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Proposing an integrated approach for tackling the uncertainties in the ageing and estimation of growth parameters of *Trachurus murphyi* in the South Pacific

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Proposing an integrated approach for tackling the uncertainties in the ageing and estimation of growth parameters of Jack mackerel (*Trachurus murphyi*) in the South Pacific

a proposal for discussion at the
1st Meeting of the Scientific Committee (SC-01) of the SPRFMO

by

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Introduction

The proper determination of the fish age and growth is of the outmost importance for studying the population dynamics of exploited fish stocks, for assessing their state of exploitation and their productivity, and thus for taking fisheries management decisions. It is on the basis of properly estimated age and growth that population net growth, mortality, recruitment, and other important population parameters and indicators are determined and assessed.

As pointed out in the various contributions being presented to this SC-01 meeting (IMARPE-PRODUCE 2013, Dioses 2013, Goicochea *et al* 2013, Diaz 2013, Canales 2013), there are fundamental differences in the age determinations and estimated growth parameters available for the Jack mackerel (*Trachurus murphyi*) stocks in the northern and the southern parts of the Southeast Pacific, respectively corresponding to the Peruvian or far-north stock and to the Chilean or center-south stock(s), and these differences may have substantial impacts on the assessments being undertaken. Discerning if these differences are ontological or methodological, or result from a combination of both is therefore of the greatest importance for the future stock assessment work on Jack mackerel in the context of the South Pacific Regional Fisheries Management Organisation (SPRFMO).

It has been noted that assigning the age to specimens of Jack mackerel *T. murphyi* through traditional methods such the reading of annual rings in hard bone structures such as otoliths can lead to underestimations or overestimations of age. It has also been noted that this can introduce serious biases in any stock assessment approach based on size or age structured analyses.

The presence of false annual rings in the otoliths of Jack mackerel as well as the variations in the appearance of the rings on the different parts of the surface of the otolith are a common source of errors and of discrepancies in the determination of the age in this species.

From the analysis of the various age and growth estimates available for Jack mackerel *T. murphyi,* it is clear that discrepancies do exist in the region. Therefore, and in an attempt to elucidate the causes of these discrepancies we propose coupling the traditional annual ring readings approach with the more advanced analyses of micro-increments or daily rings combined with the simpler and faster methods based on length frequency anlysis as a way forward to tackle these discrepancies and solve the Jack mackerel age and growth question in the context of the SPRFMO assessments.

Background

Although scales have also been used, otolith reading is what has been used more often for Jack mackerel in the Southeast Pacific. Three techniques are being used in the region for the preparation and interpretation of growth rings in the sagittal otoliths of Jack mackerel *T. murphyi*. These are: (a) traditional (routine) reading of annual rings in whole otoliths; (b) reading annual rings in cross-sections of otoliths; and, (c) reading micro-increments or daily rings.

For comparison purposes Table 1 shows the growth parameters estimated for Jack mackerel *T. murphyi* from different areas of the Southeast Pacific by different authors using one or more of the methods mentioned above. The asymptotic lengths (L_∞) estimated on the basis of total length (LT) in the original papers by Dioses

Table 1. Parameters of the fork length von Bertalanffy growth equation for Jack mackerel in the Southeast Pacific estimated with various methods by different authors (adapted from IFOP 1995 and Alegría *et al* 1995).

