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Reproductive Timing and Maturity at Length and Age of Jack Mackerel *Trachurus murphyi*, in the Chilean Coast

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Abstract

The main spawning season is analyzed as well as the maturity at length and age of male and female specimens of jack mackerel (*Trachurus murphyi*) in the coast of Chile. The histological analysis of male and female gonads confirmed that the reproductive activity of the species tends to concentrate in September and December. Mean length of mature female (L_{50}) during the reproductive season of 2011 was estimated in 22.7 cm fork length (L_H), which corresponds to 2.44 years old (E_{50}), in accordance with age determination through otoliths. In the case of male, the scarce presence of inmature individuals did not allow to estimate the parameters L_{50} and E_{50} satisfactorily. However, the estimation of 90% maturity (P_{90}) revealed significant differences ($P< 0.01$) between sexes in the process of maturation. Results showed that while males reach L_{90} of maturity at 21.5 cm L_H (1.9 year old), females did so at 24.5 cm L_H (4 years old). L_{50} of females did not vary significantly with respect to the previous estimations obtained through histological analysis. The ogive shape, nonetheless, evidenced important differences, which could be caused by the spatial and temporal coverage of samplings as well as the criteria used in each case to assign phases of ovarian maturity.

Introduction

A relevant feature in the life cycle of a species is the transition from juvenile to sexual maturity. In terms of fisheries and stock assessments, the size and age at which sexual maturity is reached constitutes a basic reproductive parameter that allows distinguishing the mature fraction of a fish stock; it is considered a key component of stock dynamics due to its influence on the intrinsic rate of population growth. Besides, it is often used as a biological reference point in an attempt to allow fish to reproduce at least once before being caught (Lowerre-Barbieri. et al 2011a).

The sexual maturity estimation procedure is based on determining maturity ogives, depending on size or age. Ogive adjustment should adequately represent the stock, on the basis of coverage of most of the species distribution area, with an adequate coverage of the spectrum of lengths and/or ages of the stock and temporal scale (Hunter & Macewicz, 2003, Lowerre-Barbieri et al. 2011b). For an adequate description of the maturity process, a precise categorization of the different gonadal development stages is required, with an optimum sample size, particularly in the transition of specimens from immature to mature (Murua et al. 2003; Brown-Peterson et al. 2011).

Jack mackerel (*T. murphyi*) mean maturity length (L_{50}) estimates show a wide fluctuation, between 21.6 cm (Alegría et al. 1995) and 39.0 cm fork length (LH) (Adrianov, 1985). These estimates have been made for different areas and time periods in the coasts of Chile and Peru, considering the different methodologies and criteria for classification of gonadal development stage. When analyses are based on ovary histology, results report less variable values –around 23 cm, with a maximum of 26.7 cm L_H (Cubillos & Alarcón, 2010). However, currently there are no national estimates of the mean size of sexual maturity for jack mackerel on the basis of a protocol of representative sampling and under commonly-agreed criteria of gonadal development.

In addition, possible male/female differences in the maturity process remain unknown. Neither there are studies on the process of maturity at age based on direct otolith reading.

Thus, the study is aimed at obtaining a maturity ogive, updated in terms of biology, distribution, and behavior of the resource during the spawning season; it will allow estimating the national size and age of jack mackerel maturity within the range of its distribution in Chile.

Materials and Methods

The annual reproductive cycle, and maturity at length and age of jack mackerel in the East coast of the South Pacific were studied. The concerned area covered the coasts of Chile between 18°21' and 46°00'S. Information to carried out the study was taken from the biological monitoring of the species conducted by the Fisheries Research Institute, IFOP, covering the area of operation of the purse-seine fleet in national waters (Fig.1).

The sampling design corresponds to the simple stratified type, carried out monthly between February and December 2011. The number of histological samples obtained to monitor the reproductive activity is presented in Table 1.

The reproductive activity was studied through monthly variation of the GSI, according to Nikolsky (1963) and verified with the frequency of maturity stages. The 2011 GSI was compared with the global pattern showed by the index between 2006 and 2010.

