Eighth International Meeting: Science Working Group
SP-08-SWG-JM-10

Interpretation of biological-fishing indicators of jack mackerel exploited off central-southern Chile

Cristian Canales (ccanales@ifop.cl) & Rodolfo Serra (rserra@ifop.cl).
Instituto de Fomento Pesquero, Chile

Abstract

The performance of indicators of the jack mackerel fishery off central-southern Chile is simulated. The population was simulated within a 10-year horizon, under two recruitment scenarios and different levels of fishing mortality, focused on the adult fraction of the population. Results showed that, in a recruitment failure scenario the mean size of specimens in the catches increases, while the biomass of the population and the relative abundance indexes decrease. In such scenario, increments of fishing mortality are detrimental to the sustainability of the resource. Constant recruitments lead to proportionality between mean size or age of individual in the catches and biomass; in this situation an increase in fishing mortality determines the reduction of the biomass and mean size in the catches. Finally, considering the indexes observed in the jack mackerel fishery off Chile, the probable failure in recruitments is inferred and the need to prevent an increase in fishing mortality is stressed.

1.- Introduction

Information obtained from the data collected in the fishery, which is considered the base to assess the stock of a specific resource and determine its status, is often available. Nevertheless, when results of a stock assessment are not available, establishing the condition of the resource becomes more complex if some theoretical concepts related to stock dynamics are not considered. In this document, the response of the stock subject to exploitation is evaluated, simulating a jack mackerel-like stock under different recruitment scenarios and exploitation levels in a 10-year horizon.

2. Materials and Methods

The jack mackerel dynamics is represented by an age dynamics model, exploited in differentiated terms by age groups (Fournier and Archibald, 1982: Deriso et al., 1985; Hilborn, 1990b; McAllister and Ianelli, 1997, Maunder et al., 2000; Hilborn et al., 2003; Ianelli and Lamberson, 2003). Known biological parameters of jack mackerel were used, and the performance of the population was analyzed simulating its exploitation from a virginal condition under two recruitment scenarios. Observation models correspond to landing, catch at size, and relative abundance index, which were assumed without observation errors (i.e. without stochastic variability), in order to highlight the expected performance of the fishery.

a) Dynamics Model:

The model considers that recruitment occurs by the beginning of the year and exponential-type survival. The initial condition is in an age-stable equilibrium. Natural mortality (constant) and age-specific fishing mortality are considered as mortality sources.

$$N_{a,y} = \begin{cases} R_a & a = 2 \\ R_a \exp(-(a-2)M) & a > 2; y = 1 \\ N_{a-1,y-1} \exp(-Z_{a-1,y-1}) & a > 2; y > 1 \end{cases} \quad (1)$$

$$Z_{a,y} = F_{a,y} + M \quad (2)$$

$$F_{a,y} = S_a F_{ref} \quad (3)$$

$$S_a = \left[1 + \exp\left(-\log(19) \frac{a - \theta_{50}}{\theta_{95} - \theta_{50}} \right) \right]^{-1} \quad (4)$$

$$B_y = \sum_{a=2}^{12} S_a N_{a,y} w_a \quad (5)$$

Where a is age, *y* is year, *N* is the number of specimens, *R* is the annual recruitment, *Z* is the instantaneous rate of total mortality, *F* is fishing mortality rate, *M* is natural mortality rate, *B* is biomass, and *S* is age-specific selectivity. The parameters of the selectivity model (4) are age at 50% ($\theta_{50\%}$) and 95% ($\theta_{95\%}$) retention, which, according to Canales and Serra (In: SUBPESCA, 2008), are at around 5 and 7 years old respectively, and corresponds to a fraction of the stock exploited off central-southern Chile.

The recruitment value used corresponds to the average of the 1988-2007 series, estimated by Canales and Serra (2008), while biological growth parameters were taken from Cubillos *et al* (2008). To all purposes, recruitment was assumed to be constant over time, implying that, in nature, those values vary randomly around the mean value.

