Chilean jack mackerel stock assessment model

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Abstract

Herein, we present the methodological details of the evaluation model for the Chilean jack mackerel stock off Chile, within and outside of the EEZ. The model uses a statistical age at catch approach in which the information is considered to be subject to an observation error and is analyzed through verisimilitude estimators. The data input into the model correspond to a series of landings from 1975, age catch compositions made by Chile and the former USSR, age compositions from acoustic cruises, acoustic biomass series off central-southern Chile, and an estimated spawning biomass index from cruises for eggs and larvae. We model two hypotheses of processes related to the exodus from fishing zones and decreased abundance.

1. Introduction

Jack mackerel stock evaluations have been done by the IFOP since 1990. Diverse evaluation approaches were employed until 2001 (ASP, VPA, ADAPT) and, as of 2002, a statistical age at catch approach has been used (Hilborn et al., 1993; Quinn & Deriso, 1999; amongst others). The results of the evaluation models have served as a reference, guiding the management actions instated by the Fishery Undersecretary. As of 2003, important changes were recorded in the distribution and exodus from fishery zones, along with a dramatic reduction of biomass within the EEZ, generating a variety of hypotheses that have been modeled and analyzed for management purposes (Serra, Canales and Caballero, 2007).

2. Materials and Methods

The assessment model considers two zones: the northern zone, which corresponds to the northern limit of Chile until 24°S, inside the EEZ; and the central-southern zone from 24°S to the south, inside and outside the EEZ. The west limit is delimited by the historical ex-URSS fleet operation (until 105°W).

The assessment period spans 33 years, with a data series from 1975 to 2007. The information used corresponds to the following:

- Estimates of growth, maturity, and natural mortality (M=0.23) parameters.
- Landings for the northern and central-southern fleets (1975-2007).
- Age at catch (2 - 12+ years) matrices per fleet/zone. In this context, the length compositions data from ex-URSS fleet, were assumed to be similar to the data collected in the central-southern zone of Chile.
- Average weight at age matrices.
- Age compositions from the acoustic cruises (1997-2006) in the central-southern zone.
- Acoustic biomass (1997-2007).
- Spawning biomass indices estimated by the daily egg production method (DEPM) (1999-2001; 2003-2006).
- CPUE for the central-southern purse seine fleet (1996-2003).

2.1. Process model

The model supposes that the catch is instantaneous in the middle of the year (Pope, 1972) and that the births occur in January of each year. The dynamic of the abundance at age (*a*) and per year (*y*) is represented by

$$N_{a,y} = \begin{cases} N_{a,y} & a = 2-12; y = 1 \\ N_{a-1,y-1}e^{-M} - \hat{C}^{tot}_{a-1,y-1}e^{-0.5M} & a = 2-11; y = 2-33 \\ \left(N_{a-1,y-1}e^{-M} - \hat{C}^{tot}_{a-1,y-1}e^{-0.5M}\right) + \left(N_{a,y-1}e^{-M} - \hat{C}^{tot}_{a,y-1}e^{-0.5M}\right) & a = 12; y = 2-33 \end{cases} \quad (1)$$

,where C^{tot} is the estimator of the total catch at age and per year and M is natural mortality (M=0.23) and $N_{a,1} \sim U[0, \infty + [$

b. Recruitment

Recruitment is estimated by the model subject to a Ricker-type stock-recruit relationship with a process error of ε:

$$R_1 = \alpha SB_{y-2} e^{-\beta SB_{y-2}} e^{-\varepsilon_y} \tag{2}$$

,where $\varepsilon_y \sim N(0,0.6^2)$. Here, α and β are parameters to be resolved

c. Spawning biomass

The spawning biomass is estimated in mid-October as

$$SSB_y = \sum_a (N_{a,y} e^{-0.5M} - \hat{C}^{tot}{}_{a,t}) e^{-3.5/12M} O_a w_{a,y} \tag{3}$$

, where O is the maturity ogive at age (*a*) and w is the average weight at age and per year.

