is applied, which is the criterion that has been applied so far in the age determination of jack mackerel in the SE Pacific. However, the results of our analyses with the 2nd reading criterion (GBR) support the thesis of the bi-annual formation of the growth rings in otoliths of jack mackerel, which would form from the first semester and not from the first year of age as assumed so far.

The periodicity in the formation of the growth rings after the first formed ring was determined by counting the daily microincrements in two separate samples of jack mackerel otoliths. A first sample of 5 otoliths was used to analyze the type I formation pattern and a second sample of 10 otoliths was used to analyze the type II formation pattern.

The results of the analysis of type I formation pattern are presented in Table 4 and the results of the analysis of type II formation pattern are presented in Table 5. From these analyses we determine that in the type I formation pattern the average number of days elapsed from the first to the second growth ring is 92.2 days with a length of the increment of 0.519 mm, and from the second to the third ring the elapsed time is 93.1 days and the length of the increment 0.407 mm. While in the type II formation patterns the average number of days from the first to the second growth ring is 183.8 days with a length of the increment of 0.962 mm, and from the second to the third ring the elapsed time is 182.5 days with a length of the increment of 0.660 mm. Examples of these two types of formation patterns are shown in Figures 6 and 7.

Table 4. Length of the increment and days counted in the analysis of type I formation pattern of the growth rings in otoliths of jack mackerel (*T. murphyi*) from southern Peru

Date	Total body length (cm)	Length of the increment from the 1 st to the 2 nd ring (mm)	Days from the 1 st to the 2 nd ring	Reading 1	Reading 2	Reading 3	CV %	Length of the increment from the 2 nd to the 3 rd ring (mm)	Days from the 2 nd to the 3 rd ring	Reading 1	Reading 2	Reading 3	CV %
27/1/07	37	0.43	93	95	93	90	2.72	0.39	90	88	90	92	2.22
27/1/07	36	0.49	90	86	92	92	3.85	0.39	95	96	97	93	2.18
27/1/07	34	0.65	91	94	88	91	3.30	0.41	96	98	95	95	1.80
29/1/07	32	0.47	90	88	91	92	2.30	0.37	93	90	94	94	2.49
31/1/07	38	0.56	97	95	97	99	2.06	0.48	91	93	89	92	2.28
Average		0.52	92.2	91.6	92.2	92.8	2.85	0.41	93.1	93	93	93.2	2.20
D.S.		0.09	2.87	4.28	3.27	3.56		0.04	2.56	4.12	3.39	1.30	

Table 5. Length of the increment and days counted in the analysis of type II formation pattern of the growth rings in otoliths of jack mackerel (*T. murphyi*) from southern Peru

Date	Total body length (cm)	Length of the increment from the 1 st to the 2 nd ring (mm)	Days from the 1 st to the 2 nd ring	Reading 1	Reading 2	Reading 3	CV %	Length of the increment from the 2 nd to the 3 rd ring (mm)	Days from the 2 nd to the 3 rd ring	Reading 1	Reading 2	Reading 3	CV %
1/27/07	38	1.05	185	180	189	187	2.55	0.65	182	183	188	176	3.31
1/27/07	38	0.98	181	177	184	182	1.99	0.80	181	179	184	180	1.46
1/27/07	32	1.04	184	181	184	186	1.37						
1/27/07	34	0.80	192	189	194	192	1.31						
1/27/07	32	1.24	187	188	184	189	1.41						
1/27/07	35	1.06	180	184	177	180	1.95	0.60	187	183	191	187	2.14
1/29/07	35	0.80	183	179	187	184	2.20	0.56	178	184	174	177	2.88
1/29/07	34	0.78	183	181	188	180	2.38	0.75	186	189	182	187	1.94
1/29/07	37	1.08	184	184	189	180	2.45	0.60	180	184	177	180	1.95
1/31/07	31	0.79	179	175	185	178	2.86						
Average		0.96	183.8	181.8	186.1	183.8	2.05	0.66	182.5	183.7	182.7	181.2	2.28
D.S.		0.16	3.58	4.49	4.48	4.59		0.09	3.37	3.20	6.44	4.79	

The photograph in Figure 6 clearly shows the daily microincrements formed between the second and third growth ring in the otolith of a 36 cm long (TL) jack mackerel illustrating the formation pattern type I, where it is worth noting that the count of daily increments will just get to a total close to 90 days. Then, the photograph in Figure 7 clearly shows the daily microincrements formed between the first and second growth ring in the otolith of a 32 cm long (TL) jack mackerel illustrating the formation pattern type II, where the count of microincrements or daily rings is close to 180 days.