Table 1
Jack mackerel biological parameters used in a simulation model

Parámetro	Valor
M (year^{-1})	0.23
R_y (n)	14×10^6
$\theta_{50\%}$ (year)	5.0
$\theta_{95\%}$ (year)	7.0
F_{ref} (year^{-1})	0.1; 0.6; 1.0
L_{00} (cm)	72
k (cm year^{-1})	0.094
t_0 (year)	-2.25
Cv	0.04
α	0.01
β	3.0
Age range (year)	2-12
Length range (cm)	10-65

b) Observations Model

b.1) Catches model

The model of catch at age and year is the following:

$$C_{a,y} = \frac{F_{a,y}}{Z_{a,y}} N_{a,y}\left(1 - \exp(-Z_{a,y})\right) \quad (4)$$

Likewise, with a view to generate size compositions of catches, catch at age is transformed into catches at size $C_{l,y}$ through a stochastic transformation of the form:

$$C_{l,y} = P_{l,a} C_{a,y} \quad (5)$$

Where $P_{l,a}$ is the probability of size l for each group of age a. This transformation is modeled assuming that the modal size for each age group is a random variable normally distributed (pdf), so as:

$$l_a \sim N(\bar{l}_a, \sigma_a^2) \quad (6)$$

and whose parameters are:

$$\bar{l}_a = L_{00}(1 - \exp^{-k(a-t_0)}) \quad (7)$$
$$\sigma_a = cv\,\bar{l}_a$$

where *cv* is the coefficient of variation of size at age, while the size probability in each age group is given by the integral:

$$P_{l,a} = \int_{l_1}^{l_2} pdf(l)dl \quad (8)$$

b.2) Landing model

Annual landings correspond to the sum of products between catch at age and weight of the form:

$$Y_y = \sum_{a=2}^{12} C_{a,y} w_a \quad (9)$$

$$w_a = \alpha \left(L_{00}(1 - \exp^{-k(a-t_0)}) \right)^{\beta} \qquad (10)$$

b.3) Abundance indexes model

Abundance indexes such as acoustic surveys or CPUE are assumed to be proportional to the population biomass:

$$I_y = qB_y$$

Where q is the catchability (fleet) or availability (surveys) coefficient.

3. Results

Simulation analyses were conditioned to two recruitment scenarios; the first, with constant recruitments, and the second, with total recruitment failure. In each case, age, size and landing compositions, as well as abundance indexes that should be observed in the fishery were estimated. Besides, in each case, different constant fishing mortality levels were applied, in order to evaluate the response of the population.

Growth model and distribution of the size probability show that recruitments (2 years old individuals) are distributed between 20 cm and 25 cm length (Figure 1). It is also important to note that when specimens reach 12 years old, their mean length should be around 52 cm. Following the model (5), this probability matrix of size at age is used to transform age compositions of catches to size compositions.

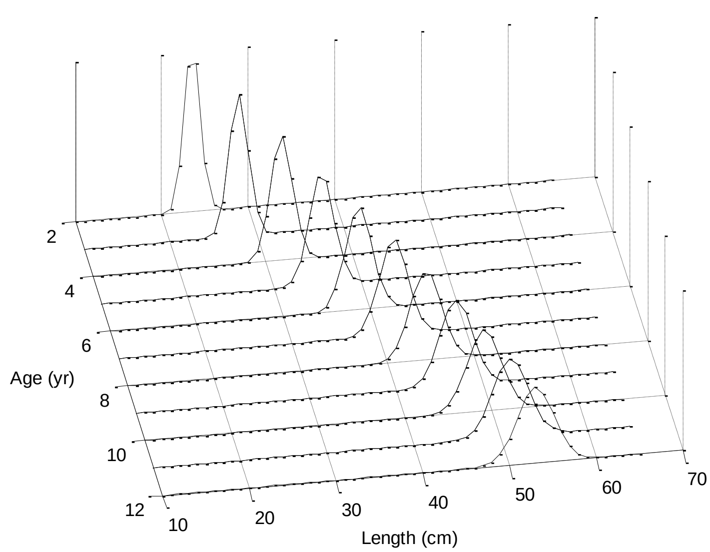

Figure 1. Probability distribution of the size at age for jack mackerel.