No	Ageing from	Author & method used	L_∞	k	t_0	Zone
1	Otoliths	Kaiser (1973) annual rings	70.08	0.184	-0.341	Chile north-central
2	Otoliths	Pavez y Saa (1978) annual rings	106.28	0.109	-0.877	Chile central
3	Otoliths	Abramov y Kotlyar (1980) annual rings	72.47	0.093	-2.233	Peru
4	Otoliths	Aguayo et al. (1981) annual rings	45.90	0.167	-0.882	Chile north
5	Scales	Nekrasov (1982) annual marks	74.30	0.086	-2.676	Peru
6	Otoliths	Shevshuk y Chur (1984) annual rings	90.41	0.115	-1.429	Peru-Chile
7	Otoliths	Castillo y Arrizaga (1987) annual rings	85.23	0.074	-2.410	Chile south
8	Scales	Nekrasov (1987) annual marks	96.00	0.060	-2.617	Peru
9	Scales	Nosov et al. (1989) annual marks	77.80	0.077	-1.613	Peru
10	Otoliths	Kochkin (1994) annual rings	74.24	0.111	-0.811	Peru
11	Otoliths	Shcherbithch (1991) annual rings	91.23	0.091	-1.583	n/a
12	Otoliths	Alegría et al. (1995) daily rings	78.48	0.154	-0.098	Chile north
13	Otoliths	Alegría et al. (1995) annual rings (whole)	53.50	0.111	-1.797	Chile north
14	Otoliths	Alegría et al. (1995) annual rings (cut)	46.40	0.184	-0.945	Chile north
15	Otoliths	Arcos y Arancibia (1995) annual rings whole	79.88	0.068	-2.369	Chile central-south
16	Otoliths	Arcos y Arancibia (1995) annual rings (cut)	70.72	0.088	-2.107	Chile central-south
17	Otoliths	Arcos y Arancibia (1995) annual rings (w., retrocalc.)	70.80	0.094	-0.896	Chile central-south
18	Otoliths	Arcos y Arancibia (1995) annual rings (c., retrocalc.)	63.03	0.119	-1.113	Chile central-south
19	Otoliths	Gang Li et al. (2011) annual rings	73.80	0.107	-1.080	Chile central-south
20	Otoliths	Dioses (2013) annual rings	73.56	0.155	-0.356	Peru
21	Length freq.	Babayan y Bulgakova (1994) LFA	94.50	0.099	-1.240	S. Pacific high sea
22	Length freq.	Babayan y Bulgakova (1994) LFA	96.10	0.104	-1.090	S. Pacific high sea
23	Length freq.	Cubillos y Grenchina (1994) LFA	75.30	0.144	-0.170	Chile
24	Length freq.	Díaz (2013) LFA	74.32	0.167	-0.600	Peru
25	Otoliths	Goicochea et al. (2013) annual rings	68.43	0.165	-0.817	Peru

