# Reproductive Parameters and Spawning Biomass of Jack Mackerel (*Trachurus murphyi*), in 1999-2006, determined by The Daily Egg Production Method

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**ABSTRACT**

The daily egg production method, DEMP (Lasker, 1985), it was applied to estimate the spawning biomass in jack mackerel (*Trachurus murphyi*) in the maximum reproductive period. In addition, reproductive parameters are described for the population, which has a widespread oceanic spawning habitat off central Chile, extending more than one thousand nautical miles offshore.

The analyses were made on the basis of seven surveys carried out in oceanic waters (32°S–39°S, 75°W–92°W), from 1999 to 2006. In each survey, a grid of plankton stations was sampled through vertical hauls with WP2 plankton nets by using several purse-seine fishing ships sampling simultaneously along the E–W transects. In the same surveys, adult jack mackerel were randomly sampled from fishing sets. For to characterizer the reproductive condition of the population, the follows parameters were estimated: mean weight of mature females (W), spawning fraction (*S*), batch fecundity (F) and the sex ratio (R). For the estimation of the spawning biomass, the spawning area and the daily egg production rate ($P_0$) were estimated, according to Stauffer and Picquelle (1980).

The reproductive parameters in jack mackerel showed a high variability between years, especially the spawning fraction (range of 7 - 19 % of the population). The mean weight of mature females (W) and the batch fecundity (F) have shown to an important increase in the last years, which is

coincident with the present situation of the resource (major lengths and weights in the most recent years). In the application of DEMP, it is suggested that the daily egg production ($P_0$) and the spawning fraction (S) are the parameters with greater uncertainty and their fluctuations, influence of direct way in the estimation of the spawning biomass. Further research is suggested for improvements future DEPM application for jack mackerel.

## 1. INTRODUCTION

The stock assessment of Chilean jack mackerel is carried out by using age/length-structured models that take into account indexes of relative abundance. In the past, has been used catch per unit effort (CPUE) and acoustic estimates of biomass in central-southern Chile. However, operational changes of the fleet due to the regime of individual quotas and changes in the availability of the resource in the coastal zone cause that the evaluation models need to look for a new independent estimation of biomass.

In 1997, an evaluation of the spawning condition, spawner distribution and abundance of eggs and larvae in oceanic waters were required in order to advance in looking for new independent information about the stock. Later, it was postulated that the daily egg production method (Lasker, 1985), have the potential to be applied in Chilean jack mackerel.

After three years of work, Cubillos *et al*., (2003), realized for the first time estimations of the spawning biomass of jack mackerel from the estimations of egg production and reproductive parameters of studies FIP 99-14, (Sepúlveda *et al*., 2001), FIP 2000-10 (Cubillos *et al*., 2002), y FIP 2001-12 (Cubillos, 2003). As of that date, it has been managed to improve year after year the estimations of spawning biomass and the parameters that define the reproductive condition of the same, thanks to the cooperation of originating international experts of countries that successfully carry out this type of estimations such as: John Hunter (NMFS), Nancy Lo (NOAA), Beverly Macewicz (NOAA), Miguel Bernal (IEO, Spain), Andres Uriarte (AZTI, Spain) and Paula Alvarez (AZTI, Spain).

In the present manuscript, the estimations of spawning biomass of jack mackerel are reported, generated from originating information of cruises of investigation realized in the period of maximum reproductive activity of this resource, distributed in oceanic waters off central-south Chile, for period 1999-2006.

## 2. MATERIALS AND METHODS

### 2.1 Surveys and Study Area

The daily egg production method (MPDH) considers an intensive sampling of the total egg production in the spawning area, and of the biological attributes of the adults who are spawning in terms of the population mean fecundity, spawning fraction of females, mean weight of the mature females, and proportion of females (Hunter y Lo 1993, Alheit 1993).

For it, ichthyoplanktonic cruises between years 1999-2006 were developed (Projects FIP), tending to know the condition of the resource in their maximum reproductive period. The design bases of each of these cruises consisted in a grid of plankton stations sampled through vertical hauls with WP2 plankton nets by using several purse-seine fishing ships sampling simultaneously along the E–W transects, separated each 20 nautical miles. In the same surveys, adult jack mackerel were randomly sampled from fishing sets. The study area corresponded to the main zone of spawning of jack mackerel (75°00-92°00'W - -32°00-39°00'S) (Figure 1). The detail of each cruise appears in Table 1.

