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CPUE of Jack mackerel in the center-south area off Chile 1983-2014

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CPUE of Jack mackerel (*Trachurus murphyi*) in center-south area off Chile 1983-2014.

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Summary

In this work, the jack mackerel CPUE is updated through a Generalized Lineal Model based on the purse-seine information at center-south area off Chile. The fishing effort is defined as haul capacity displaced by day out of port, and several factor were considered to explain the CPUE variations and the catches success. In this sense, the abundance index is the result of the product between estimators of CPUE and success of catches.

Results show that population declined steadily until the mid-1990s. After a transient stability state, a faster declination has been observed since 2006 and the stock depletion had reached the lower value equivalent 12% of the CPUE recorded in 1983. However, the scale change occurred in 2012 due to an availability/catchability change, the population has continued declining.

1. Introduction

The stock assessment of jack mackerel is the most important scientific activity carried out by the Scientific Committee of South Pacific Regional Fisheries Management Organization (SPRFMO). This activity implies the analysis of several information sets provided for countries members of this organization, being the Catch per Unit of Effort (CPUE) one of these. CPUE is an abundance index and in this sense its update is very important because gives to stock assessment model an important support in order to precise the population trend, particularly for recent years.

In order to evaluate the CPUE variability, is necessary to consider an appropriate statistical analysis which permit to explore the main factors that determine it, being one of these the year effect commonly considered as abundance index. In this report, the CPUE modelling work for jack mackerel is informed which corresponds to purse seine fleet in center-south area off Chile (Fleet 2) between 1983 and 2014.

2. Materials and Methods

The fishing logbooks of purse seine fleet in center-south area off Chile 1983-2014 were analyzed. The area was divided in 9 sub-zones based on 3 latitudinal strata: 32°10'S - 34°50'S, 34°50'S - 38°00'S and 38°00'S - 47°00'S, and 3 ranges of coast distance: 0-100 mn; 101-200 mn; >200 mn. (Fig. 1). Also, the fleet was conformed by 10 groups based on its haul capacity: <250 m³; 250-350 m³; 351-500 m³; 501-600 m³; 601-750 m³; 751-850 m³; 851-910 m³; 911-1.100 m³; 1.101-1.500 m³ and 1.501-2.071 m³, while the intra annual variability was modeled based on quarters. The unit of

effort corresponds to the haul capacity displaced by days out of port ($m^3 \times \text{dop}$) and CPUE is the rate between the catch by trip in tons, and the effort unit before indicated.

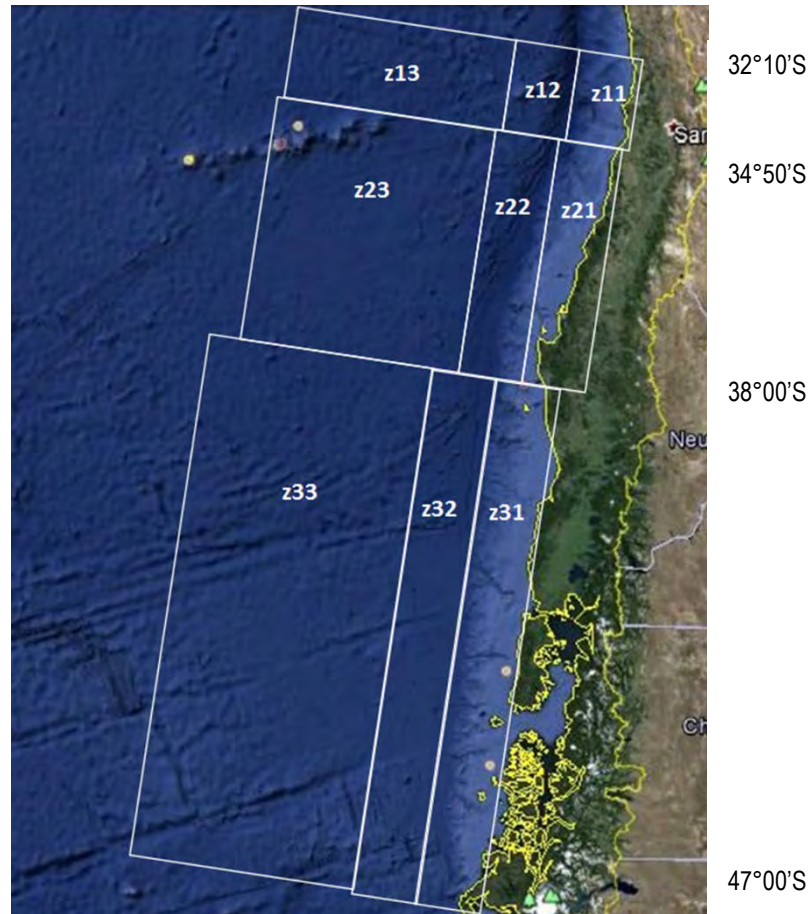


Figure 1. Spatial representation of Jack mackerel fishing zones in center-south area off Chile.