Table 1. **Number of histological samples for the reproductive activity study of jack mackerel, February-December 2011.**

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec	Total
Male		25	83	82	17	34	58	175	59	23	202	172	930
Female		22	56	126	45	40	119	210	70	28	176	204	1096
Total		47	139	208	62	74	177	385	129	51	378	476	2126

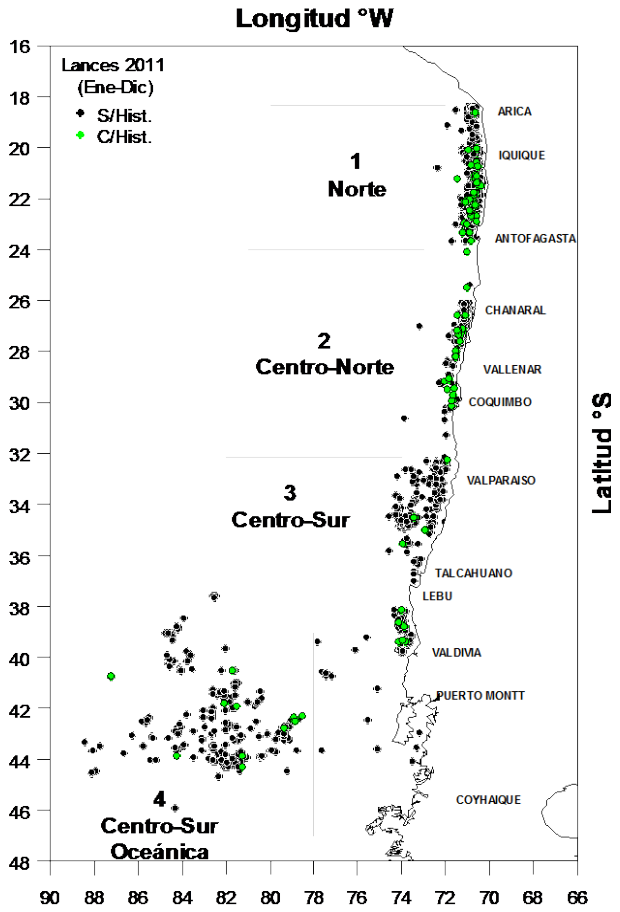

Figure 1. **Total sets of the fleet that operated on jack mackerel Feb-Dec 2011 and out of which the samples for the histological monitoring were obtained (green circles).**

The study considered both male and female of *T. murphyi*. Each fish was measured, recording its total weight (*Tw*, ± 0,1 g) and fork length (F_l, ± 0,5 cm). The testicle/ovary of each specimen was extracted, weighed, and fixed in neutralized and diluted formaline (10%), for further processing.

At the lab, samples were histologically processed to assign the different phases of maturity through microscopic criteria. The classification of the gonadal maturity stages was based on the proposal of Brown-Peterson et al. (2011), for male and female of teleost fishes. This scale was analyzed and discussed at an international workshop to review histological criteria for the assignment of jack mackerel gonadal maturity phases (Saborido-Rey & Leal, 2011).

For the maturity at age study of both sexes, along with the gonadal tissue, the otolith of each specimen started to be extracted since September. Age was estimated through the growth rings of these structures.

A logistic model was used to describe the mature specimens at length (L) or age (E) ratio. The equation that defines the logistic shape/form of the curve is described by:

$$P = \frac{1}{1 + \exp(\beta_0 - \beta_1 * L, E)}$$

where P is the mature specimens at length (L) or age (E) ratio, β_0 y β_1, are parameters that represent the position and slope of the curve, accordingly. These parameters were obtained by maximum likelihood, assuming a binomial distribution (mature/immature) of the random variable. The function of log-likelihood estimate had the form:

$$L(\beta_0, \beta_1) = \sum k \ln(P) + (1 - h) \ln(1 - P)$$

where k indicates the presence or absence of mature specimens, and P is the logistic function previously described. Both male and female were classified as mature since the phase called Development (II). Such phase is characterized, in the case of female, by the presence of cortical alveolus in the ovocyte cytoplasm.

Mean length or mean age at maturity is defined when the logistic function reaches 50% likelihood to observe mature specimens at lenth(L_{50}) or age (E_{50}) and is obtained as the ratio between parameters β_0 y β_1, *i.e.*

$$E_{50}, L_{50} = \frac{\beta_0}{\beta_1}$$

The confidence interval for the mean maturity length was obtained through a Monte Carlo type re-sampling approach of parameters β_0 y β_1, as suggested by Roa *et al.* (1999) for this type of analysis.