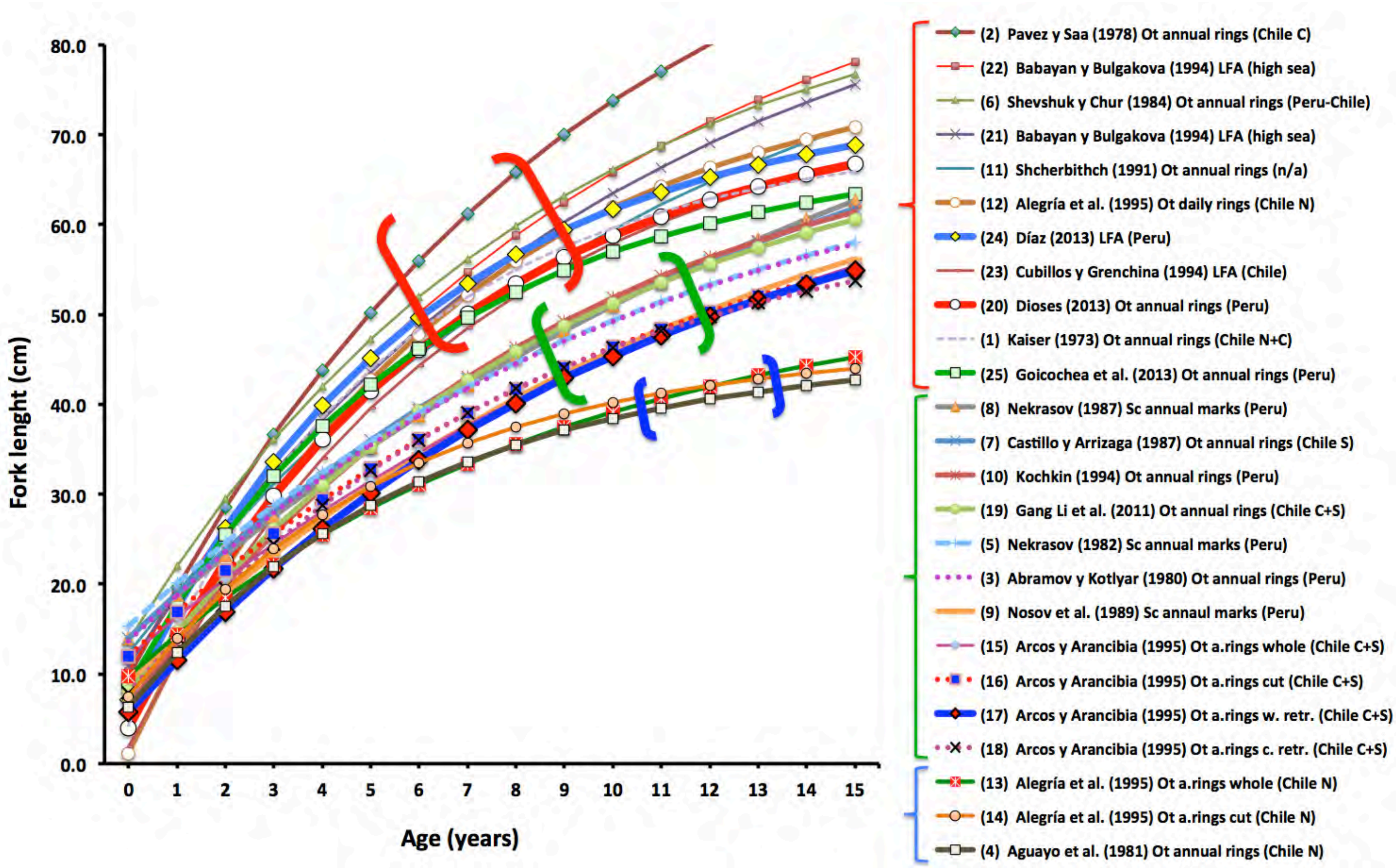

Figure 1. Growth curves and theoretical length at age of Jack mackerel T. murphyi estimates by different authors and methods and for different areas of the Southeast Pacific (the parameters are those from Table 1)

(2013), Diaz (2013) and Goicoechea *et al.* (2013) have been converted to fork length (LH) using the Cubillos & Arancibia (1995) equation LT = 0.514 + 1.091LH. The various theoretical growth curves generated from the parameters in Table 1 are shown in Figure 1.

As can be noted, there is a wide difference in the estimated growth parameters as well as in theoretical lengths-at-age resulting from them. Up to three groups of curves can be identified in Figure 1: the first group identified by red brackets correspond to a typical faster-growing animal; the second group identified by green brackets correspond to a mid-growing one; and the third one identified by the blue brackets correspond to a slow-growing animal, *T. murphy* in all three cases.

As has already been noted for the case of *T. murphyi* (Csirke 2013, Dioses 2013, Goicochea et al 2013 & Diaz 2013), these differences in the ageing and growth estimations could be:

- ontogenic, i.e. due to actual differences in the growth rate of *T. murphy* from different stocks (and different geographic areas);

- methodological, which can be due to differences in the ageing methodology being used, the ageing criteria being applied, differences in equipment, sampling problems (extreme sizes/ages poorly represented), etc.; or,
- a combination of both.

As stated above, distinguishing the causes of these differences is of the outmost importance for the future stock assessment work of the Jack mackerel in the context of the SPRFMO.

In this respect, it is worth noting that within the first group in Figure 1 (faster growing, red bracket) we find the growth curves calculated with the parameters estimated from routine otolith readings by Dioses (2013) (N° 20 in Table 1) for the Peruvian stock (far-north stock) of Jack mackerel *T. murphyi*, which have been confirmed by the independent estimates of Goicochea et al (2013) using both annual rings readings (N° 25 in Table 1) and micro-increments readings (results not shown), as well as by the estimates of Diaz (2013) (N° 24 in Table 1) using length frequency analysis. Also, the growth curve calculated from the parameters estimated by Alegría et al (1995) (N° 12 in Table 1) for the Jack mackerel in northern Chile by reading micro-increments in otoliths from ages 1 to 5 give similar results to those estimated by Dioses (2013), Goicochea et al (2013) and Diaz (2013) for the far-north stock. It is further noted that the recent Peruvian age and growth studies mentioned above suggest that there has been no change in the growth pattern of the Peruvian *T. murphyi* since the first age and growth study by Dioses (1995).