The CPUE analysis was done considering a Lineal Generalized Model (GLM; McCullagh & Nelder, 1989). Following the proposal of Stefánsson (1996), Welsh et al. (1996) and Fletcher et al. (2005), the data without catches were analyzed independently of trips with catches following a Delta model where an estimator of expected CPUE value as abundance index corresponds to a mixture of models given by:

$$CP\hat{U}E_y = CP\hat{U}E_y^+ * \hat{P}_y \quad (1)$$

$$\log(CPUE_{y,q,cb,z}^+) = c1 + Y_y + Q_q + CB_{cb} + Z_z + \sigma_{y,q,cb,z} \quad (2)$$

$$\log\left(\frac{P_{y,q,cb,z}}{1-P_{y,q,cb,z}}\right) = c2 + Y'_y + Q'_q + CB'_{cb} + Z'_z + \varepsilon_{y,q,cb,z} \quad (3)$$

where $CPUE_y^+$ is the annual CPUE (y) for days with catch and \hat{P}_y is the annual proportion of these days, and also is defined as fishing success. The terms c1 and c2 are constants, Y is the year factor, Q the quarter, CB the haul capacity strata and Z the zone. $\varepsilon_y\sigma$ are terms related to observation error. A deviance analysis was conducted to evaluate the significance of each effect and three models were defined:

Table 1.

GLM models applied to jack mackerel data in center-south area off Chile

Modelo	Variable	Family	Link function
1	log(CPUE)	Gauss	Identidad
2	CPUE	Gamma	Log
3	Binary	Binomial	logit

The estimators of CPUE and catch success in annual base were estimated as:

$$CPUE_y^+ = \exp(c1 + Y_y + 0.5\sigma^2) \quad (4)$$

$$\hat{P}_y = \frac{\exp(c2 + Y'_y)}{1 + \exp(c2 + Y'_y)} \quad (5)$$

3. Results

3.1. Data exploratory analysis

The nominal CPUE showed a steady decline throughout the analysis period. While the number of trips declined significantly since 1995, the duration of these gradually increased as a result of fishing areas expansion (Table 2). The spatial and temporal distribution of fishing effort indicates that together to increasing of catches, fishing effort was gradually covering more remote areas far of coast and at mid 90's, the fleet had more participation outside the EEZ south-central Chile (Table 3). This operation outside the EEZ had its peak between 2008 and 2011 with fishing trips over six days as average, situation that radically changes the most recent years where the most important fishing areas were within the EEZ and mainly north of 38° S.

Regarding the modeling, the examination of the data shows a level of significant correlation between the logarithm of the average of CPU and the logarithm of the variance of the CPUE, in which the slope has a value two and the intercept a value zero (p-value <0.025), suggesting that in the GLM

could be considered a Gamma link function as initial candidate (Stefánsson, 1996; Brynjarsdóttir & Stefánsson, 2004). (Fig. 2)