The simulation of recruitment scenarios and mortality indicates that, in a constant recruitment regime, a high level of fishing mortality (segmented lines) would cause the removal of the largest specimens of the population, and subsequently, the population gets younger (Figure 2, left side). On the other side, if the resource shows recruitment failures, the fishery presents increasingly larger specimens in the catches due to the absence of young individuals (smaller than 30 cm). In this case, a high level of fishing mortality (F=1.0) does not have a great impact in size composition in the long term, as it acts only at the beginning removing efficiently the largest individuals of the population (Figure 2, right side).

Consistently with the above mentioned, under a constant recruitment regime and increasing fishing mortality, the mean size of specimens in the catches and relative abundance indexes decrease proportionally with adult population. It is important to point out that, in this situation, initial landings decrease, but they remain steady over time at constant level with fishing mortality and abundance (Figure 3).

On the other side, recruitment failures translate into an increase of the mean size of the catches, which can even exceed the mean size of the catches from a virgin stock (app. 42 cm). The age or size structure grows older and abundance indexes decrease faster than in the constant recruitment scenario. Here, the increase of fishing mortality causes an increase of the population reduction slope; depending on its level, mean size will have an inverse performance with respect to the relative biomass, while landings will show an inevitable accelerated fall even with low level of effort and fishing mortality. (Figure 4)

The summary of analyzed cases and the expected response in the indicators of the fishery are shown in Table 2.

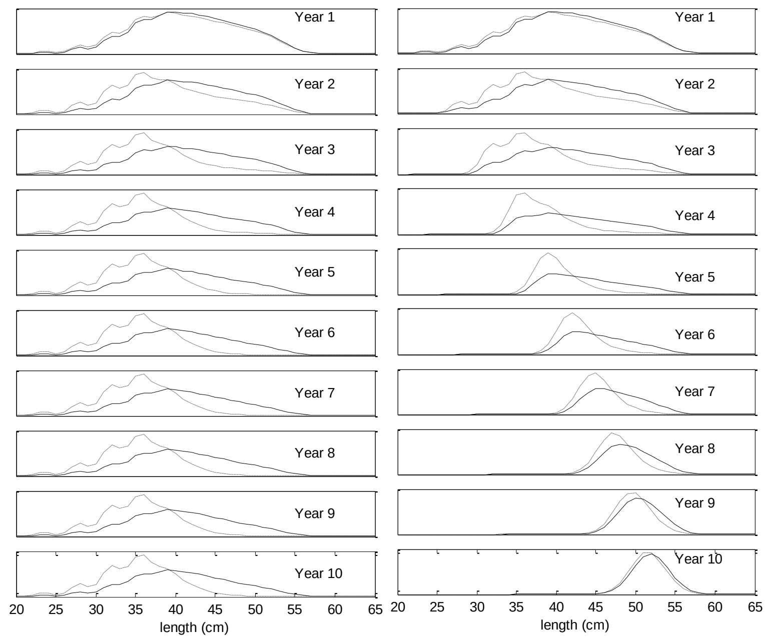

Figure 2. Size composition of catches simulated in 10 years. The left side considers constant recruitments and the right side considers recruitment failures. The solid line represents a low fishing mortality F=0.1, and the segmented line represents a high fishing mortality F=1.0

