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REPRODUCTIVE PARAMETERS AND SPAWNING BIOMASS OF CHILEAN JACK MACKEREL (*Trachurus murphyi*), IN 1999-2008, DETERMINED BY THE DAILY EGG PRODUCTION METHOD

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ABSTRACT

The daily egg production method, DEPM (Lasker, 1985) was applied, in order to estimate the spawning biomass in Chilean 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 for more than one thousand nautical miles offshore.

The analyses were made on the basis of nine surveys carried out in oceanic waters (30°S–39°S, 75°W–92°W) from 1999 to 2008. In each survey, a grid of planktonic stations was sampled through vertical hauls with WP2 plankton nets by using several purse-seine fishing vessels sampling simultaneously along the E–W transects. In the same surveys, adult jack mackerel were randomly sampled from fishing sets. To characterize the reproductive condition of the population, the following parameters were estimated: mean weight of mature females (W), spawning fraction (*S*), batch fecundity (F) and sex ratio (R). For estimating 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 Chilean 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 and the batch fecundity have shown an important increase in the last years, which is consistent with the current situation of the resource (increase in length and weight in recent years). The implementation of DEPM suggested that the daily egg production (P_0) and the spawning fraction (S) are the parameters with greater uncertainty, and their fluctuations influence directly the estimation of the spawning biomass. Further research is suggested for improving future DEPM implementations for the Chilean jack mackerel.

INTRODUCTION

The stock assessment of Chilean jack mackerel is carried out by using age structured models that take into account indexes of relative abundance. Catch per unit effort (CPUE) and acoustic estimates of biomass in central-southern Chile have been used in the past. 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 caused that the evaluation models require looking for a new independent estimation of biomass.

In 1997, an evaluation of the spawning condition, distribution of spawners and abundance of eggs and larvae in oceanic waters was required in order to advance toward a new independent information source about the stock size. Later, it was proposed that the Daily Egg Production Method, DEPM, (Lasker, 1985), has the potential to be applied to the Chilean jack mackerel.

In 1999 the spawning biomass of Chilean jack mackerel was assessed for the first time, based upon the DEPM (Sepúlveda *et al.*, 2001, Cubillos *et al.*, 2002 and Cubillos, 2003).

In this document, the estimations of spawning biomass of Chilean jack mackerel are reported, considering the 1999-2008 time period.

MATERIALS AND METHODS

Surveys and Study Area

DEPM considers an intensive sampling of the total egg production in the spawning area, and the biological attributes of adults, in terms of the population mean fecundity, spawning fraction of females, mean weight of the mature females, and the proportion of females (Hunter and Lo 1993, Alheit 1993). In this context, between 1999-2008 ichthyoplanktonic cruises were conducted in the peak of the spawning period (November-December). The cruises design consisted in a grid of planktonic stations sampled through vertical hauls with WP2 plankton nets, by using several purse-seine fishing vessels which sampled simultaneously along the E–W transects. Transects were separated by 20 nautical miles. In the same surveys, adult jack mackerel were randomly sampled from fishing sets. The study area corresponded to the main spawning grounds of jack mackerel (74°00'-92°00'W - 30°00'-39°00'S) (Figure 1). The detail of each cruise is shown in Table 1.

Table 1 Basic information on the surveys carried out from 1999 to 2008.

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
2007	25/11 – 12/12	30°00' – 35°50'	10	445	-
2008	25/11 – 06/12	32°30' – 38°45'	16	707	5

*In 2008, two vessels covered until the 94°W.

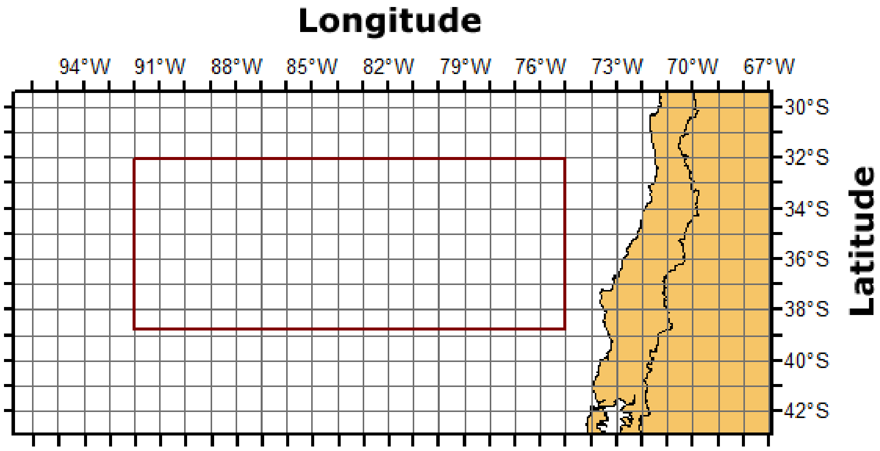

Figure 1 General study area, period 1999-2008.