All this would tend to confirm the observation that *T. murphyi* in the northern stock (Peru far-north stock) grows faster and larger than *T. murphyi* in the southern stock (Chile central-south stock). Particularly since the commonly accepted growth parameters for the Chilean stock estimated by Arcos and Arancíbia (1995) and Gili et al (1996) (N° 17 in Table 1) estimate much lower lengths for the same ages, as shown in Figure 1. These and other Chilean estimates would place *T. murphyi* from the Chilean stock amongst the mid-growing group (green brackets) in Figure 1. However, this cannot be ascertained because for the Chilean stock(s) there are some estimates that fit within the faster growing group as well as with the slower growing group in Figure 1.

On this, it is noted that all parameters and growth curves that fit within the mid-growing and slow-growing groups in Figure 1 have been estimated from annual rings readings in otoliths and/or scales, while all the estimates based on readings of micro-increments (daily rings) in otoliths or from some type of length frequency analysis fall within the faster-growing group, together with those most recently estimated and confirmed for *T. murphyi* in the Peruvian (far-north) stock. This clearly raises the question of validation of the annual rings readings for the Jack mackerel *T. murphyi* in the rest of the South Pacific, and particularly in the area of application of the SPRFMO Convention.

At present, the main sources of uncertainty seems to come from the age determinations based on the interpretation of annual rings in the otoliths, and it is well known that discriminating true and false annual rings in otoliths of Jack mackerel *T. murphyi* is rather complicated. Actually, the traditional (routine) technique of reading annual rings in whole otoliths usually takes as real (annual) rings all the hyaline rings that are visible in the otolith, and this is the major source of discrepancies amongst readers. An example of a typical Jack mackerel otolith with various alternative age-readings is shown in Figures 2 and 3.