To evaluate potential differences in length and age at maturity of male and female, ogives of maturity at size and age were compared between both sexes through an analysis of deviance (Dobson, 2002).

Results

Reproductive cycle

The 2011 GSI confirmed the pattern observed in 2006-2010. Low values between January and August, and an increase since September, were observed (Fig.2**).**

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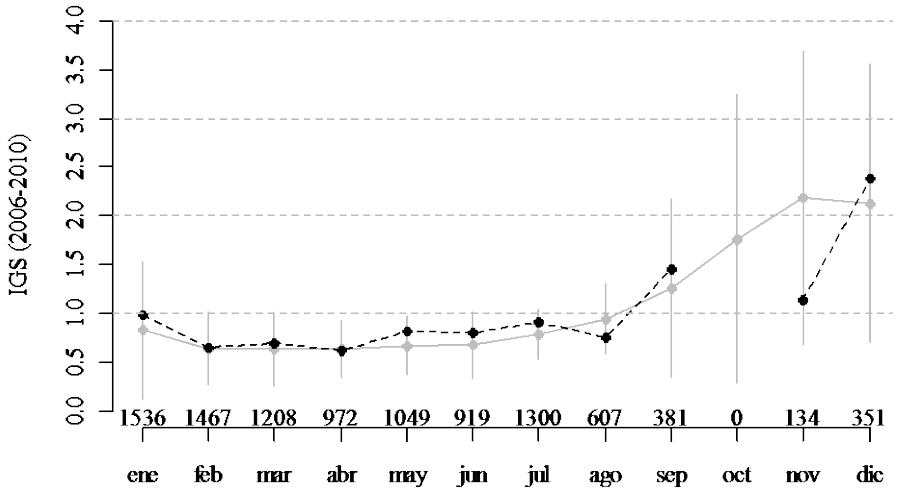

Figure 2. **Global pattern of the GSI and its respective standard deviation, grouping the information of 2006-2010 (grey lines and circles accordingly). Monthly variation of the GSI during 2011 (black circles). Values by axis X correspond to the number of records used in building the GSI in 2011.**

The annual reproductive cycle of males and females studied during 2011 through histological analysis confirm that the reproductive activity of the species is concentrated in the second semester, between September and December (Fig. 3). The analysis of the overall information confirmed a prolonged period of reproductive resting between February and July, period largely dominated by specimens in regression and regeneration.