2.2. Observation models

a. Catches

The catches are modeled in proportion to the stock at the beginning of the year such that:

$$\hat{C}^{tot}{}_{a,y} = \hat{C}^1{}_{a,y} + \hat{C}^2{}_{a,y} \tag{4}$$

$$\hat{C}^f{}_{a,y} = \mu^f_{a,y} N_{a,y} \tag{5}$$

$$\mu^f_{a,y} = \mu^f_y S^f{}_a \tag{6}$$

$$\mu^f_y = \frac{Y^f_y}{BV^f_y} = \frac{Y^f_y}{\sum_a N_{a,y} S^f_a w_{a,y} e^{-0.5M}} \tag{7}$$

, where *f* is the fleet-zone (1 or 2), μ is the exploitation rate, Y is the landing, and S is age-specific selectivity modeled according to the fleet-zone as:

- northern fleet: considers the periods of the years as well as the exploitation pattern (1975-1986, 1987-2007).

$$S^{f}_{a,t} = e^{-\frac{1}{2s_t^2}(a-\mu_t)^2} \tag{8}$$

- central-southern fleet: considers the following periods of the exploitation pattern: 1975-1987, 1988-1992, 1993-2004, 2005-2007.

$$S^{f}_{a,t} = \left[1 + e^{-\ln(19)\frac{a-a^{f}_{50\%,t}}{\Delta f_t}}\right]^{-1} \tag{9}$$

b. Acoustic biomass

$$\hat{B}^{c}_{y} = q^{c}_{y} \sum_{a} (N_{a,y} e^{-0,5M} - \hat{C}_{a,y}) S^{c}_{a} w_{a,y} \tag{10}$$

q^{c}_{y} is the coefficient of catchability for acoustic cruises based on the two hypotheses analyzed herein.

Change in distribution: this supposes that, as of 2002, the resource underwent a change in its distributional core beyond 200 nm. Thus, the estimated biomass in the acoustic surveys from 5 to 400 nm is comparable with the biomass estimated prior to 2002 between 5 and 200 nm.

$$q^{c}_{y} = \exp\left[\frac{1}{n}\sum_{i}\log\left(\frac{B_y}{\hat{B}_y}\right)\right] \tag{11}$$

Contraction of biomass: a population reduction starting in 2002 has been much faster (effect of hyper-reduction) along the distribution borders (first 200 nm from the coast) than at the nucleus of the population.

$$q_y^c = \begin{cases} \exp\left[\frac{1}{n}\sum_i \log\left(\frac{B_y}{\hat{B}_y}\right)\right] & y < 2002 \\ & B_y \in [5-400]mn \\ \eta \hat{B}_y^{\ \lambda} & y \geq 2002 \\ & B_y \in [5-200]mn \end{cases} \tag{12}$$

On the other hand, S_a^c is the age-specific availability factor modeled as:

$$S_{a,t}^c = \left[1 + e^{-\ln(19)\frac{a-a_{50\%,t}^c}{\Delta c_t}}\right]^{-1} \tag{13}$$

where t corresponds to different periods: 1975-2004 and 2005-2007.

c. Spawning biomass index

$$B_{mph,y} = q^{mph}\sum_a (N_{a,y}e^{-6/12M} - C_{a,t})e^{-3.5/12M}O_a w_{a,y} \tag{13}$$

$$q^{mph} = \exp\left[\frac{1}{n_2}\sum_y \ln\left(\frac{B^{mph}{}_y}{\sum_a (N_{a,y}e^{-6/12M} - C_{a,t})e^{-3.5/12M}O_a w_{a,y}}\right)\right] \tag{14}$$

n_2 is the number of years with information from eggs/larvae surveys

d. Catch per Unit Effort (CPUE)

The CPUE from the central-southern zone is considered to be a good index of relative biomass between 1996 and 2003. Later changes in the fishery have affected this signal.

$$C P\hat{U}E_y = q \sum_a N_{a,y} e^{-0,5M} S^f_{a,y} \overline{w}_{a,y} \tag{15}$$

$$q = \exp\left[\frac{1}{n}\sum_y \ln\left(\frac{CPUE_y}{\sum_a N_{a,y} e^{-0,5M} S^f_{a,y} w_{a,y}}\right)\right] \tag{16}$$

2.3. Observation model errors (likelihood estimators)

a. Age at catch compositions: a multinomial error distribution is assumed.

$$-\ln L_{p^f} = n \; p^f_{a,y} \ln(\hat{p}^f_{a,y}) \tag{17}$$

where $p^f_{a,y} = \frac{C^f_{a,y}}{\sum_a C^f_{a,y}}$ and n is the size of the effective sample.

b. Acoustic survey age compositions: a multinomial error distribution is assumed.

$$-\ln L_{p^c} = n \; p^c_{a,y} \ln(\hat{p}^c_{a,y}) \tag{18}$$

where $p^c_{a,y} = \frac{N^c_{a,y}}{\sum_a N^c_{a,y}}$ and $\hat{p}^c_{a,y} = \frac{(N_{a,y} e^{-0,5M} - \hat{C}_{a,y}) S^c_a}{\sum_a (N_{a,y} e^{-0,5M} - \hat{C}_{a,y}) S^c_a}$. N^c is the abundance of the age observed.