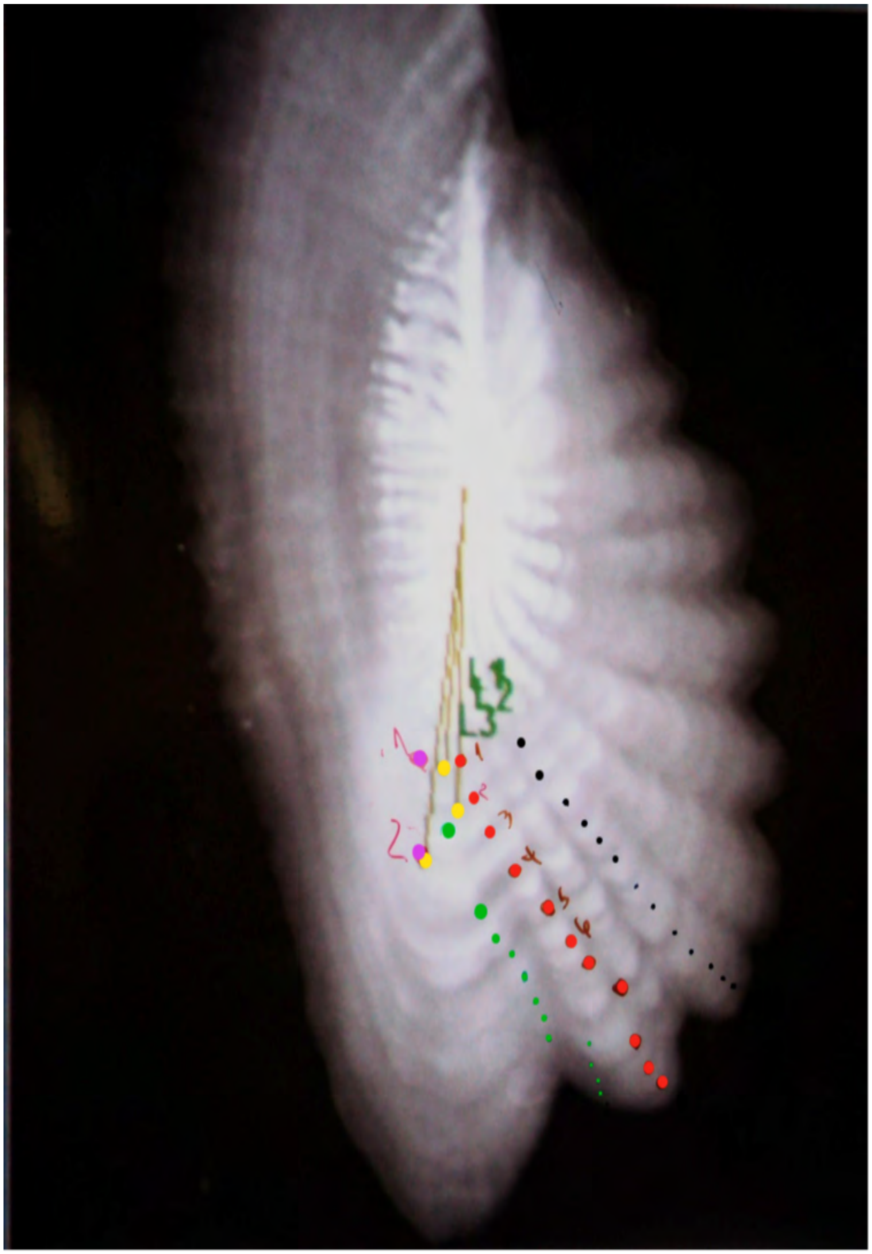

Figure 2. Otolith of a Jack mackerel *T. murphyi* of 58 cm (fork length) with alternative age readings (11 to 13 years) by different readers. Reader 1 (green dots) identifies 12 rings, reader 2 (red dots) identifies 11 rings, reader 7 (black dots) identifies 13 rings and reader 6 (purple dots) identifies the first 2 rings. The yellow dots and lines show the place and radius of the first three rings, being 2.1 mm, 2.4 mm and 2.8 mm respectively (adapted from Serra 2011)

As can be seen in Figure 2 and in the enlarged detail in Figure 3, there is a mismatch between the annual rings being identified by each reader and, except for Reader 2 (smaller darker red dots), all readers fail to identify the first three annual rings identified by the measurements of the radius (yellow lines). This also illustrates other source of discrepancies amongst readers, where some readers identify as annual rings what others interpret as false rings. This is the case of a presumably "false ring" between age-rings 4 and 5 for Reader 2 (darker red dots), which is interpreted as a real annual ring by Readers 1 (green dots) and 7 (black dots).

