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Updated Status of the Chilean Jack Mackerel Stock

by

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1. Introduction

Jack mackerel stock assessment has been done by the IFOP since the beginning of the nineties, and from 2002 a statistical catch-at-age approach has been applied (Hilborn et al., 1993; Quinn & Deriso, 1999). The results of the assessment have been used as a reference for the management of the fishery by the Undersecretary of Fisheries. From 2003 important changes were recorded in the spatial distribution of the catch interpreted as a change in the distribution in the fish, along with a dramatic reduction of the biomass within the EEZ. These represent important sources of uncertainty and different hypotheses were generated to explore their implications (Serra, Canales and Caballero, 2007).

In this document, we report the results of different stock assessments scenarios and give an update on the stock condition to 2008.

2. Data and method

The assessment model assumes a single stock of jack mackerel distributed inside and offside the EEZ off Chile. It considers two zones (fisheries): the northern fishery, from the limit with Peru to 24°S, inside the EEZ; and the south- central fishery from 24°S to the south, inside and outside the EEZ. The western limit is limited by the main distribution of the catch of the ex-Soviet Union fleet (105°W). The assessment period spans 34 years, with a data series from 1975 to 2008. The information used corresponds to the following:

2.1. Fishery data

The assessment considers the data gathered from the fishery from 1975 to 2008.

- Landings: by fishery and total are provided in **Annex 1** (**Table 1 and 2**)
- Standardized CPUE of the Talcahuano fishery (1981-2005).
- Catch-at-age data for the Chilean fisheries; the age composition for the foreign fleets was assumed to be similar to the fishery off south-center Chile (or Talcahuano fishery). The age composition of the former Soviet Union catch was also included and was obtained applying age-length keys from the Talcahuano fishery to the size composition of the catch of this fleet due to the similarity of their size composition.
- Weigth-at age data by year for the Chilean fisheries.

The information of Chilean landings is based on statistics provided by the Instituto de Fomento Pesquero (IFOP) for 1975 - 2001 and official data provided by the Servicio Nacional de Pesca (SERNAPESCA) for the years 2002 to 2008. The statistics for the south-centrel fishery (Talcahuano fishery) contains the catch from inside and outside the EEZ off the Chilean south central zone and from a small fishery located between 24ºS and 30ºS. Data for the former Soviet Union fleet is based on catch statistics for the period 1978 – 1992. Data for the fleet of the People's Republic of China Vanuatu, Holland and Faroe Island were obtained from information provided during meetings of the SWG from the SP-RFMO (**Annex 1, Table 2**).

2.2. Biological information

- Maturity schedule

Age	2	3	4	5	6+
% Mature	0	0.04	0.5	0.96	1

- Natural mortality: was taken as M=0.23 yr^{-1} for all ages and years.

2.3. Fishery independent data

The fishery independent indexes are:

- Biomass estimates from acoustic surveys off south-central Chile (1997-2008).
- Age composition of the abundance obtained by acoustic surveys.
- Spawning biomass obtained from eggs surveys and by using the Daily Egg Production Method (DEPM)(1999-2001, 2003-2007).

2.4. Method.

Chilean jack mackerel stock was assessed using a statistical catch-at-age model based on a Bayesian estimate approach (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).

According to Hoyle and Maunders (2005) the term "statistical" indicates that the model implicitly recognizes that data collected from fisheries do not represent with precision the population; there is uncertainty in our knowledge about the dynamics of the system and about how the observed data relate to the real population. The model uses annual time steps to describe the population dynamics. The parameters of the model are estimated by comparing the predicted catches, age compositions and abundance indexes to information collected from the fishery (observations). The model is run assuming that the landings are known and errors exist in the catch age composition.

In the stock assessment model, the catch-at-age information is modeled using a multinomial probability distribution and lognormal distributions are employed in modeling the relative abundance indexes (cpue, acoustic biomass, spawning biomass from the eggs production method). In a manner consistent with changes in availability by age groups along the coast, for the Chilean fleet operating in the northern area a "dome shape" selectivity is applied. In the south center fishery ─including the former URSS catch and present foreign fleet catch─ a logistic model is applied.