Table 1. Basic information projects FIP, period 1999-2006.

| Year | Date | Latitudinal range | N° Transects | N° Plankton stations | N° Fishing sets |
|---|---|---|---|---|---|
| 1999 | 14/11 – 22/11 | 33º06' – 38º12' | 18 | 751 | 37 |
| 2000 | 25/11 – 04/12 | 32º06' – 37º48' | 20 | 880 | 12 |
| 2001 | 18/11 – 30/11 | 31º42' – 36º54' | 16 | 694 | 18 |
| 2003 | 10/11 – 22/11 | 33º06' – 38º00' | 16 | 694 | 30 |
| 2004 | 21/11 – 01/12 | 33º00' – 38º00' | 20 | 910 | 31 |
| 2005 | 22/11 – 02/12 | 33º00' – 38º40' | 18 | 784 | 14 |
| 2006 | 14/11 – 26/11 | 32°60' – 38°50' | 18 | 805 | 32 |

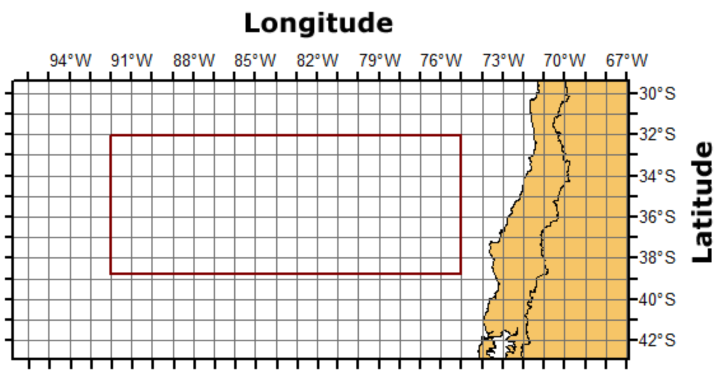


Figure 1. General study area, projects FIP "Biological Condition of Jack Mackerel in High Sea", period 1999-2006.

## 2.2 Sampling

Plankton: In each cruise, identical WP2 nets were used to collect plankton samples. The number of planktonic stations was variable between years (Table 1) and depends on the number of the vessels used. The diameter of the WP2 net frame was 0.6m and the tow was vertical to minimize the volume of water filtered per unit depth. A mesh size of 0.33 um, and tow depth of 100m were used. Sea surface temperature was recorded at each plankton station. All jack mackerel eggs were sorted from the plankton and identified based on characteristics described by Santander and Castillo (1971). Each egg sample was placed in a wash glass with water and examined with a stereoscopic microscope. The density of eggs taken in the WP2 net was expressed as the number of eggs per $10m^2$ of sea surface water.

Adults: In each cruise and in each vessel, adults of jack mackerel were randomly sampled. The number of fishing sets available in each year is presented in the Table 1. First, a random sub-sample of fishes was dissected by mid-ventral incision to determine sex proportion. Each adult was analyzed by measuring folk length and total weight (body weight). A random sub-sample of mature females was taken from each set and each ovary was preserved in 10% buffered formaldehyde solution, and subjected to histological analysis. In addition, any extra females macroscopically detected with hydrated ovaries were preserved in formaldehyde solution for subsequent analysis of batch fecundity. These extra females were not used in adult parameter analysis.

## 2.3 Adult Reproductive Parameters

The mean weight (*W*) of mature females: The number of mature females in each set was corrected by histology and the mean weight by year was estimated weighted by the number of the mature females in each set.

The spawning fraction (*S*): It was assessed by ageing postovulatory follicles (POFs) according to the criteria developed by Hunter and Goldberg (1980) and Hunter and Macewicz (1985). Spawning fraction was estimated from the proportion of 1-day old POFs for samples captured mainly during daytime (mainly from 6:30 to 18:00 h). We used day-1 because day-2 POFs may appear the same in histology for a longer period than 24 h.