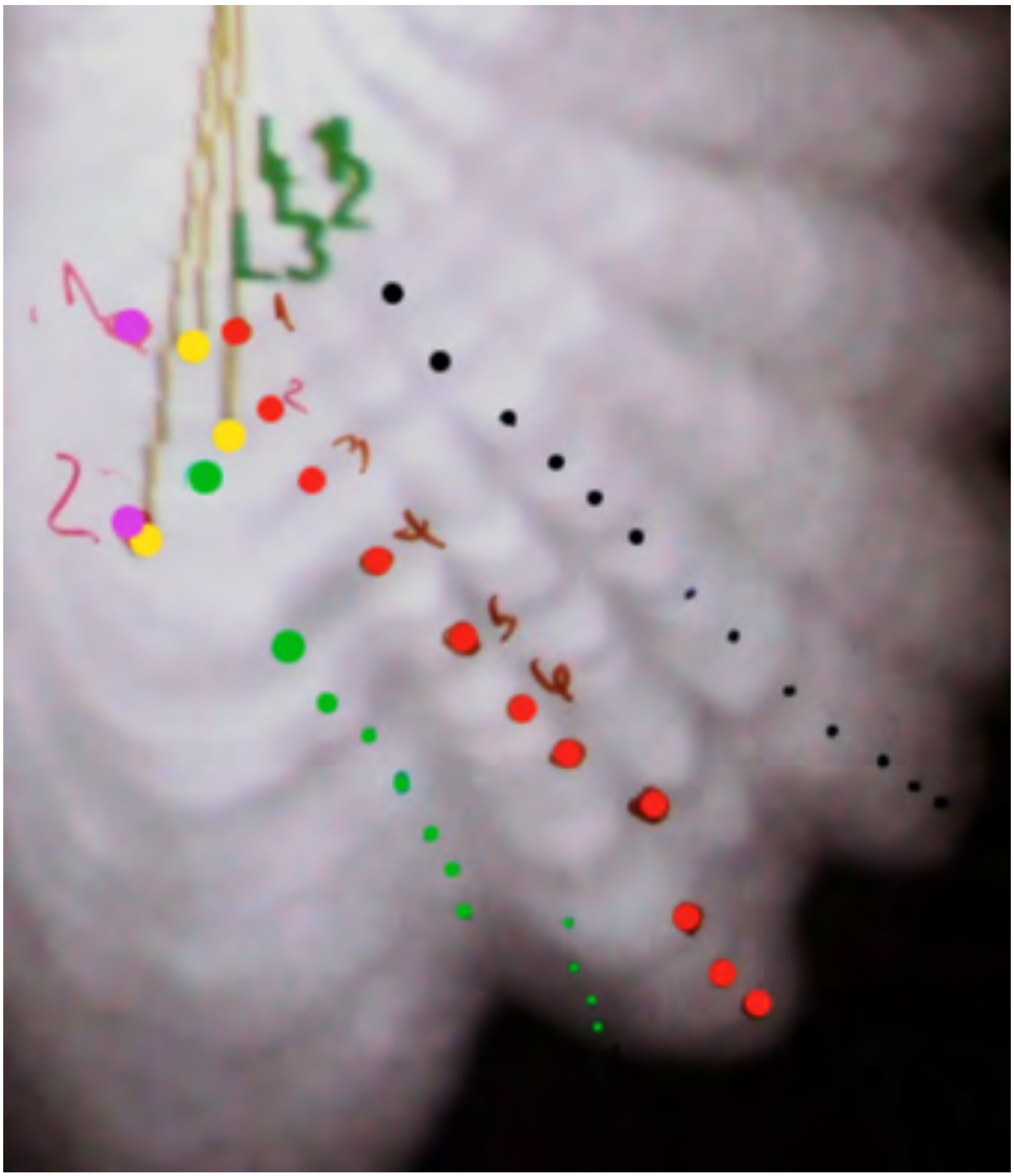

Figure 3. Enlarged detail of the otolith of a 58 cm fork length Jack mackerel *T. murphyi* shown in Figure 2 (adapted from Serra 2011)

Validation by other independent methods should provide a way to correct possible biases or errors in the traditional age interpretation of hyaline (annual) marks in the otoliths of *T. murphyi,* and/or to confirm the observed differences in the growth rates of the Jack mackerel *T. murphyi* from Peru (far-north stock) and from Chile (Chile central-south stock), and possibly from the open high sea in the South Pacific.

One method for validating the age readings in otoliths is by analyzing the formation of the daily growth increments in the otoliths. This method has been applied in *T. murphyi* by Araya et al (2003) by performing an experiment of marking live specimens of Jack mackerel *T. murphyi* in captivity with equal doses of oxy-tetracycline at a 30-days interval. Then, by reading the number of micro-increments between marks they were able to demonstrate that the otoliths of Jack mackerel *T. murphyi* do form one micro-increment per day. Based on the findings of Araya el at (2003), other authors have used the reading of micro-increments in the otoliths to determine age and estimate growth parameters for *T. murphyi* from different locations in the Southeast Pacific, as are the cases of Alegría el al (1995) for the northern part of Chile and Goicochea et al (2013) for Peru.

Goicochea et al (2013) applied the same technique of micro-increment analysis or daily rings reading applied by Alegría et al (1995) and concluded that at one year of age (365 days) the Peruvian Jack mackerel *T. murphyi* would have a total length of 195.3 mm (177 mm fork length). Also, these authors identified the presence of a strong year class in January 2011, which they could clearly identify and follow throughout January 2012, monitoring month-by-month the increase of the total radius of the otoliths. They found that during this time-interval, corresponding to the formation period from the second to the third ring, the otoliths grew on average 0.62 mm. Goicochea et al (2013) then undertook an age and growth study by the conventional interpretation of annual rings, and their estimated growth parameters (No 25 in Table 1) were compatible with those of Dioses (1995, 2013) and the faster-growing group in Figure 1. It is believed that a similar approach applied more widely within the context of the SPRFMO could take us a long way into resolving the uncertainties in the ageing and estimation of growth parameters for further use in the JJM and other stock assessment applications the SPRFMO Scientific Committee might have in mind.