The parameters are resolved minimizing the negative sum of the log likelihood identified to model the information error and the "a priori" log distributions considered for some parameters. This is equal to maximizing the "a posteriori" distribution from a Bayesian perspective. In this sense, and in order to have risk measurements for the relevant variables, uncertainty analysis is done by integrating the a posteriori distribution using the MCMC (Markov Chain MonteCarlo) re-sampling technique. A description of the model was given by Canales & Serra (2008b) and is included in **Annex 2**.

A stock assessment generally has different sources of uncertainty (observation, processes) being important to explore at least the most important. In the case of the jack mackerel different sources of uncertainty were explored; one is how to include the biomass estimated by acoustic survey due to the fact of the strong decline of the abundance inside the EEZ. Two hypotheses have been raised: change in the jack mackerel distribution from inshore to offshore and contraction or shrinking in its distribution due to the decrease in its abundance. Another important process error are the selectivity pattern for the fishery off south center Chile and the value of M (an option with a value of 0.3 was included). Also, the consequences of different weighing factors were examined. Finally 26 scenarios were explored and one based on the distribution change hypotheses was identified as the baseline model.

3. Results from the application of the statistical age-structured model

3.1 Baseline model fit

Figures 1, **2** and **3** show the results of the goodness of fit for relevant information. The model reproduces fairly well the dynamics of the age structure of the catch in Chile's north and south-central (Talcahuano) fisheries. The model fit for the acoustic biomass index reproduces well the strong decrease of the population but the fit for the spawning biomass index is less satisfactory because the assessment can not reproduce the strong drop from 2001 to 2003 in the spawning biomass.

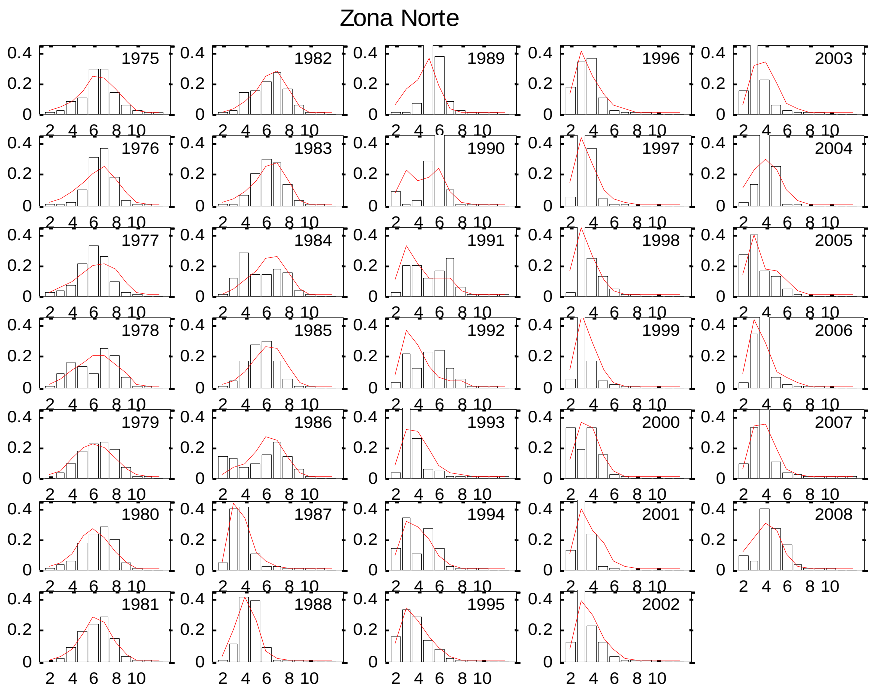

Figure 1. Model fit to the catch-at-age information of the jack mackerel in the Northern fishery off Chile. (Source:IFOP)