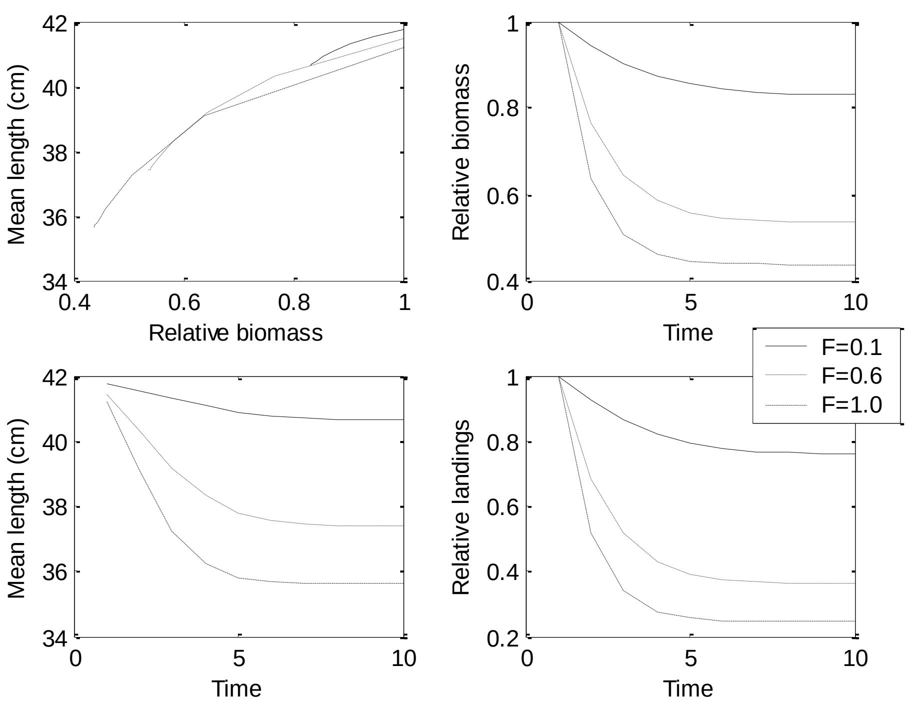

Figure 3. Theoretical performance of mean size and relative biomass under a constant recruitment scenario.

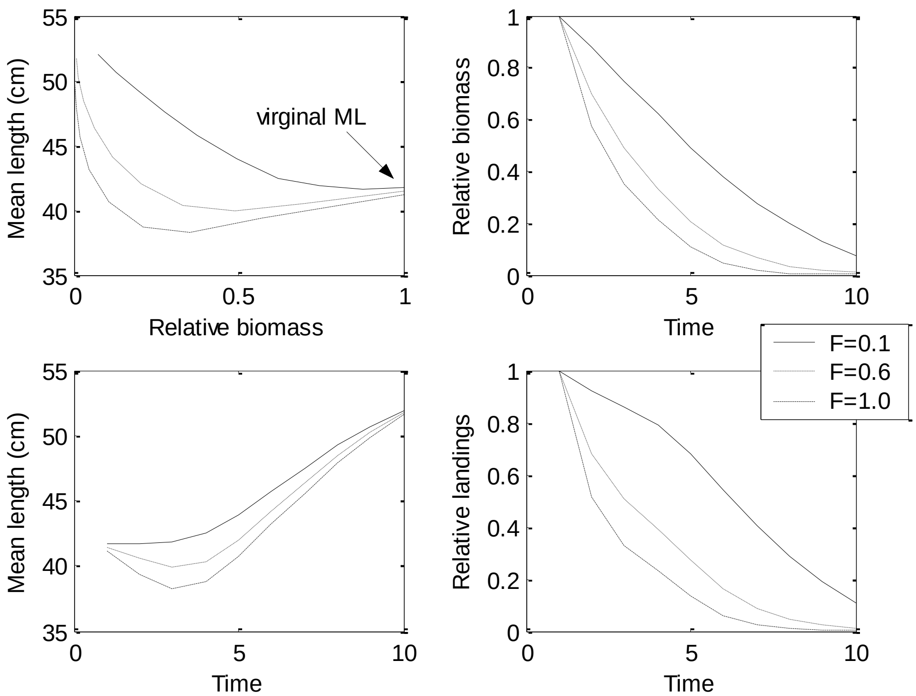

Figure 4. Theoretical performance of mean size and relative biomass under a recruitment failures scenario.

Table 2

Expected indicators of the jack mackerel fishery in different recruitment and fishing mortality scenarios.