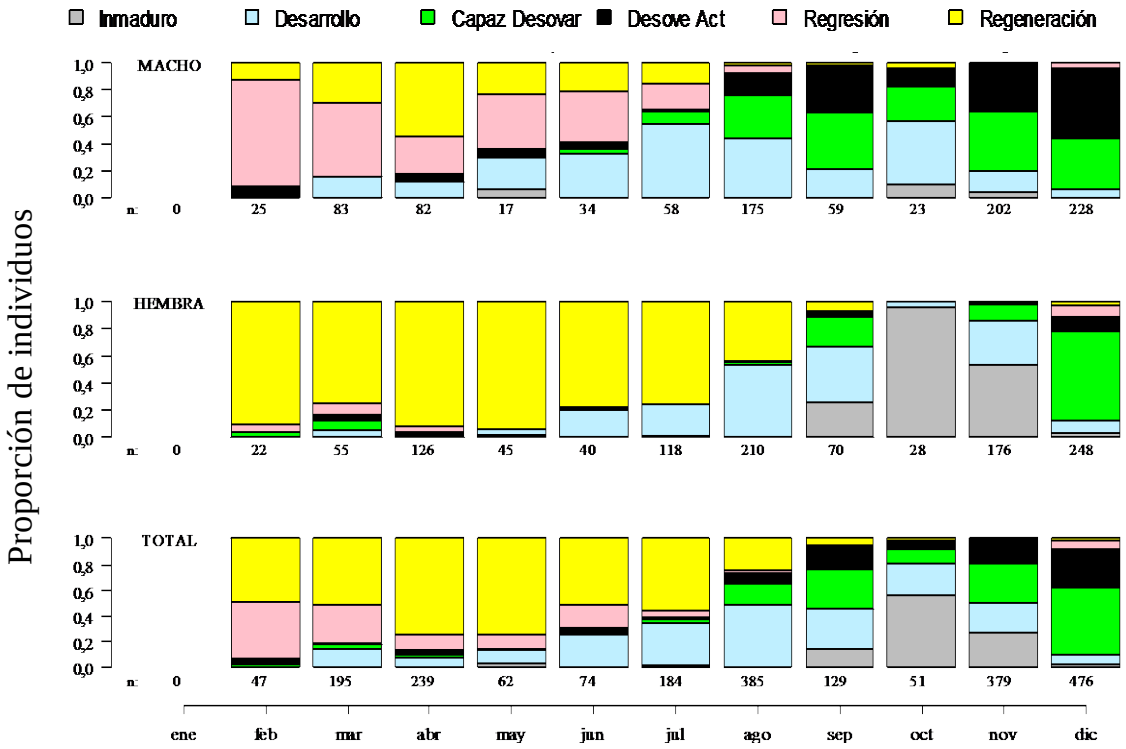

Figure 3. **Monthly proportion of stages of histological maturity (EM) of male, female and the whole jack mackerel sample, in the coasts of Chile during 2011. (The value under the bars is the number of samples).**

Maturity Length

The size range of females analyzed for the maturity at length study fluctuated between the 20 and 39 cm FL Results of the logistic model indicate a rapid maturity process between the 20 and 25 cm FL. At 21 cm FL, only 3% of females was classified as mature; all females over 24 cm FL were classified as the mature fraction of the stock (Fig 4a**).**

Mean maturity length (L_{50}) of *T. murphyi* female between September and December 2011 was estimated at 22.7 cm FL. The confidence interval at 95% for L_{50} was estimated between 22.3 and 23.2 cm FL. Parameters β_0 y β_1 describing the logistic equation showed values of 32.93 and 1.45 accordingly, with standard error of 15.09 for β_0 and 0.67 for β_1.

In the case of male, the size range of the fish analyzed varied between the 20 and the 42 cm FL. Immature specimens had a low representation within the samples. Only 10 (21-23 cm FL) out

of the 456 specimens analyzed at a national level were classified as immature. Thus, L_{50} estimated at 19.8 cm FL has a high uncertainty level, due to the lack of observations in the first part of the curve (Fig. 4a**). Nonetheless, a comparative analysis of the zone with information within the model showed that while male reached 90% of maturity (L_{90}) at 21.5 cm FL, females reached it at 24.5 cm FL. Statistical analyses showed significant differences ($p<0.01$) in the L_{90} of males and females.**

Age at maturity

Results of the logistic model indicate that below 2 years old, the proportion of mature female decreases significantly, and since 4 years old, it is highly likely that they will all be mature (Fig. 4b**).**

Mean age at maturity (E_{50}) of jack mackerel females in the coast of Chile between September and December 2011 was estimated at 2.44 years, with a confidence interval at 95% between 2.0 and 3.0 years. Parameters β0 y β1 describing the logistic equation reach values of 4.31 and 1.76 accordingly.

Males, as well as females, show a fluctuation in the age range, between 2 and 6 years. Similar to length study, the scarce presence of immature juveniles in the samples (Fig. 4b**), make it impossible to estimate a likely value for E_{50}. However, significant differences ($p< 0.01$) were established between both sexes when evaluating the proportion at 90% of maturity (E_{90}). Results of the analysis indicate that males reached E_{90} of maturity at 1.86 years old (IC: 1.35 – 2.37), while females did the same at 4 years old (IC: 2.75 – 5.3).**