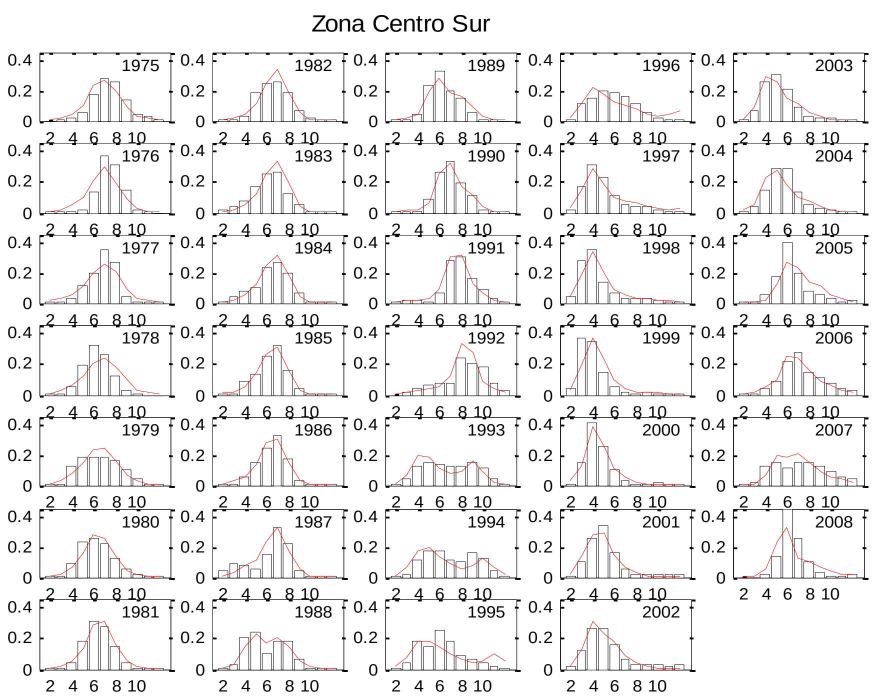

Figure 2. Model fit to the catch-at-age information of the jack mackerel in the South- Central fishery off Chile (Source:IFOP)

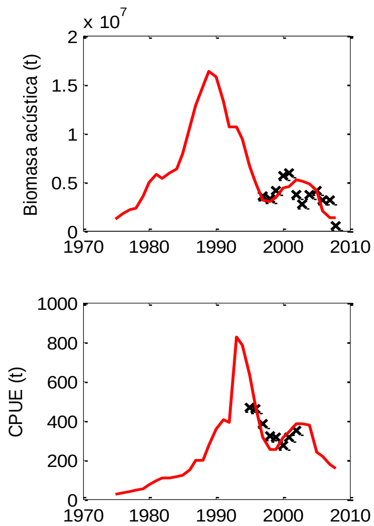

Figure 3. Model fit to relative biomass indexes of the jack mackerel off South-Central Chile (Source:IFOP)

3.2 Results from different scenarios

The results of the effort in exploring the different sources of uncertainty is synthesize in **figure 4**. Here, the main uncertainties are related to initial condition. The higher values in 1975 represent the dome-shape selectivity assumptions under a steady-state condition for the initial population. This is due to the fact that in these years no information related to abundance indexes exist being likely that the biomass levels are sub-estimated in those years. The lowest values in the most recent years belong to the population contraction hypothesis, while the highest values represent the hypothesis of distribution changes in the population using a higher natural mortality value (M=0.3). However, the 26 scenarios analyzed show a robust pattern of population and recruitment decline since 2003.