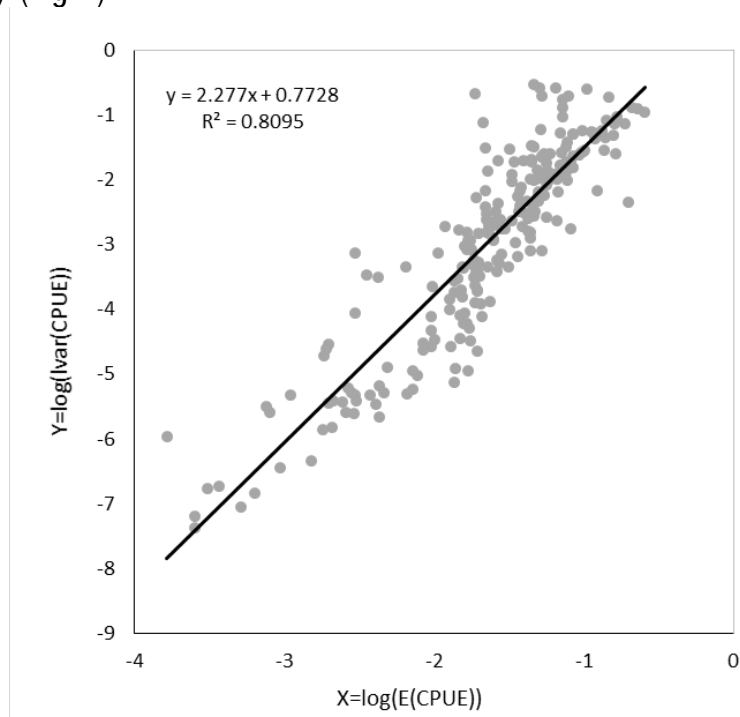


Figure 2. Relationship between log-mean and log-variance of the CPUE of jack mackerel

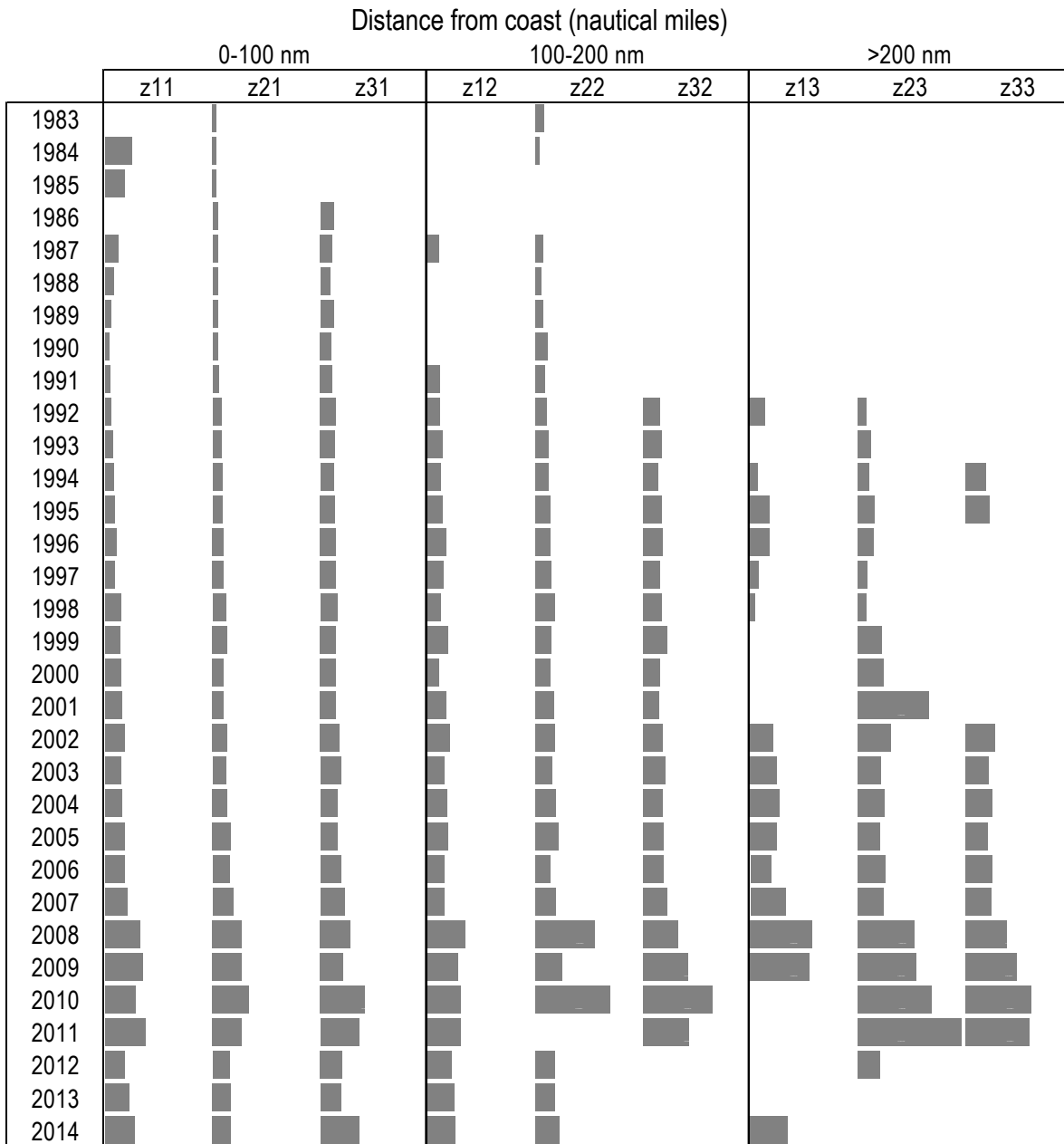
Table 2.