	Simple size (n)
Northern zone	20
Central-southern zone	50
Acoustic survey	10

c. Acoustic biomass: a log-normal type of error distribution is assumed.

$$-\ln L_{B^c} = \frac{1}{2\sigma^2}\ln\left(\frac{B_y^c}{q^c\sum_a (N_{a,y}e^{-0,5M} - \hat{C}_{a,y})S_a^c\overline{w}_{a,y}}\right)^2 + cte_1 \qquad \sigma = 0.2 \tag{19}$$

d. Spawning biomass index: a log-normal type of error distribution is assumed.

$$-\ln L_{B^{mph}} = \frac{1}{2\sigma^2}\ln\left(\frac{B_y^{mph}}{q^c\sum_a (N_{a,y}e^{-6/12M} - C_{a,t})e^{-3.5/12M}O_a w_{a,y}}\right)^2 + cte_2 \qquad \sigma = 0.7 \tag{20}$$

e. CPUE: a log-normal type of error distribution is assumed.

$$-\ln L_{CPUE} = \frac{1}{2\sigma^2}\ln\left(\frac{B_y^c}{q^c\sum_a N_{a,y}e^{-0,5M}S_{a,y}^f\overline{w}_{a,y}}\right)^2 + cte_3 \qquad \sigma = 0.15 \tag{21}$$

f. Objective function: corresponds to a Bayesian approach and considers the sum of the negative marginal contributions of the log-likelihood of the data and a *prior* of the process error associated with the recruitment. The parameters priors were assumed non-informative.

$$-\ln L_{tot} = \ln L_{p^f} + \ln L_{p^c} + \ln L_{B^c} + \ln L_{B^{mph}} + \ln L_{CPUE} + \ln L_{\varepsilon} \tag{22}$$

3. Results/discussion

Canales and Serra (2008) reported the details of the jack mackerel stock evaluation at the meeting of the science group (SGW-SPFRMO) held in Guayaquil (March 2008). The results of the two hypotheses show spawning biomass values that vary between 4.0 million tons for the biomass contraction hypothesis (S2) and 4.8 million tons for the change in distribution hypothesis (S1). Both hypotheses indicate that the parent population is reduced by at least 30% of the dynamic virgin biomass, which is worrisome considering that the desired objective of management is not to reduce more than 40% of the spawning biomass (Table 1). The Akaike information criterion indicates that the statistical contrast between the hypotheses is not significant, although it slightly favors the change in distribution hypothesis. Even in the most optimistic of cases (S1), the population is reduced to a level lower than is recommendable.

Table 1. Summary of the jack mackerel stock evaluation per hypothesis.

Hypothesis	SSB (ton)	SSB/SSBo	-log Like	p	AIC
S1=Distribution change	4,807,400	0.2697	4,360	61	8842
S2= Contraction of biomass distribution	4,083,400	0.2418	4,372	63	8871

SSB: Spawning biomass, SSBo: Virginal Spawning biomass, -log Like: - log likelihood, p: parameters number, AIC: Akaike information criterion

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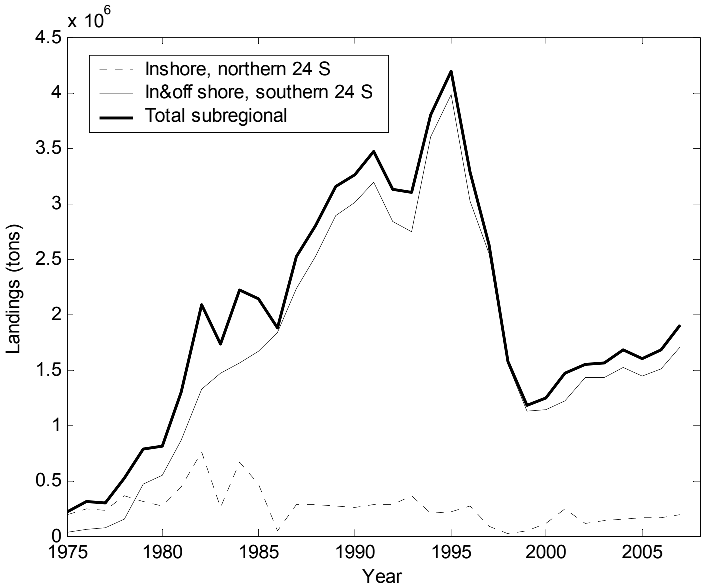