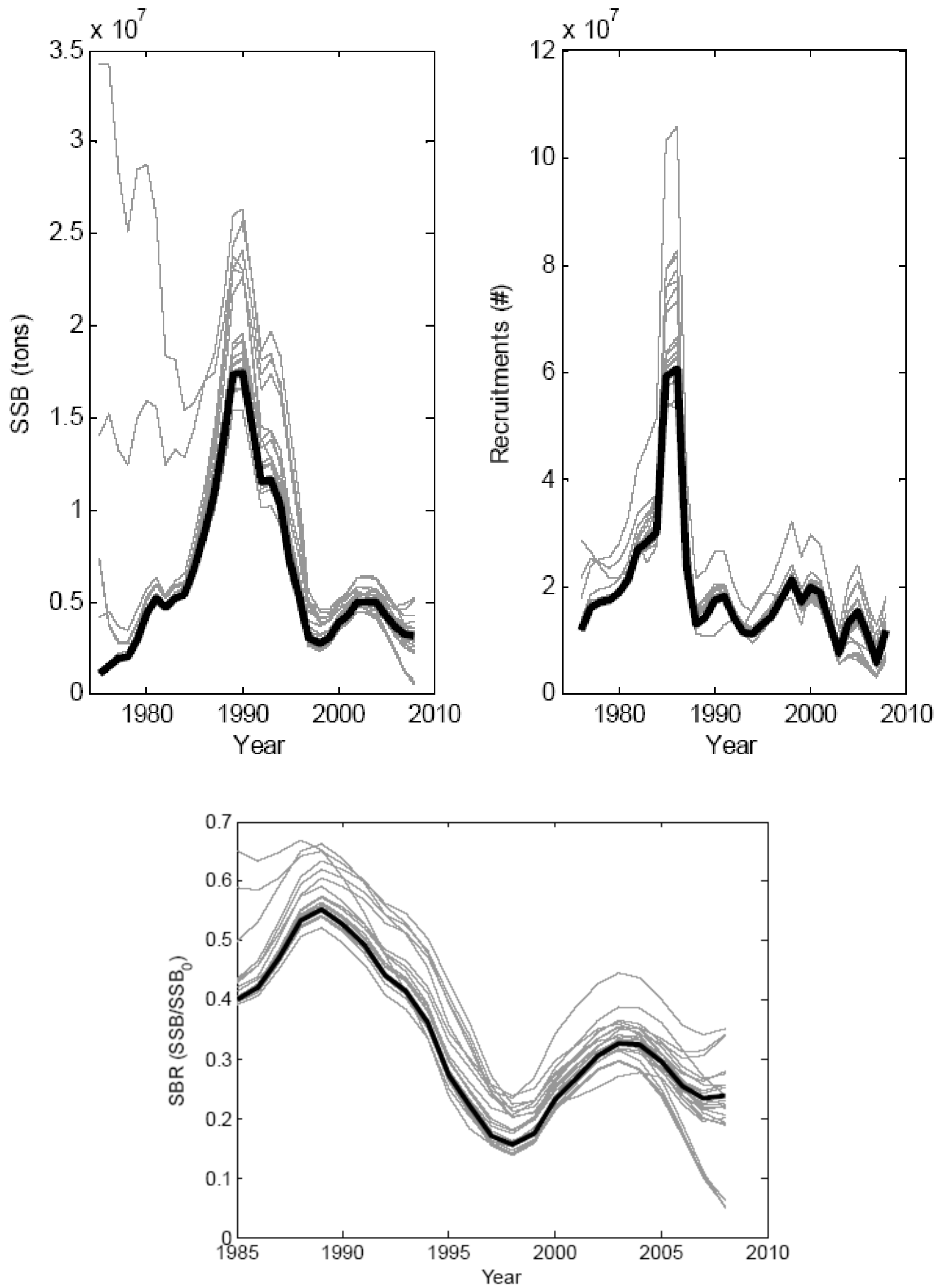

Figure 4. Chilean jack mackerel spawning biomass (SSB), recruitment and spawning biomass ratio (SBR) trends from the 26 scenarios. The bolded line represents the baseline case.

4. Results from baseline model.

The jack mackerel biomass grew from 1975 to 1985 due to a sustained growth in recruitment (**Figure 5**). The increase of the jack mackerel abundance in this region was informed before by Serra (1991) and Elizarov et al. (1993). Jack mackerel recruitment reached its peak in 1985 and

1986, decreasing sharply in 1987 and 1988. It kept fluctuating at this lower level since showing a decreasing trend since 2001. Simultaneously with the drop in recruitment landings grew rapidly between 1985 and 1991 to high levels (about 88%), attaining a maximum of 4.2 million tons in 1995 and declining thereafter (Table 1).