Fishing mortality level	Constant recruitment	Recruitment failure
High	- Reduction of mean size - Drop in abundance indexes - Stable landings in a low level	- Increase of mean size - Reduction of abundance indexes. - Systematic reduction of landings
Low	- Mean sizes and abundance indexes without trend, or increasing - Landings stable in a high level	

4. Discussion

The jack mackerel population was simulated under two possible recruitment scenarios and three levels of fishing mortality. The results showed that indicators derived from the fishing activity and biomass indexes have different performance and interpretation, depending on the recruitments process.

It is confirmed that when there is stability in the recruitments, the main biological-fishing indicators follow proportionally the variations of the population biomass, where the increase of the fishing effort causes higher mortality of big specimens, reduction of the biomass, and reduction of mean size or age of catches. Under certain mortality levels, the fishery may present steady landings over time.

The most extreme case occurs when there is recruitment failures, in which, a drop of the biomass indexes and an increase in the mean age and size of the catches should be expected. The population gets older due to the absence of young fish, and the rise of fishing mortality has much more severe impacts on the population; landings drop inevitably, even with low levels of fishing mortality.

In the jack mackerel fishery off central-southern Chile, an important decreasing trend has been observed in the reference biomass, estimated in the acoustic surveys in the EEZ (5-200 nm) conducted over the last 8 years (Córdoba et al., 2008) along with the parallel and sustained increase in the mean size of catches (Bernal et al., 2008) (Figure 5). This evidence is consistent with a low-recruitment-level scenario, where catches have not followed the expected decreasing path, as fishing effort has not been constant, but increasing, over the last year, in terms of searching time. According to this, and while this scenario is not ruled out, increases in the fishing mortality should be avoided, in order to prevent a major negative impact in the jack mackerel population.