Sampling

Plankton:

In each cruise identical WP2 nets were used to collect plankton samples, with a frame of 0.6 m and mesh size of 0.33 um. The number of planktonic stations was variable between years (Table 1) and depended on the number of the vessels used. The tow was vertical to minimize the volume of water filtered per unit depth and from a depth of 100 m. Sea surface temperature was recorded at each plankton station.

All jack mackerel eggs were sorted from plankton samples 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 10 m^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 Table 1. First, a random sub-sample of fishes was dissected, by making a mid-ventral incision, to determine the sex. Each adult was analyzed by measuring fork 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-seawater 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 estimates.

Adult Reproductive Parameters

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 mature females in each set.
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). The spawning fraction was estimated from the proportion of 1-day old POFs for samples obtained mainly during daytime (from 6:30 to 18:00 h). Day-1 was used because day-2 POFs may show the same in histology for a period longer than 24 h.

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 hydration, fully hydrated) but not with 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 piece 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.

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

Daily Egg Production (P0)

The number of eggs was assumed to decline at a constant exponential rate according to the model:

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

where *Pt* is egg abundance at age *t* (egg per 10 m^2 per day) (estimated by an egg development model), *P*0 is the daily egg production per 10 m^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 whole survey area were computed according to procedures described by Picquelle and Stauffer (1985).

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), P0 is the daily egg production (number of eggs per m^2 per day), A is 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).

RESULTS

Adult Reproductive Parameters

The length structure of jack mackerel observed in the cruises has shown 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 constant decrease of the percentage below the minimum legal length (< 26 cm FL) (Table 2).

Table 2 Parameters of the length structure of Chilean jack mackerel in oceanic waters, 1999-2008

Year	Range	Principal Mode (cm)	% Below Minimum 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
2007	29-55	(*)	0.0
2008	28-47	37	0.0

(*) Undetermined, only 116 adults of jack mackerel were sampled.

In this context, the mean weight of mature females and their respective fecundity also show a progressive increase, being considered for the last year of study a mean weight of 624 g and a batch fecundity of 55.419 oocytes (Table 3). The sexual proportion varied between 0.39 and 0.49 of females per year, with a deviation of only 0.04 for all the analyzed series. The spawning fraction displayed a high variability between years; the lowest fraction was estimated in 2006 (7%) and the highest in 2004 with 19% (Table 3).

Daily Egg production and spawning area

In general, the cruises presented a suitable coverage of the spawning area, being observed in the period 1999-2004 the highest coverage, with values near 80%. For 2005-2008, the percentage of coverage was smaller, with values below 50%. It is important to highlight year 2008, in which the lowest value was recorded with a 34% (Table 3). Eggs distribution maps for the surveys are shown in Figure 1 of the Annex 1.

The daily egg production (P_0) was computed for the total spawning area by year. A representative plot of eggs density against mean age within each daily cohort for each sampled station in the spawning area is shown in Figure 2. For every year analyzed there was a good representativeness of all ages of jack mackerel eggs, which ensured a good estimation of the daily egg production. The values of P_0 estimated by year are shown in Table 3, showing a high variability between years. The range of estimations varied from 3.56 to 97.94 eggs per m^2 (years 2007 and 1999, respectively).

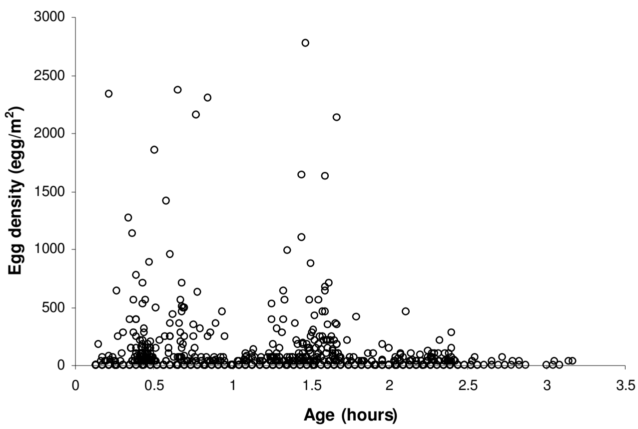

Figure 2. Representative plot of the data used in the daily egg production estimation.