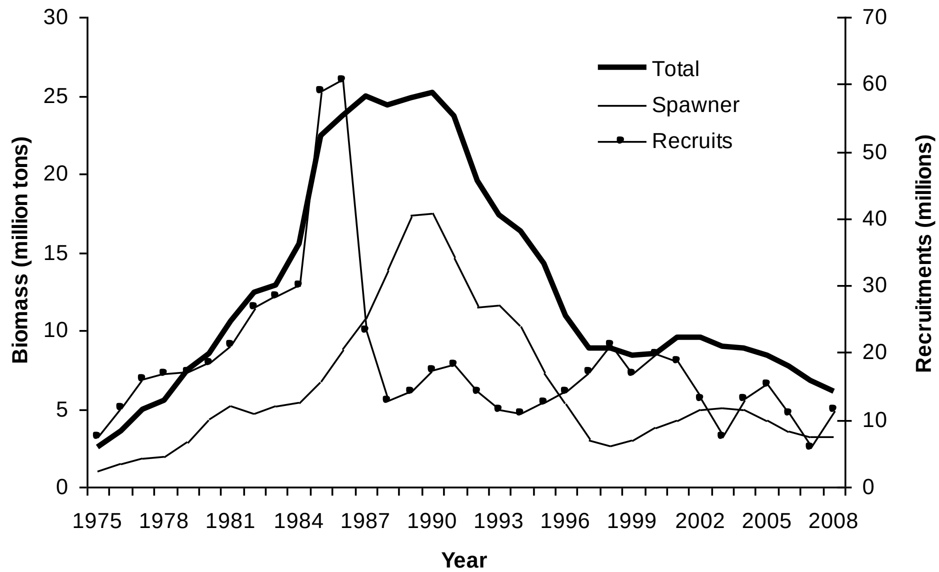

Figure 5. Biomass and recruitments of Chilean jack mackerel total biomass from the baseline model. (Source:IFOP)

As a result of decreased level of recruitment since 1987 and the large catches during the same period the fishing mortality grew to high levels (**Figure 6**), exceeding the recommended level of $F_{40\%SBR}$ (Ffr=0.38; $F_{40\%SBR2+}$=0.1; $F_{40\%SBR4+}$=0.17). The overfishing process is also demonstrated by the fact that the catches exceed the surplus production (SP) of the stock (**Figure 7**) and that the spawning biomass ratio (SBR), i.e. the ratio between the SB that would have been without exploitation and the actual SB, (**Figure 4**) dropped to levels of 15%, which is significantly less than the biological target (40%SBR). Afterwards and beside the declining trend of the spawning biomass since early 2000 an 80% of the 26 cases examined indicate for the most recent years that the SBR ratio was located in 2008 on the range 20%-30% of a spawning biomass without fishing (**Figure 4**).

Since 2000 the fishing mortality increases again (**Figure 6**) indicating the intensification of the exploitation process and surpassing the level of $F_{40\%SBR}$, and from 2003 ahead the SP is exceeded by the catch again, what explains the further decline in the total and the spawning biomass. In **figure 6** F2+ represent the overall weighted fishing mortality by the abundance of the ages 2 and older and F4+ the same but for the adult stock. The intensification of the exploitation process is explained by a lower average level of the recruits from 2003 ahead which however the rather stable level of the catch (about 1.6 million tons in total; Annex 1) causes the decrease in the stock level and the increase in the fishing mortality, which point a positive trend since.