Summary of information from logbooks and nominal CPUE of jack mackerel in south-central area off Chile 1983-2014.

Year	Total trip	Trips with catches	Days out of port (average)	CPUE (t*m ⁻³ /dop)	
				mean	max
1983	9232	6356	0.61	0.50	3.91
1984	8832	6051	0.63	0.46	3.85
1985	11998	7465	0.63	0.37	4.00
1986	13187	8679	0.74	0.32	3.89
1987	12890	8834	0.72	0.40	3.99
1988	13399	8889	0.73	0.35	3.75
1989	13254	9394	0.80	0.35	3.83
1990	15782	10284	0.85	0.28	3.90
1991	13208	9826	1.01	0.34	3.88
1992	11132	7707	1.36	0.29	4.00
1993	10221	7240	1.60	0.26	3.69
1994	10232	8206	1.75	0.29	3.96
1995	11431	9032	1.76	0.27	3.85
1996	7848	6379	1.96	0.27	3.90
1997	9655	7415	1.92	0.19	3.55
1998	4423	3853	2.39	0.17	3.44
1999	2964	2676	2.41	0.17	1.71
2000	2737	2576	2.17	0.18	1.75
2001	2835	2677	2.08	0.22	2.37
2002	2571	2348	2.83	0.18	2.91
2003	2196	2082	3.07	0.17	2.35
2004	1999	1902	3.00	0.17	2.47
2005	1687	1606	3.28	0.16	1.84
2006	1434	1399	3.13	0.19	2.06
2007	1629	1537	3.94	0.13	0.92
2008	996	850	6.48	0.08	2.66
2009	1062	934	6.47	0.07	3.28
2010	452	362	7.60	0.05	0.76
2011	528	452	6.92	0.03	0.23
2012	524	490	3.12	0.11	0.95
2013	513	486	3.48	0.09	0.48
2014	325	310	3.98	0.07	0.33

Tabla 3.

Fishing effort representation by year and fishing zone.



3.2. Modeling of CPUE and catch success

The CPUE model that considered the Gama link function (Model 2) explained the CPUE variability in a better way in relation the model of the log-CPUE based on canonical link function (model 1). With the first of these, the explanation of the total deviance reached 21% (Table 4). Regardless of the model and while all factors were significant (p -value <0.025), the year effect was the factor with the greatest impact in the explanation of the total deviance (15% -17%), followed far behind by the quarterly effect with less than 3%, and the hold capacity and the fishing area with a 1%.

Meanwhile, the binomial model applied to the proportion of days with catches shows that the level of explanation of the deviance is low and reaches 12% (Table 4). From the analyzed factors, the most important is equally the year effect but explaining only 7% of the total residual deviance. The residual's graph shows that while both models have a symmetric distribution (Fig. 3, 4), the overlap of the expected theoretical quantile on the line is higher in model 2. This comes to ratify that the best link function in the model is Gamma.

The coefficients associated with the year effect are given in Table 5 and 6, highlighting that in general all levels are significant. However, the annual effect of 1983 in model 2 CPUE (Table 5), seems to be not significant. In relation to the other factors in the model, we emphasize that the seasonal effect of the fishery has been well represented by the model where CPUE is more important in the first two quarters declining rapidly towards the end of the year.

Similarly, the spatial pattern shows that the highest densities of jack mackerel occur north of 38°S and within the EEZ, while within oceanic areas, the most abundant are located south $34^{\circ}5\text{S}$ (Fig. 5). In this context, the catch success has been located between 100 and 200 nm, as well as within the 100 mn south of 38°S . Historically, the lowest probability of success (52%) is located outside the EEZ between $34^{\circ}50'\text{S}$ and $38^{\circ}00'\text{S}$ (Fig. 6).