Spawning Biomass

A summary of the reproductive parameters used as input in DEPM for estimating spawning stock biomass is showed in Table 3. Throughout time a decline of the spawning biomass is observed, being the largest estimates those of the period 1999-2001. In the last years, the biomass presents a high variability, but with a negative trend. The Coefficient of Variation (CV) and Standard Deviation estimates for the daily eggs production and spawning biomass are summarised in Table 2 of Annex 1; and confidence intervals for the estimated values were included in Figure 2 of the annex.

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

Year	W (g)	F (nº oocytes)	S	R (g)	P0 (eggs/m²d-¹)	Study Area (Km²)	Spawning Area (Km ²)	Area Prop.	Spawning Biomass (t)
1999	191,8	26.610a	0,126a	0,433a	65.28	829.607	663.747	0,80	5.723.933
2000	211	26.069	0,148	0,472	49.16	1.011.802	823.077	0,81	4.688.208
2001	223,7	27.150	0,104	0,393	46.22	762.883	600.320	0,79	5.626.963
2003	394,7	39.846	0,09	0,480	9.20	871.179	647.968	0,74	1.387.804
2004	412,1	39.957	0,194	0,475	27.32	1.385.613	1.054.352	0,76	3.287.439
2005	364,7	40.463	0,142	0,466	9.94	1.222.143	773.602	0,63	1.042.706
2006	532,4	48.213	0,070	0,490	14.79	1.343.682	682.550	0,51	3.282.628
2007	532,4b	48.213b	0,070b	0,490b	3.56	1.420.837	544.583	0.38	626.465
2008	624,7	55.419	0.090	0,390	11.47	1.464.636	505.542	0.34	1.934.723

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

b: The reproductive parameters of 2006 were used.

DISCUSSION

The length structure of jack mackerel has changed in the last years. This is reflected in higher mean weights of the mature females and an increase of the fecundity in the jack mackerel spawning population, which is consistent with the length structures and weights reported by the commercial fleet that operates off the coasts of south-center Chile.

The reproductive parameters used as input in the DEPM for estimating spawning stock biomass showed that the most stable parameter in the jack mackerel population is the sexual proportion (mean of 0.45 for all the years analyzed), and the most variable is the spawning fraction.

In the case of P0, this parameter also displays a high variability, which depends on the density of eggs found in the study area. The bulk of the jack mackerel spawning tends to occur offshore between 80ºW and 92ºW; it is maximal at 35ºS and associated to sea surface temperatures higher than 15–16 ºC (Cubillos et al., 2008).

It is important to emphasize that the area prospected in the historical series has not varied significantly. Nevertheless, it has been observed that the proportion occupied by the spawning area, with respect to the total area of study, for years 2007 and 2008, is low (near 35%) compared to previous years.