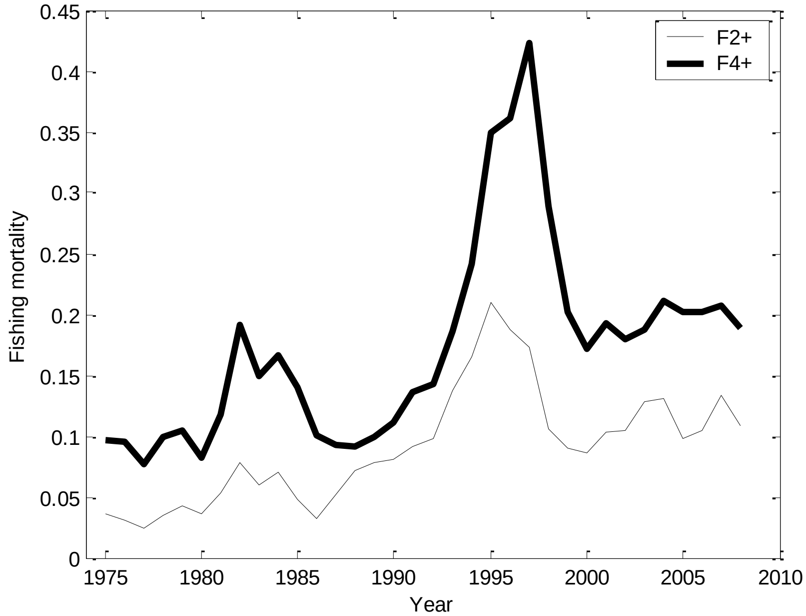

Figure 6. Weighted fishing mortality rate of the Chilean Jack Mackerel.for ages 2 and 4 plus. (Source:IFOP)

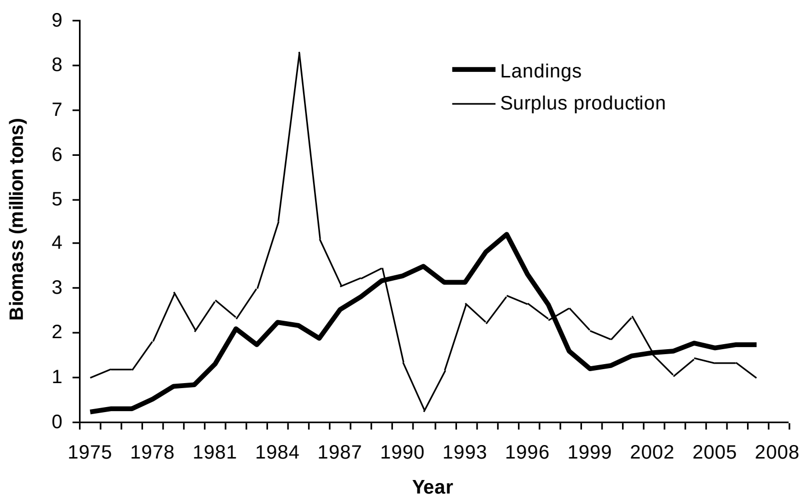

Figure 7. Landings and surplus production of the Chilean Jack Mackerel. (Source:IFOP)

5. Stock status.

The high level of fishing mortality and SBR below the 40% (close to 27%) reference point that is an adequate management target for a pelagic fish like jack mackerel, indicates that the Chilean jack mackerel is in an overfishing process. The declining trend in the spawning biomass, recruitment, together with the growing trend of the exploitation indexes and the catch gives a prospect of increasing risk for the stock and the fishery, being extremely necessary to reduce the fishing mortality to sustainable levels by setting a catch quota to avoid further stock decline.

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ANNEXES

ANNEX 1

Table 1. Jack mackerel landings by national and international fleets off Chile

Year	NZ	SCZ	N	INT	Total
1975	186890	34951	221841		221841
1976	237876	65570	303446		303446
1977	225907	75585	301492		301492
1978	367762	150319	518081		518081
1979	311682	203269	514951	269500	784451
1980	266697	215528	482225	325300	807525
1981	435061	440935	875996	420300	1296296
1982	756484	643821	1400305	679700	2080005
1983	259128	541696	800824	929100	1729924
1984	663695	677910	1341605	877000	2218605
1985	471599	923042	1394641	739100	2133741
1986	42536	1103200	1145736	731200	1876936
1987	280594	1416781	1697375	819042	2516417
1988	278701	1703037	1981738	811713	2793451
1989	265861	2031058	2296919	856910	3153829
1990	258233	2150956	2409189	852363	3261552
1991	282817	2649828	2932645	539816	3472461
1992	285387	2796812	3082199	36320	3118519
1993	359947	2745099	3105046		3105046
1994	197414	3596904	3794318		3794318
1995	211594	3984244	4195838		4195838
1996	264631	3017165	3281796		3281796
1997	88276	2541981	2630257		2630257
1998	19278	1546704	1565982		1565982
1999	44582	1130488	1175070		1175070
2000	107769	1135082	1242851		1242851
2001	244019	1216754	1460773	20090	1460773
2002	108727	1357185	1465912	76261	1542173
2003	142016	1272301.84	1414317.69	158199	1572517
2004	157647	1289819.68	1447466.82	295493	1742960
2005	165552	1248970.51	1414522.89	233575	1648098
2006	154524	1215738.34	1370262.2	362146	1732408
2007	170220	1119713.31	1289933.49	426234	1716167
2008	147440	744560	892000	426234	1318234