The batch fecundity, F (number of eggs to be spawned as a batch): It was estimated using the gravimetric method suggested by Hunter et al. (1985). Only ovaries with hydrated oocytes (early hydratation, fully hydrated) but no POFs were used which had previously been analyzed through histology of one ovary. Three sub-sections were cut from an ovary, weighed, and the number of hydrated oocytes in each counted. The total number of eggs per batch was computed by multiplying the mean number of oocytes per gram of ovary subsection by the total weight of the ovaries. Batch fecundity was related to ovary-free weight of hydrated females by considering a linear model.

The sex ratio (R): In the *i*th fishing set was computed from the weight of females divided by the sum of total weight of females and males.

### 2.4 Daily Egg Production (P0)

Egg numbers were assumed to decline at a constant exponential rate according to the model:

$$Pt = P0 \exp^{(-zt)} \qquad (1)$$

where *Pt* is the egg abundance at age *t* (egg per $10m^2$ per day) (estimated by a egg development model), *P*0 the daily egg production per $10m^2$ per day, and *Z* is the daily total mortality rate. The daily egg production was computed only for the positive stratum (spawning area). For this, polygons enclosing the positive stations (density of eggs positive) were considered in the computation of the spawning areas, including a few negative stations within these polygons.

The fitting procedure of Eq. (1) to observed data was based on a generalized linear model (GLM). The package MASS (Venables and Ripley, 2002), written for the statistical language and environment R (Ihaka and Gentleman, 1996; http://www.rproject.org) was used for the estimations. Finally, the daily egg production and variance in the total survey area were computed according to procedures described in Picquelle and Stauffer (1985).

### 2.5 Biomass Estimation

According to Stauffer and Picquelle (1980) the spawning stock biomass is expressed by:

$$B = \frac{P0AW}{RSF} K \qquad (2)$$

where *B* is the spawning stock biomass (*t*), *P*0 the daily egg production (number of eggs per $m^2$ per day), *A* the total survey area ($Km^2$), *W* the average weight of mature females (g), *k* the conversion factor from grams to tons, *R* the fraction of mature females by weight, *S* the fraction of mature females spawning per day, and *F* is the batch fecundity (mean number of eggs per mature female per spawning).

# 3 RESULTS

## 3.1 Adult Reproductive Parameters

The length structure of jack mackerel observed in the cruises has show an increase of the most adult fraction of the population through the years. This situation is reflected in a progressive increase of the principal mode and in the maintained diminution of the percentage under minimal length (< 26 cm of FL) (Table 2).

Table 2. Parameters of the length structure of jack mackerel in oceanic waters, 1999-2006.

| Year | Range | Principal Mode (cm) | % Under Minimal Length |
|---|---|---|---|
| 1999 | 21-56 | 25 | 56.8 |
| 2000 | 21-54 | 26 | 27.0 |
| 2001 | 20-57 | 26 | 32.8 |
| 2003 | 18-60 | 28 | 15.7 |
| 2004 | 20-65 | 29 | 11.4 |
| 2005 | 23-52 | 31 | 0.2 |
| 2006 | 26-61 | 35 | 0.0 |

Concordant in this way, the mean weight of the mature females and its respective fecundity also have shown to a progressive increase, being considered for the last year of study a mean weight of 532 g and a batch fecundity of 48.213 oocytes (Table 3).The sexual proportion varied between 0.39 and 0.49 per year, with a deviation of only a 0.01 for all the analyzed series. The spawning fraction displayed a high variability between years; the lowest fraction was estimated in 2006 just by a 7% and highest in 2004 with a 19% (Table 3).

## 3.3 Daily Egg production and spawning area

All the cruises presented a suitable cover of the spawning area, being observed that for every year, the spawning area is superior to a 70% of the total area of study, with the exception of the years 2005 and 2006 that presented only 63 and 51% respectively (Table 3).

The daily egg production ($P_0$) was computed by the total spawning area by year. A representative plot of eggs density against the mean age within each daily cohort for each sampled station in the spawning area is shown in Figure 2. For every year analyzed, was a good representativeness of all ages of jack mackerel eggs, which assured a good estimation of the daily egg production. The values of $P_0$ estimated by year are shown in the Table 3, showing a high variability between years.

The rank of the estimations varied between 9,94 to 65,2 eggs per $m^2$ (years 2005 and 1999 respectively).