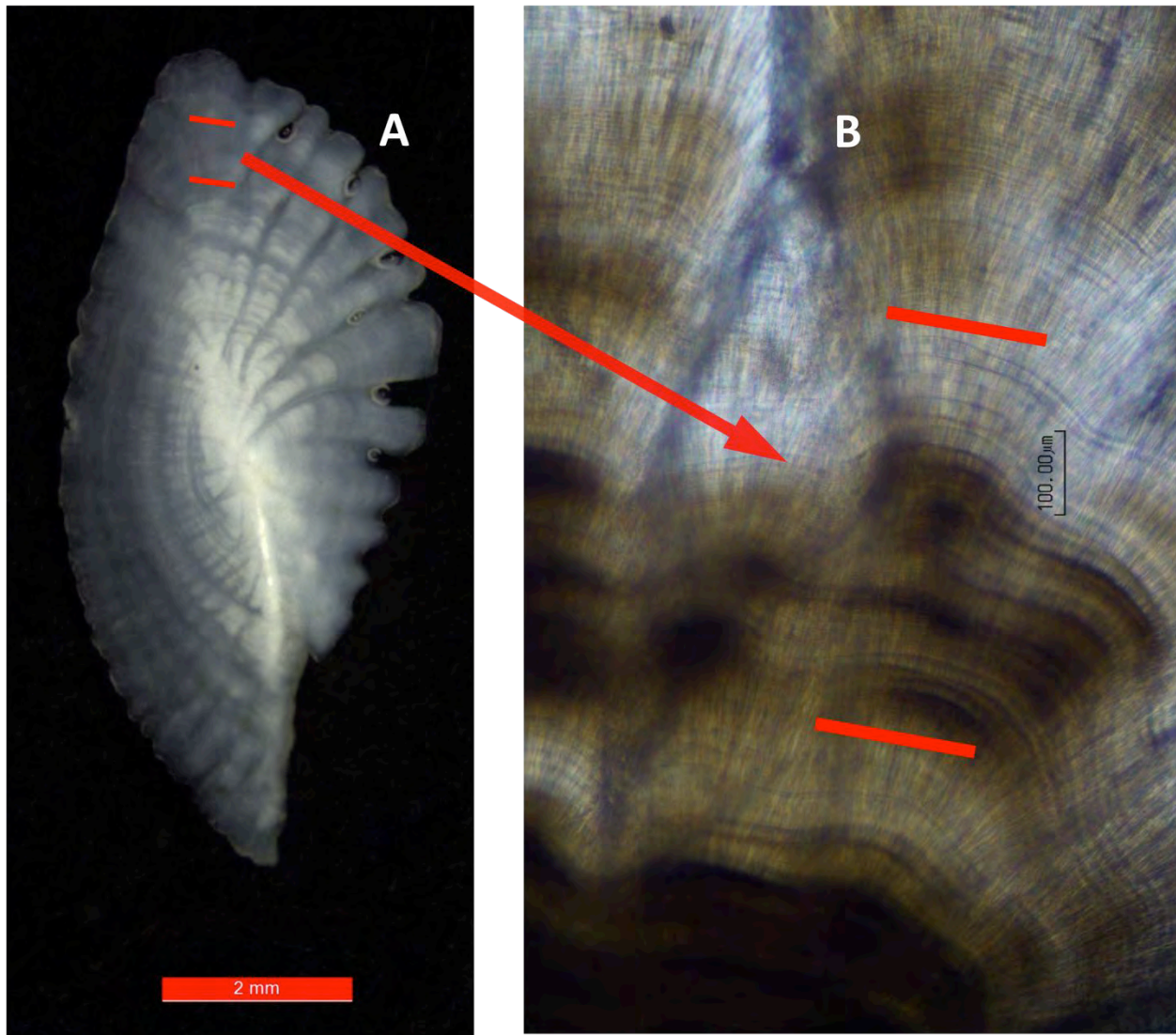


Figure 6. Otolith of a 36 cm TL jack mackerel (*T. murphyi*) showing the third growth ring formed with the type I formation pattern (panel A, left), with a zoomed detail of the microincrements formed between the second and third growth ring (panel B right)

These results would indicate that the formation of the growth rings in the otoliths of jack mackerel have, respectively, a quarterly and a biannual periodicity. In this regard it is noted that the annual rate of increase in length of the growth rings from the first to the second ring and from the second to the third ring estimated by Goicochea et al (2013) were 0.88 mm and 0.62 mm respectively, and this latest growth rate was estimated by monthly monitoring throughout a full year the growth of the otolith radius between the second and third ring in jack mackerels from a well-defined cohort that appeared consistently in the Peruvian commercial fishery in 2011 and 2012. However, the results of this study estimate semiannual rates of increase between the first and second ring and between the second and third ring of 0.96 mm and 0.66 mm respectively for the type II rings, which are similar to the annual rates reported by Goicochea et al (2013). That is, the increments are similar but one is semiannual and the other one is annual.