The annual effect of GLM for both models of CPUE with catches data does not show major differences in its trends, which are characterized by a significant decline during most of the period of analysis and with the exception of 2012, in which the CPUE increase was due to fleet orientation to operate within the ZEE. Meanwhile, the annual signal of capture success shows three periods, the first from 1983-1996 with an average of 70% catch's success, a second from 1997-2000 with a sustained increase in catch success, and the third from 2001 with an average of 96% in catch success on days out of port (Fig. 7).

Table 4

Deviance analysis for GLM fitted to the data of jack mackerel fishery. The percentage indicates the proportion of the total deviance explained.

Model 1 (Gaussian)					
Explained deviance		19%			
	d.f	Deviance	d.f.resid	Resid. Dev.	%
NULL			147498	201973	
year	32	30553	147466	171420	15%
Quart	3	6275	147463	165146	3%
Zone	8	1152	147455	163993	1%
Hold capacity	9	1051	147446	162943	1%

Model 2 (Gamma)					
Explained deviance		21%			
	d.f	Deviance	d.f.resid	Resid. Dev.	%
NULL			147498	158247	
Year	32	27201	147466	131046	17%
Quart	3	3050	147463	127996	2%
Zone	8	1476	147455	126520	1%
Hold capacity	9	1446	147446	125074	1%

Model 3 (Binomial)					
Explained deviance		12%			
	d.f	Deviance	d.f.resid	Resid. Dev.	%
NULL			198199	225403	
year	32	16058	198167	209345	7%
Quart	3	3215	198164	206130	1%
Zone	8	4904	198156	201226	2%
Hold capacity	9	2924	198147	198301	1%