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Annex 1

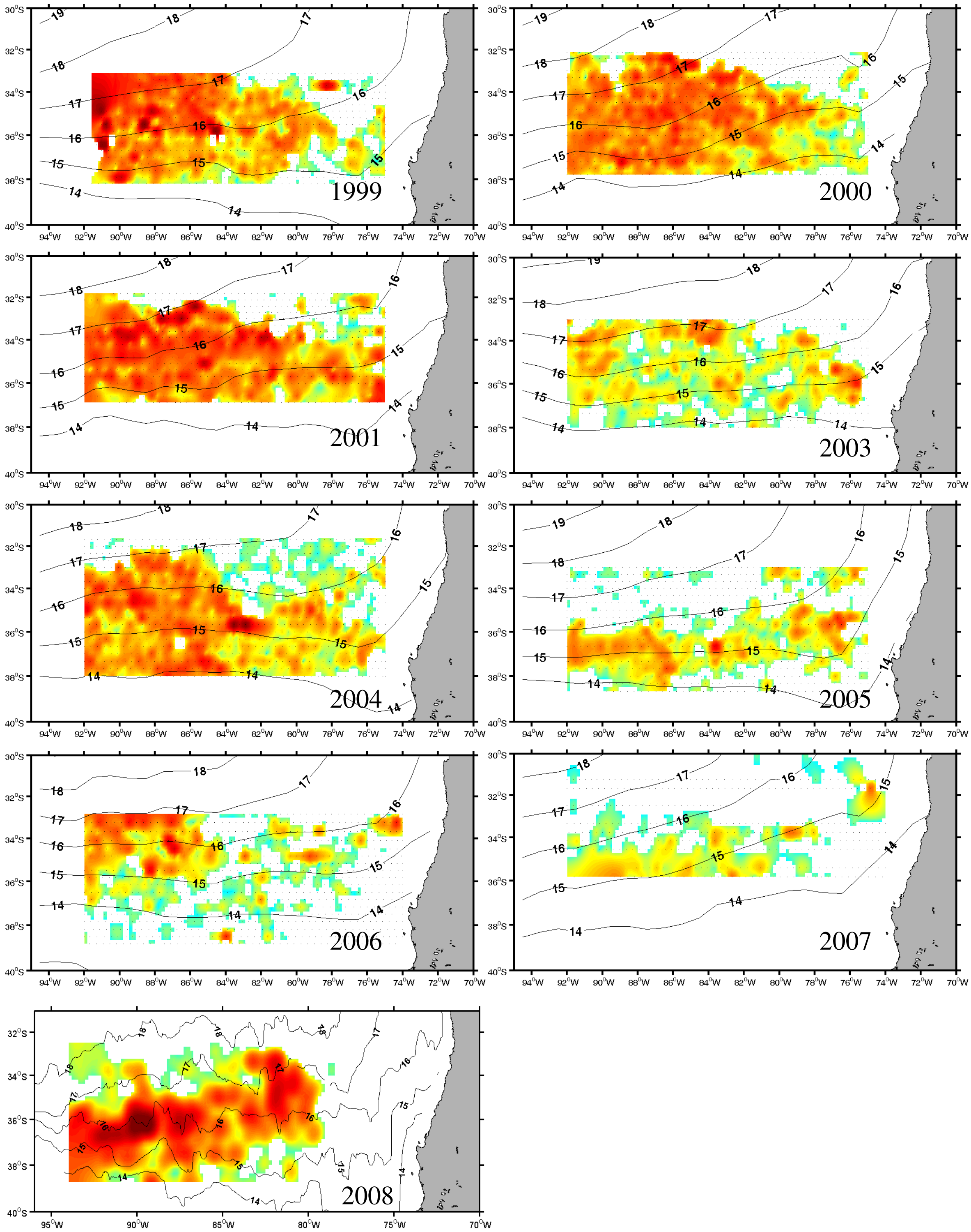
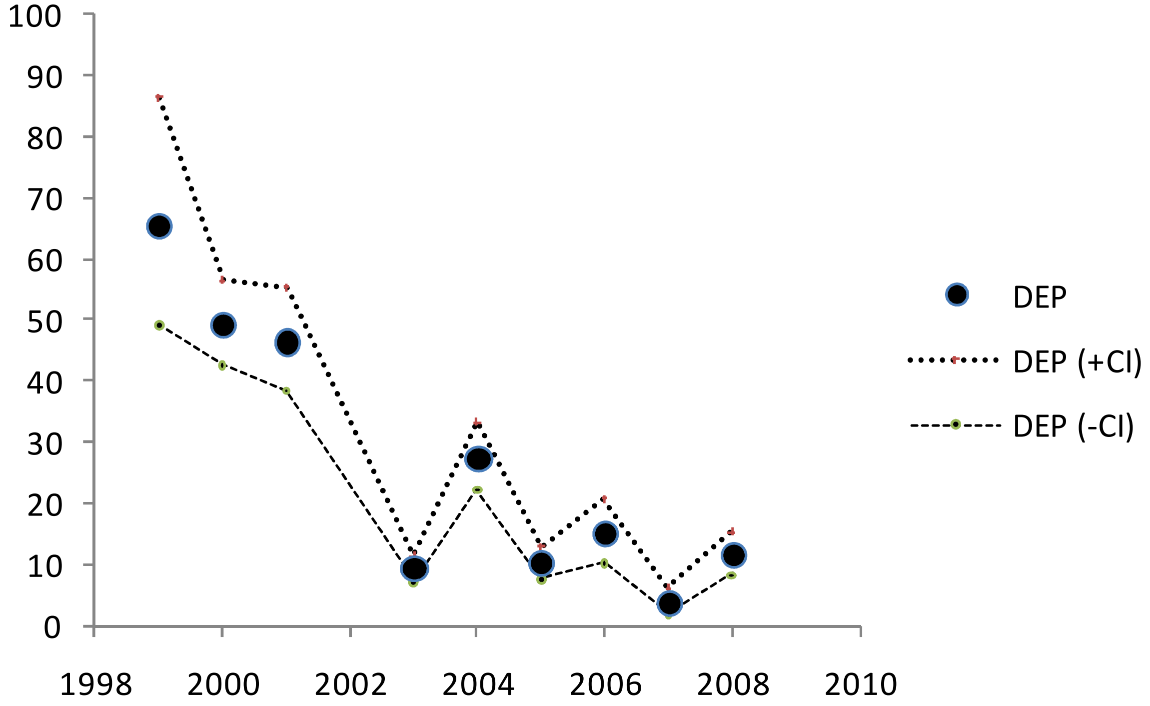