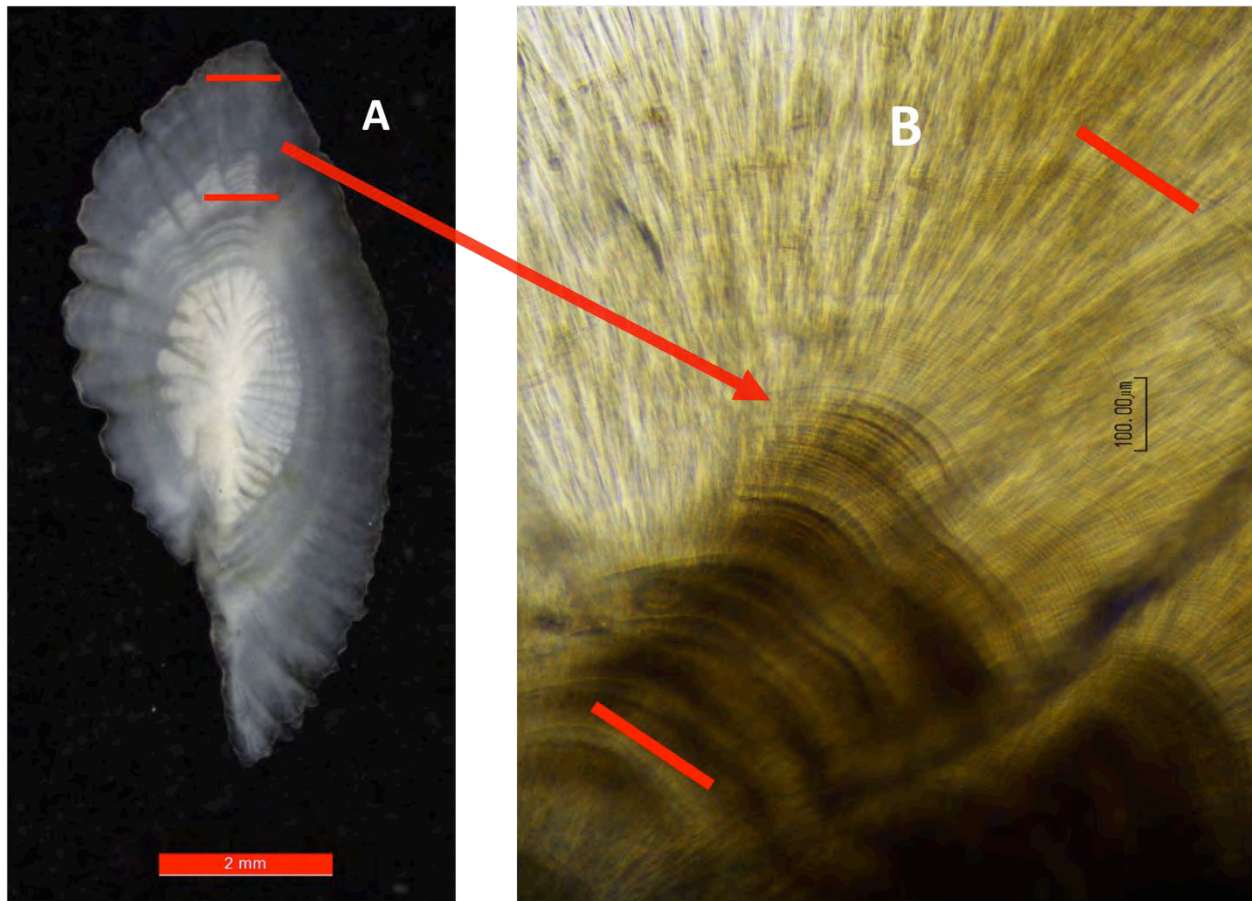


Figure 7.- Otolith of a 32 cm TL jack mackerel (*T. murphyi*) showing the second growth ring formed with the type II formation pattern (panel A, left), with a zoomed detail of the microincrements formed between the first and second growth ring (panel B, right)

DISCUSSION AND CONCLUSIONS

One main conclusion from the readings described above is that jack mackerel (*T. murphyi*) has in fact a very fast growth rate, confirming once more the high growth rate estimates from Dioses (1995, 2013), Diaz (2013) and Goicochea et al (2013) even though, depending on the reading criterion used, the growth rate could be even faster than estimated to date.