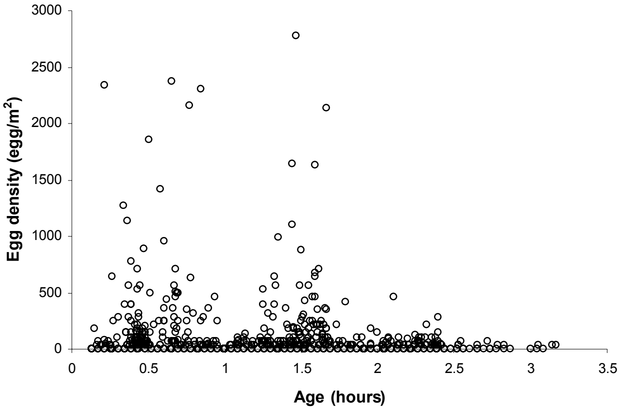


Figure 2. Representative plot of the data used in the daily egg production estimation.

### 3.4 Spawning Biomass

A summary of the reproductive parameters used as input in the daily egg production method for estimating spawning stock biomass is showed in Table 3. Throughout the time a diminution of the spawning biomass is observed, being observed the majors estimations in period 1999-2001. In the last years the biomass varies between 1 to 3 million tons.

Table 3. Resume of the reproductive parameters and the spawning biomass estimation by year of cruise.

| Year | W (g) | F (nº oocytes) | S | R (g) | Po (eggs/$m^2d^{-1}$) | Study Area ($Km^2$) | Spawning Area ($Km^2$) | Area Prop. | Spawning Biomass (t) |
|---|---|---|---|---|---|---|---|---|---|
| 1999 | 191,8 | 26610a | 0,126a | 0,433a | 65,275 | 829.607 | 663.747 | 0,80 | 5.723.933 |
| 2000 | 211 | 26069 | 0,148 | 0,472 | 49,163 | 1.011.802 | 823.077 | 0,81 | 4.688.208 |
| 2001 | 223,7 | 27150 | 0,104 | 0,393 | 46,217 | 762.883 | 600.320 | 0,79 | 5.626.963 |
| 2003 | 394,7 | 39846 | 0,09 | 0,480 | 9,204 | 871.179 | 647.968 | 0,74 | 1.387.804 |
| 2004 | 412,1 | 39957 | 0,194 | 0,475 | 27,318 | 1.385.613 | 1.054.352 | 0,76 | 3.287.439 |
| 2005 | 364,7 | 40463 | 0,142 | 0,466 | 9,94 | 1.222.143 | 773.602 | 0,63 | 1.042.706 |
| 2006 | 532,4 | 48213 | 0,070 | 0,490 | 14,79 | 1.343.682 | 682.550 | 0,51 | 3.282.628 |

a: No reproductive data available, is an average of the years 2000-2001.

## 4 DISCUSSION

The length structure of jack mackerel has change in the last years. This situation is reflected in majors mean weights of the mature females and an increase of the fecundity in the jack mackerel spawning population, which agrees with the length structures and weights reported by the industrial fleet that operates against the coasts of Chile South-Center.

The reproductive parameters used as input in the daily egg production method for estimating spawning stock biomass showed that the most stable parameter in the jack mackerel population is the sexual proportion (mean of 0.46 for all the years analyzed), however most variable is the spawning fraction. Recent studies (Cubillos et.,al, 2007) show to the same situation, suggesting it estimation of this parameter must carefully be analyzed at the time of being applied in partial spawners.

In the case of Po, this parameter also displays a high variability, which depends on direct form of the density of eggs found in the study area. The bulk of the jack mackerel spawning tends to occur offshore between 80◦Wand 92◦W, is maximal at 35◦S and associated to SST warmer than 15–16 ◦C (Cubillos et.,al 2008), therefore the date of execution of the cruises is vitally important, so that the optimal conditions for a successful spawning occur.

From the point of view of the management and the stock assessment, the estimation of the spawning biomass of jack mackerel by the daily egg production method constitutes a new alternative of direct estimation of biomass. In the past, to develop a task of this type on a species that owns a reproductive strategy like the jack mackerel seemed to be not very successful.

The repetition of this project year after year and thanks to the cooperation of originating international experts of countries that successfully carry out this type of estimations has allowed to as much generating improvements in the methodology that is applied in the cruise, like in the later analysis of the parameters involved in the estimation.

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