Table 2. International landings employed in the stock assessment

Year	P. R. China	EC	Faroe I.	Korea	Russia	Vanuatu	Total
2001	20090						20090
2002	76261						76261
2003	94690			2010	7540	53959	158199
2004	131020			7488	62300	94685	295493
2005	143000	6179			7040	77356	233575
2006	160000	62137		10474		129535	362146
2007	140582	123511	38700	10940		112501	426234

ANNEX 2:

JACK MACKEREL STOCK ASSESSMENT MODEL

Initial conditions

The vector of number-at-age (a=2-12) at the beginning of the first year es resolved by the model being as a parameter

$$N_{a,1} \sim U[0,\infty[$$

Process model

The model assumes 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

$$N_{a,y} = \begin{cases} N_{a,y} & a = 2-12; y = 1 \\ & a = 2-11; y = 2-34 \\ N_{a-1,y-1}e^{-M} - \hat{C}^{tot}_{a-1,y-1}e^{-0.5M} & \\ \left(N_{a-1,y-1}e^{-M} - \hat{C}^{tot}_{a-1,y-1}e^{-0.5M}\right) + & a = 12; y = 2-34 \\ \left(N_{a,y-1}e^{-M} - \hat{C}^{tot}_{a,y-1}e^{-0.5M}\right) & \end{cases} \quad (1)$$

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

Recruitment

Recruitment is estimated assuming a Ricker-type stock-recruit relationship; ε is the process error:

$$R_1 = \alpha SB_{y-2}e^{-\beta SB_{y-2}}e^{-\varepsilon_y} \quad (2)$$

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

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.

Observation models

Catch

The catch is 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 catch, and S is age-specific selectivity modeled according to the fleet-zone as:

- northern fleet: considers the periods (t) 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 (t) of the exploitation pattern: 1975-1987, 1988-1992, 1993-2004, 2005-2007.

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

Acoustic biomass

$$\hat{B}_y^c = q_y^c \sum_a (N_{a,y} e^{-0,5M} - \hat{C}_{a,y}) S_a^c w_{a,y} \quad (10)$$

q_y^c is the coefficient of catchability for acoustic cruises estimated taken in consideration the two hypotheses identified.

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.

$$q_y^c = \exp\left[\frac{1}{n} \sum_y \log\left(\frac{B_y}{\hat{B}_y} \right) \right] \quad (11)$$

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.

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

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 2005-2008.

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

Catch per unit of effort (CPUE)

The CPUE from the south- central fishery is considered to be a good index of relative biomass between 1996 and 2003. A later change in the fishing regimes of the fishery has affected this signal.

$$CP\hat{U}E_y = q \sum_a N_{a,y} e^{-0,5M} S_{a,y}^{f} w_{a,y} \tag{15}$$

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

Observation model errors (likelihood estimators)

Catch-at-age compositions: a multinomial error distribution is assumed.

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

where $p_{a,y}^f = \dfrac{C_{a,y}^f}{\sum_a C_{a,y}^f}$ and n is the size of the effective sample.

Biomass age compositions from acoustic survey: a multinomial error distribution is assumed.

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

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

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

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

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

(19)

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

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

(20)

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

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

(21)

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.

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