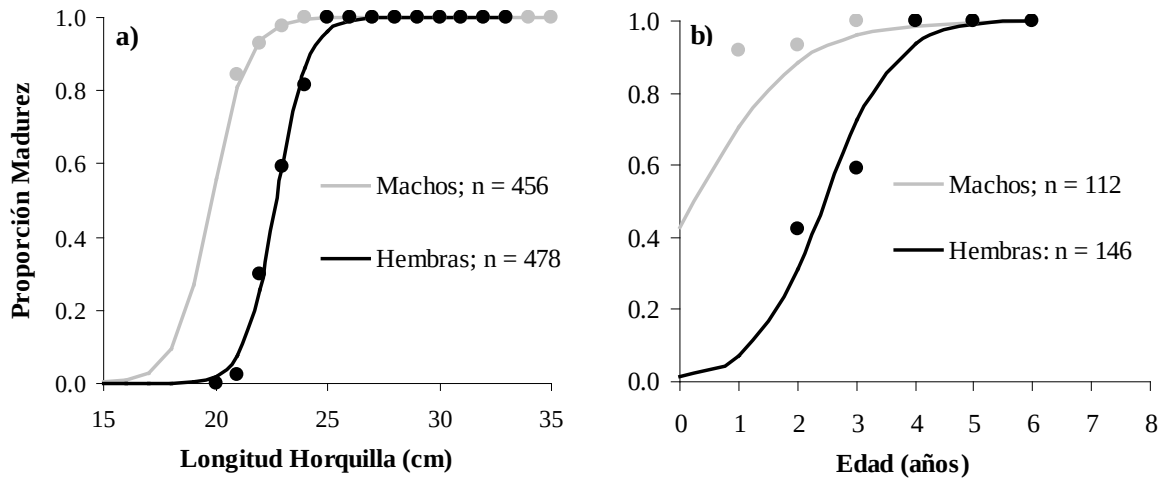

Figure 4. **Maturity ogive at length (a) and age (b) for males and females of jack mackerel (*Trachurus murphyi*) in the coast of Chile.**

Discussion

The purposes of this study were to obtain an updated estimation of maturity at length of jack mackerel *T. murphyi* at a national level and analyze maturity at age process of this species. One of the requirements for this was to establish a scale of maturity, based on commonly-agreed criteria, which can be used as a reference for future national fish reproduction studies.

Analyses of the reproductive activity confirmed a main spawning season of *T. murphyi* in the coast of Chile, which extends between September and December. Such results are coherent with previous reports that indicated a season with higher reproductive activity in the spring-summer season with maximums between October and November (Arancibia & Cubillos, 1993; Grechina et al. 1998; Oyarzún et al. 1998). L_{50} of females estimated at 23 cm FL corresponds to 2.44, according to otolith reading, reaching full stock maturity at 24.5 cm FL, around 4 years old. Inmature males were scarcely represented in the sample; the lack of observations in the lower section of the curves of maturity at length and age made it difficult to estimate the parameter L_{50}. In spite of the restrictions, when the 90% maturity (L_{90}) was estimated, results showed significant differences in the process of maturity at length and age between the sexes. Males should reach full stock maturity at 21.5 cm FL, near the 2 years old.

Differences in the maturity process of both sexes are consistent with Adrianov (1985), who indicates that males reached maturity earlier than females of *T. murphyi* in the coasts of Peru. Abaunza et al (2003) explains that in the north Atlantic, males of *T. trachuruss*, reach maturity at a lower length when compared to females.

In both sexes, maturity length and age can be considered premature for a species that can reach 60 cm FL (Kochkin, 1994) and with maximum ages estimated at 16 years old (Abramov & Kotlar, 1980). Nonetheless, L_{50} of females estimated in this study is within the mean values previously reported for the species in different periods and areas off Chile and Peru. These values are summarized by Cubillos and Alarcón (2010) and vary mainly between 21 and 25 cm FL, when the histological technique was used to assign the phases of gonadal maturity. Results do not significantly differ from the estimates made in the framework of the jack mackerel national scientific committee (Claramunt et al, 2010), though the shape of the curve contrasts a great deal. According to Saborido-Rey (*com. pers*), while parallel curves often indicate differences in the sampling (spatial-temporal), crossed curves indicate differences in the criteria used to assign maturity.

The current estimation is considered to successfully describe the maturity at length and age process of females. Such estimation was carried out on a wide range of sizes, covering an extensive zone of the species distribution in Chile. The study also used criteria to assign gonadal maturity, which had been discussed at an international workshop (Saborido-Rey & Leal, 2011); these criteria should constitute a reference for future national fish reproduction studies.

Acknowledgements

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