Figure 1. Landings by zone employed in the jack mackerel stock assessment

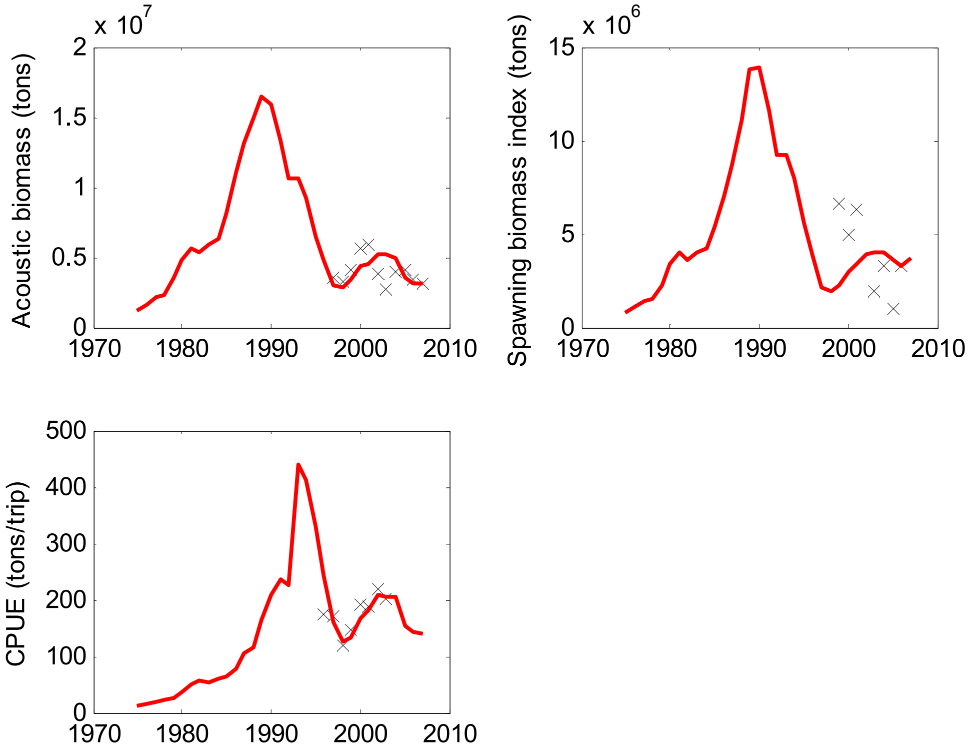

Figure 2. Model fit to abundances indexes employed in the jack mackerel stock assessment (Scenario 1).

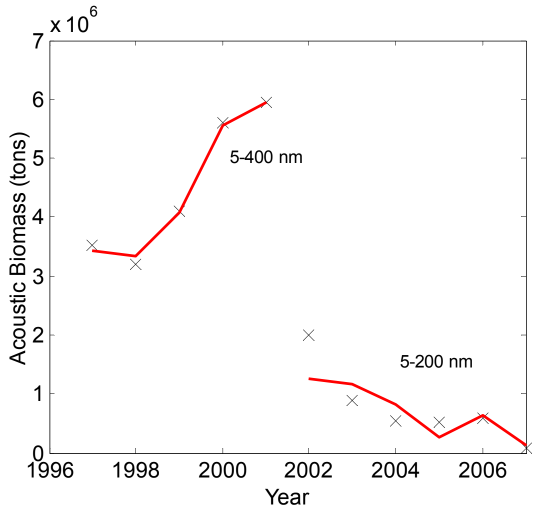

Figure 3. Model fit to acoustic biomass employed in the jack mackerel stock assessment. (Scenario 2)

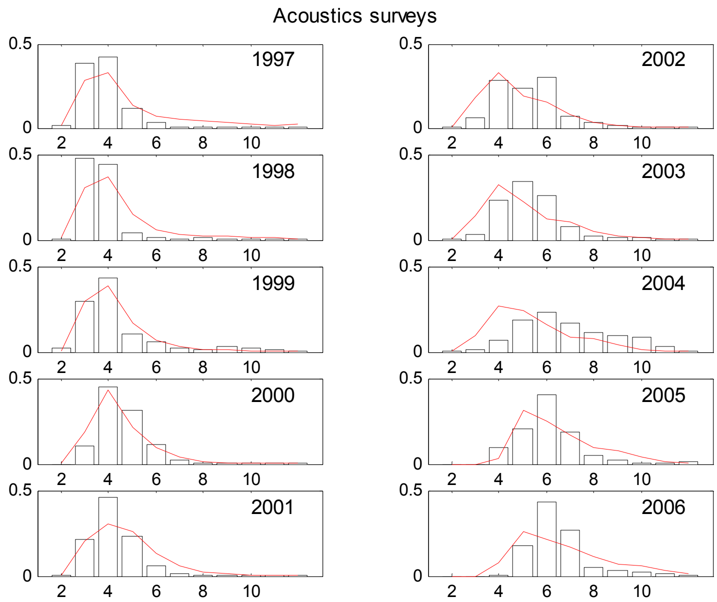

Figure 3. Model fit to catch-at-age surveys information employed in the jack mackerel stock assessment