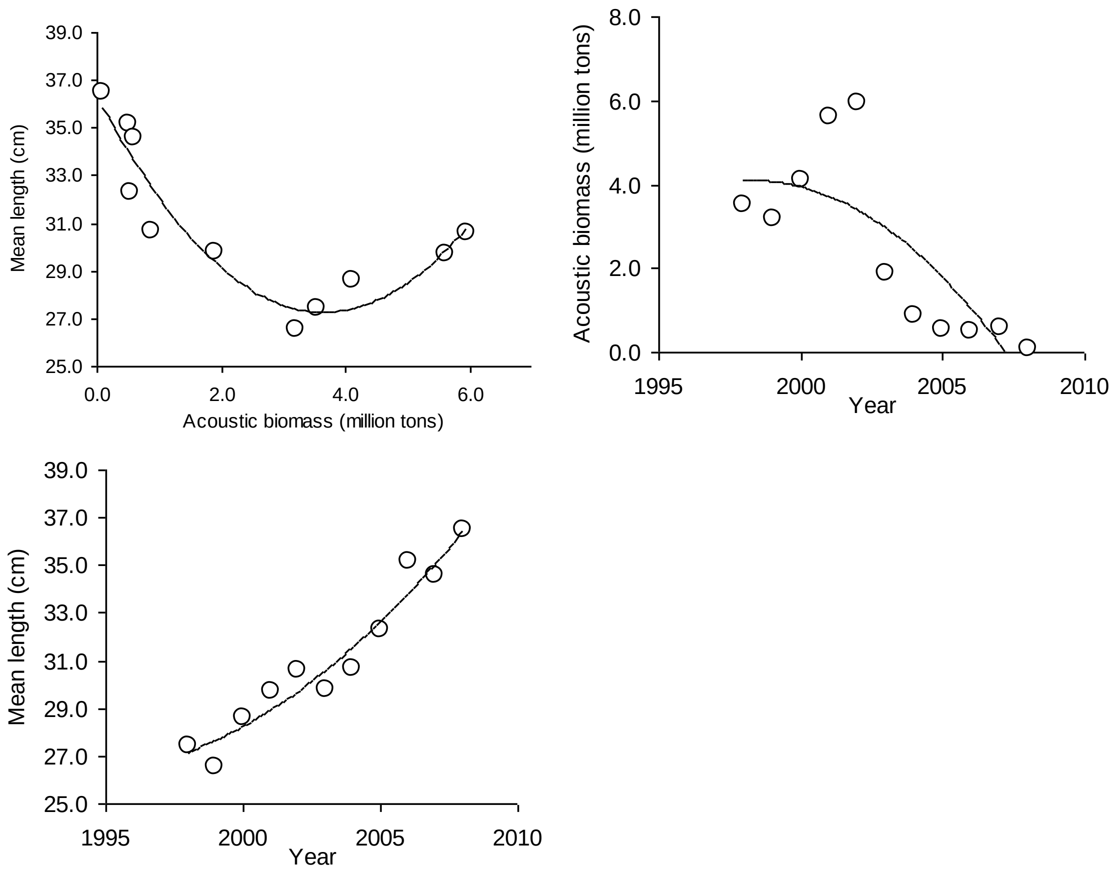

Figure 5. Relation between mean size of catches and acoustic biomass of jack mackerel (EEZ) off central-southern Chile 1998-2008.

5. References

Bernal C., A. Aranís, C. Martinez & C. Canales, 2008. Catch size compositions for jack mackerel (Trachurus murphyi) off Chile (1975-2006). CHJMWS pap #12. Chilean Jack Mackerel Workshop, FAO, Santiago, 2008: 9 pp

Canales C. & R. Serra., 2008. Updated Status of the Chilean Jack Mackerel Stock. Document SPRFMO-V-SWG. Technical Summary. Guayaquil, 2008: 9 pp.

Cordoba J., R. Bahamonde & V. Catasti., 2008. Jack Mackerel (Trachurus Murphyi, Nichols, 1920) acoustic survey in the central coast of Chile. CHJMWS pap #11. Chilean Jack Mackerel Workshop, FAO, Santiago, 2008: 14 pp.

Cubillos, L., C. Gatica & R. Serra., 2008. Short review of natural mortality and size at first maturity on jack mackerel (Trachurus murphyi) in the southeastern Pacific. CHJMWS pap #14. Chilean Jack Mackerel Workshop, FAO, Santiago, 2008: 4 pp.

Deriso, R.B., Quinn II, T.J., Neal, P.R., 1985. Catch-age analysis with auxiliary information. Can. J. Fish. Aquat. Sci. 42:815-824.

Fournier, D. & C.P. Archibald. 1982. A general theory for analyzing catch at age data. Can. J. Fish. Aquat. Sci., 39: 1195-1207.

Hilborn, R. 1990. Determination of fish movement patterns from tag recoveries using maximum likelihood estimators. Canadian Journal of Fisheries and Aquatic Sciences 47:635-643.

Hilborn R, Maunder M, Parma A, Ernst B, Payne J, Starr P., 2003. Coleraine: A Generalized Age-Structured Stock Assessment Model: User's Manual Version 2.0. Technical Report. School of Aquatic and Fishery Science, Fisheries Research Institute, Washington University. Rep. Fish. Res. Inst. Wash. Univ.

Hoyle S.D and M.Maunders., 2005. Status of yellowfin tuna in the eastern Pacific Ocean in 2004 and outlook for 2005. Inter-Amer. Trop. Tuna Comm., Stock Assessment Report, 4:1-100.

Ianelli J, Lamberson RH., 2003. Introduction to special issue: Modeling in fisheries science, past, present and future. Natural Resource Modeling 16, 337-340.

Maunder MN, Starr PJ, Hilborn R., 2000. A Bayesian analysis to estimate loss in squid catch due to the implementation of a sea lion population management plan. Marine Mammal Science 16, 413-426.

McAllister, M. & J. Ianelli. 1997. Bayesian stock assessment using catch-age data and the sampling-importance resampling algorithm. Can. J. Fisheries Aquat. Sci., 54: 284-300.

SUBPESCA, 2008. Research and management of Chilean Jack Mackerel (Trachurus murphyi) exploited in the South East Pacific Ocean. Undersecretariat for Fisheries. CHJMWS pap #24. Chilean Jack Mackerel Workshop, FAO, Santiago, 2008.Chile: 61 pp.