According to the otolith microstructure analysis following the first reading criterion (IMR), at one year of age (365 days) jack mackerel caught off central-southern Peru and northern Chile would have a total body length of 19.5 cm to 20.8 cm TL. This is much larger than the 15.3 cm TL estimated with the growth parameters currently in use, although in this respect we may quote Dioses (2013) in noting that *"the criteria of considering as annual rings only those complete hyaline rings that are preceded by an opaque area or ring could induce to an overestimation of the age of the younger individuals within a cohort by assigning age 1 (the first annual ring) to otoliths of fish that are only 6 to 11 months old but have already formed a first complete hyaline ring preceded by a first opaque ring or the opaque core of the otolith."*

A similar situation to that quoted from Dioses (2013) is illustrated in Figure 7 that shows an otolith of a 32 cm TL jack mackerel with the first two (allegedly annual) rings clearly visible. However, the reading of microincrements between these two rings gives a total count of 180 days, indicating that we are dealing with a semiannual ring (not an annual ring) and therefore the real age of this jack mackerel would be 1.5 years and it would be expected to reach the two years of age with a total length of 33-35 cm.

The above would explain the discrepancy between the body length at one year of age calculated from the annual rings readings that are the basis of the von Bertalanffy growth equation in use in Peru (Dioses 1995, 2013) and the body lengths at one year (365 days) of age calculated from the analysis of daily increments following the first reading criterion (IMR) presented in this study and in Goicochea et al (2013). In this case the problem would not be with the estimation of the growth rate but in the estimation of the parameter t_0 , that instead of being $t_0 = -0.365$ should be more something like $t_0 = -0.784$, while the values of k and L_∞ would remain unchanged.

The age determination is further complicated if the age reading criterion to be applied is the GBR (2nd criterion) where packets of rings are interpreted as a unit, which would result in a much faster growth rate than that obtained with IMR criterion being used at present. According to the GBR criterion jack mackerel would be reaching its first year of age with around 29 cm TL (27 FL), a length to which we have been assigning an age of two years by following the IMR criterion. It is clear that the age structure of jack mackerel as we know it would change dramatically if we conclude that the GBR criterion is the correct reading criterion to be applied in the case of this species. If the IMR criterion is the correct one, the age readings following the GBR criterion would produce a gross overestimation of the growth of jack mackerel, but if we keep using the IMR criterion and the correct criterion is the GBR we would be facing a serious problem of underestimation of the growth rate (k).

The problems and potential bias in our assessments related to the possible underestimation of growth if we err by continuing to use the IMR criterion when the GBR criterion is the correct one, or the possible overestimation if we err by switching to the GBR criterion when the IMR criterion is the correct one are sufficiently large and important as to justify a more in-depth and detailed full-fledged analysis of this matter.

With regard to the periodicity in the formation of the growth rings and the presence of quarterly type I and semiannual type II growth rings it is worth highlighting the importance of their proper identification and the need to clearly establish the differences between them. Otherwise there could be a serious bias of underestimation of the age and overestimation of the growth rate if the annual rings are interpreted as if they were semiannual (type II) rings, or worse, if interpreted as quarterly (type I) rings. Although it is more likely that we would be seeing an overestimation of the age and an underestimation of the growth rate of jack mackerel in the event that the quarterly (type I) rings and/or the semiannual (type II) are not properly identified and end up being interpreted as annual rings as we suspect it might be presently occurring. In this regard, we emphasize the noticeable difference between the annual rates of increase in length of the growth rings estimated Goicochea et al (2013) and those estimated in this study, noting that the lengths

of the increment between rings in the otoliths observed in this study over six-month periods are similar to those found on a yearly basis by Goicochea et al (2013).

This observation reinforces the suspicion of a possible overestimation of the ages and a consistent underestimation of the growth rate of jack mackerel, which would justify a thorough review and recalculation of the age structures currently in use in the assessments of jack mackerel within the context of the SPRFMO in the South Pacific.

RECOMMENDATIONS

A thorough and more extended review of the validity of the data and of the criteria being used to identify, measure and count the growth rings in the otoliths of jack mackerel is needed and is recommended here in order to properly tackle the still existing doubts and uncertainties regarding the age and growth estimates of this species. Whenever possible this could include the combined analysis of age and growth estimations from various sources, following-up and/or extending on the approach made by Dioses (2013), Diaz (2013) and Goicochea et al (2013) for the case of Peruvian jack mackerel. In so doing, due consideration should be given to the results in this study, which point to the likely risk of overestimation of the ages and underestimation of the growth rate if the differences in the reading criteria and in the type and periodicity in the formation of the microincrements in the otoliths are not properly taken into account.

Given the complexity of the interpretation of the growth rings in the otoliths of juvenile jack mackerel, especially of those rings found in the secondary growth zone (SGZ), it is recommended that the growth and formation of the microincrements in otoliths of juvenile jack mackerels be monitored and analyzed with live fish under controlled laboratory conditions. Field studies that include the marking, release and recapture of adult jack mackerels are also recommended to validate the microincrements and finally resolve the sources of uncertainty and potential disagreements on the age and growth of jack mackerel (*T. murphyi*) in the Southeast Pacific.

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