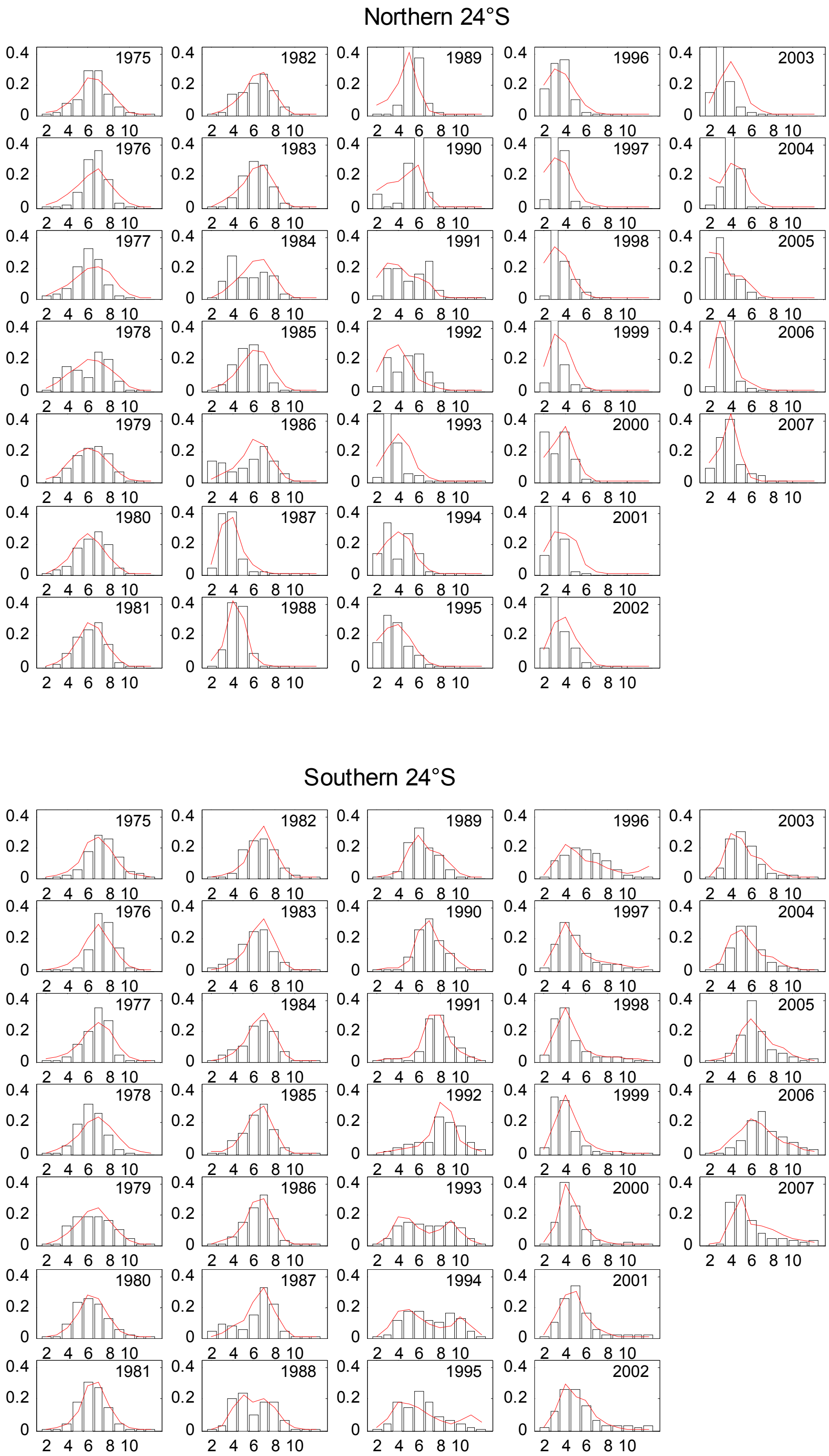

Figure 4. Model fit to catch-at-age fleet information employed in the jack mackerel stock assessment