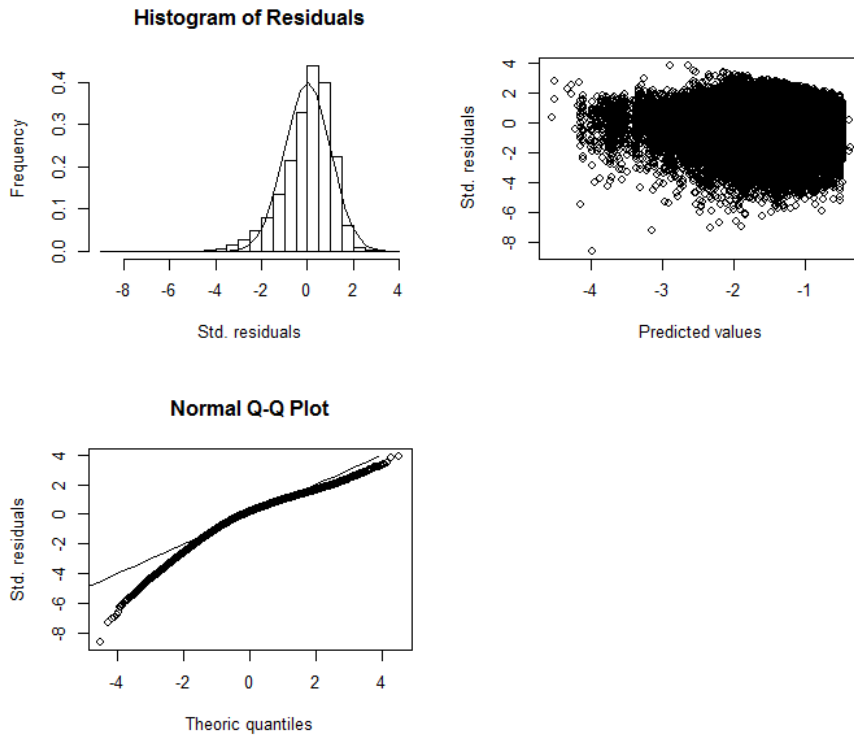


Figure3. Diagnostic of residuals GLM, CPUE data, Model 1

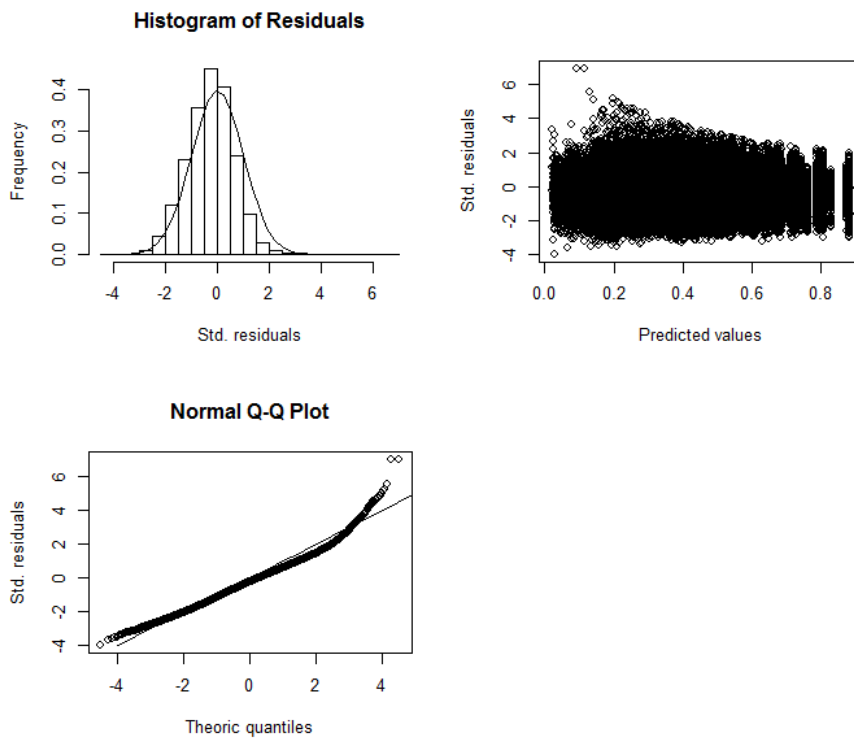


Figure4. Diagnostic of residuals GLM, CPUE data, Model 2

Table5.

GLM coefficients (model 2) fitted to positive CPUE data of jack mackerel in the central-southern Chile.

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Coefficients:
      Estimate Std. Error t value Pr(>|t|)
(Intercept) -0.144211  0.035681  -4.042 5.31e-05 ***
year1983     -0.006149  0.035541  -0.173 0.86265
year1984     -0.092706  0.035773  -2.591 0.00956 **
year1985     -0.213118  0.035601  -5.986 2.15e-09 ***
year1986     -0.377468  0.035478 -10.639 < 2e-16 ***
year1987     -0.202221  0.035590  -5.682 1.33e-08 ***
year1988     -0.324434  0.035787  -9.066 < 2e-16 ***
year1989     -0.339263  0.035792  -9.479 < 2e-16 ***
year1990     -0.484148  0.035712 -13.557 < 2e-16 ***
year1991     -0.372510  0.035958 -10.359 < 2e-16 ***
year1992     -0.441597  0.036342 -12.151 < 2e-16 ***
year1993     -0.548824  0.036493 -15.039 < 2e-16 ***
year1994     -0.472102  0.036516 -12.929 < 2e-16 ***
year1995     -0.577195  0.036593 -15.773 < 2e-16 ***
year1996     -0.568173  0.037014 -15.350 < 2e-16 ***
year1997     -0.760337  0.036715 -20.709 < 2e-16 ***
year1998     -0.924414  0.038388 -24.081 < 2e-16 ***
year1999     -0.901952  0.039705 -22.716 < 2e-16 ***
year2000     -0.925180  0.039883 -23.197 < 2e-16 ***
year2001     -0.741079  0.039883 -18.581 < 2e-16 ***
year2002     -0.870051  0.041162 -21.137 < 2e-16 ***
year2003     -0.992971  0.041372 -24.001 < 2e-16 ***
year2004     -0.907946  0.041706 -21.770 < 2e-16 ***
year2005     -0.995940  0.043102 -23.107 < 2e-16 ***
year2006     -0.905405  0.043677 -20.729 < 2e-16 ***
year2007     -1.187606  0.043972 -27.008 < 2e-16 ***
year2008     -1.551652  0.049903 -31.094 < 2e-16 ***
year2009     -1.734717  0.047830 -36.269 < 2e-16 ***
year2010     -2.025250  0.061123 -33.134 < 2e-16 ***
year2011     -2.603992  0.057129 -45.581 < 2e-16 ***
year2012     -1.476595  0.054634 -27.027 < 2e-16 ***
year2013     -1.656186  0.054864 -30.187 < 2e-16 ***
year2014     -1.942684  0.063925 -30.390 < 2e-16 ***
trim2        0.103250  0.006055  17.053 < 2e-16 ***
trim3       -0.065273  0.006606  -9.881 < 2e-16 ***
trim4       -0.382000  0.007763 -49.206 < 2e-16 ***
zona12     -0.123151  0.021724  -5.669 1.44e-08 ***
zona13     -0.441886  0.036805 -12.006 < 2e-16 ***
zona21     -0.078053  0.010042  -7.773 7.72e-15 ***
zona22     -0.105011  0.015926  -6.594 4.30e-11 ***
zona23     -0.304968  0.025252 -12.077 < 2e-16 ***
zona31     -0.342734  0.012176 -28.149 < 2e-16 ***
zona32     -0.329173  0.024506 -13.432 < 2e-16 ***
zona33     -0.379184  0.026288 -14.424 < 2e-16 ***
cb2        -0.006171  0.010412  -0.593 0.55341
cb3        -0.060120  0.009720  -6.185 6.23e-10 ***
cb4        -0.209756  0.012852 -16.321 < 2e-16 ***
cb5        -0.246076  0.011050 -22.269 < 2e-16 ***
cb6        -0.390674  0.015206 -25.692 < 2e-16 ***
cb7        -0.358613  0.016055 -22.337 < 2e-16 ***
cb8        -0.311057  0.013254 -23.469 < 2e-16 ***
cb9        -0.424288  0.013749 -30.860 < 2e-16 ***
cb10       -0.475599  0.015783 -30.135 < 2e-16 ***
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(Dispersion parameter for Gamma family taken to be 0.80561)