Figure 1. Spatial distribution of jack mackerel eggs in relation to sea surface isotherms found in egg production surveys conducted off south-central Chile (November 1999-2008)

Table 1. Coefficients of Variation (CV) of the Daily Egg Production (DEP) and Spawning Biomass (SB) estimations of Jack Mackerel off Chile (November 1999-2008).

Year	DEP (eggs.m-^{2}·d^{-1})	CV DEP	SD DEP
1999	65,28	0,14	9,1
2000	49,16	0,07	3,4
2001	46,22	0,09	4,2
2003	9,2	0,11	1,0
2004	27,32	0,10	2,7
2005	9,94	0,13	1,3
2006	14,79	0,17	2,5
2007	3,56	0,28	1,0
2008	11,47	0,15	1,7

Year	SB (tons)	CV SB	SD SB
1999	5723933	0,22	1259265
2000	4688208	0,15	703231
2001	5626963	0,17	956584
2003	1387804	0,19	263683
2004	3287439	0,16	525990
2005	1042706	0,36	375374
2006	3282628	0,27	886310
2007	626465	0,35	219263
2008	1934723	0,43	831931



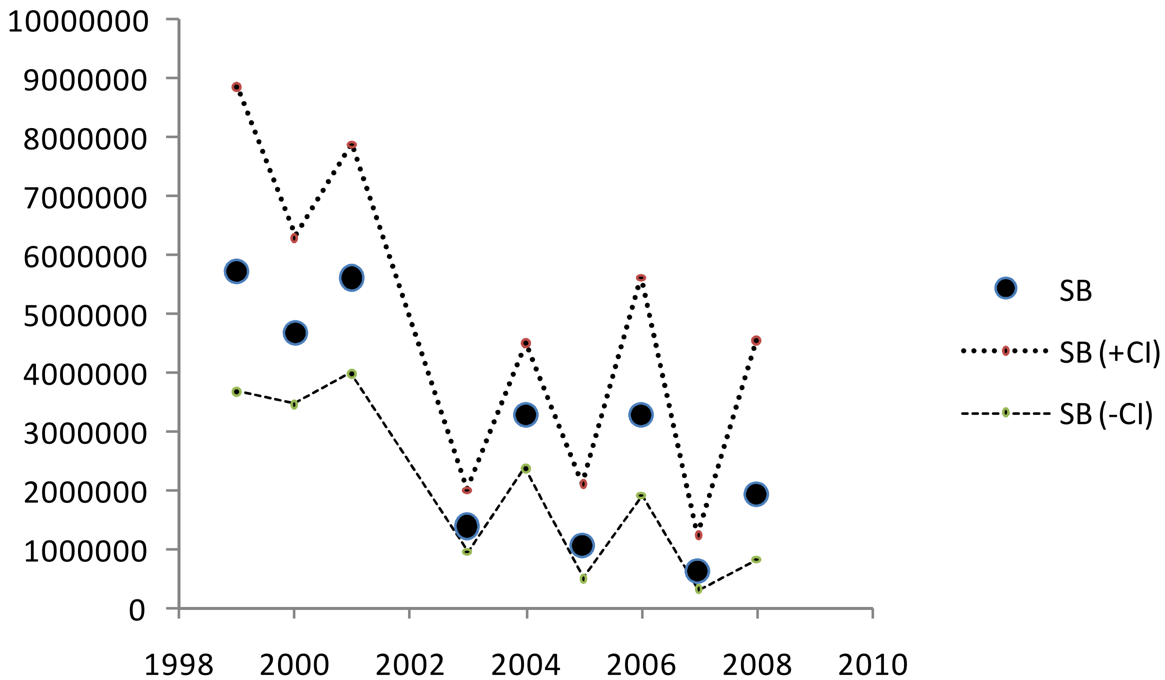


Figure 2. Confidence intervals for the estimations of Daily Eggs Production (DEP, eggs.$m^{-2}d^{-1}$) and Spawning Biomass (SB, tons) of Jack Mackerel (November 1999-2008)