The uncertainties and noticeable differences in the age and growth estimates available to this Scientific Committee should be a strong motivation to propose and support a more integrated approach to address this age and growth issue. This integrated more comprehensive approach should include an in-depth review and analysis of the existing age readings of *T. murphyi* using hard structures of like scales and otoliths, repeat annual age readings and validate these readings with more accurate analyses of micro-increments (daily rings) in the same hard structures, complemented with the application of indirect methods, such as the analysis of the temporal evolution of size frequency distributions, which could also provide valuable insights into the real growth and age-patterns present in the fishery.

Objectives

A series of national research and monitoring programs with some regional coordination under the aegis of the SPRFMO is therefore proposed, having as main objectives to:

a) Determine if the observed differences in the age and growth parameters estimated for the Jack mackerel *T. murphyi* from different parts of the South Pacific are due to differences in the methods or practices adopted by different authors in the various Laboratories working with Jack mackerel, are due to real differences in the growth of *T. murphyi* from different stocks mackerel, or a combination of both.

b) Validate annual rings age determinations though the analysis of micro-increments (daily rings) and/or length frequency analyses.

c) Establish a length-weight relationship and the growth rate for each possible stock or population unit of Jack mackerel *T. murphyi* in the South Pacific through the implementation of a comprehensive approach, involving two or more independent methods to ensure confidence and consistency in the estimations of the growth parameters to be used for stock assessment purposes.

d) Monitor possible changes in the growth parameters, which could be caused by environmental factors (e.g. El Niño, longer-term regime shifts) or by changes in fishing patterns.

Work plan

For each possible stock or population unit in the South Pacific, develop a research and monitoring programme that would include:

1. Determining the first annual ring through the determination of daily micro-increments in hard structures, preferably in otoliths (sagitta). Then use the analysis of micro-increments to determine the greater number of annual rings as possible. The determination of the first ring is crucial to determine and limit the potential biases encountered in the identification of annual rings based on the alternation of opaque and hyaline rings. For example, with criteria of relying on the formation of the annual hyaline ring to determine the age, a fish that is born closer the time or season when the hyaline rings are formed (June-August in the case of the Peruvian Jack mackerel) are more likely to be assigned 1 year of age much earlier, when in fact are only a few months old. This has been detected in the case of the Peruvian Jack mackerel, were some portion of the sampled otoliths have been found to have the first hyaline ring fully formed with only 180 to 270 daily rings or micro-increments.
2. Applying the back calculating technique in the annual ring readings, taking as a reference the formation of the first annual ring to be determined with the reading of micro-increments.
3. Following and monitoring a cohort over time through an intensive sampling of hard structures (i.e., otoliths), which should allow the quantitative description of

the progressive growth of the individuals in this cohort during its passage through the fishery.

4. Applying size frequency analysis methods to estimate growth parameters. These could be parametric (such as MULTIFAN and NORMSEP) or non-parametric methods (such as SLCA, PROJMAT, Powell-Wetherall, etc.).
5. Replicating for each possible stock or population unit the same set of procedures, promoting regional cooperation and the exchange of experiences.
6. Repeating this set of procedures with time, for example during the presence of an El Niño, during regime shifts o after major changes in exploitation rate, to determine if these could have caused changes in the age and growth of Jack mackerel.

Suggested time frame

Based on IMARPE's experience, actions under 1 to 5 above could be undertaken and concluded by each National Laboratory or participating party within one or two years if suitable otolith and length-frequency distribution samples are available for the target stock(s) or population unit(s) to be analyzed, while actions under 6 above are to be considered as a continuing exercise relying on core information and sampling for age and growth monitoring.

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