Null deviance: 158247 on 147498 degrees of freedom
Residual deviance: 125074 on 147446 degrees of freedom

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Table 6.

GLM coefficients fitted to the catches success of jack mackerel in the central-southern Chile.

Coefficients:

	Estimate	Std. Error	z value	Pr(> z)	
(Intercept)	1.53769	0.03682	41.763	< 2e-16	***
year1983	-0.61403	0.03589	-17.107	< 2e-16	***
year1984	-0.82249	0.03656	-22.496	< 2e-16	***
year1985	-1.15313	0.03449	-33.431	< 2e-16	***
year1986	-1.08957	0.03453	-31.557	< 2e-16	***
year1987	-1.05679	0.03528	-29.954	< 2e-16	***
year1988	-1.24825	0.03542	-35.244	< 2e-16	***
year1989	-1.11699	0.03632	-30.756	< 2e-16	***
year1990	-1.38524	0.03530	-39.247	< 2e-16	***
year1991	-1.05707	0.03750	-28.191	< 2e-16	***
year1992	-1.38706	0.03820	-36.313	< 2e-16	***
year1993	-1.44869	0.03934	-36.824	< 2e-16	***
year1994	-1.13506	0.04213	-26.940	< 2e-16	***
year1995	-1.17483	0.04154	-28.280	< 2e-16	***
year1996	-1.07284	0.04603	-23.310	< 2e-16	***
year1997	-0.77225	0.04660	-16.572	< 2e-16	***
year1998	-0.33050	0.07122	-4.641	3.48e-06	***
year1999	4.39174	0.70829	6.200	5.63e-10	***
year2000	0.51475	0.10866	4.737	2.17e-06	***
year2001	2.47039	0.29234	8.450	< 2e-16	***
year2002	3.35121	0.50368	6.653	2.86e-11	***
year2003	4.60149	0.50665	9.082	< 2e-16	***
year2004	5.55945	0.99709	5.576	2.47e-08	***
year2005	5.46141	1.00033	5.460	4.77e-08	***
year2006	4.01709	0.71262	5.637	1.73e-08	***
year2007	3.53605	0.31273	11.307	< 2e-16	***
year2008	2.97988	0.37180	8.015	1.10e-15	***
year2009	2.77336	0.39907	6.950	3.67e-12	***
year2010	1.99070	0.48139	4.135	3.55e-05	***
year2011	1.14610	0.40913	2.801	0.005090	**
year2012	2.95885	1.00313	2.950	0.003182	**
year2013	-0.44713	0.20902	-2.139	0.032423	*
year2014	-0.33885	0.29009	-1.168	0.242770	
trim2	0.04336	0.01486	2.918	0.003517	**
trim3	-0.42676	0.01488	-28.677	< 2e-16	***
trim4	-0.85707	0.01576	-54.378	< 2e-16	***
zona12	1.32190	0.09504	13.909	< 2e-16	***
zona13	-0.91009	0.14336	-6.348	2.18e-10	***
zona21	0.08071	0.02242	3.600	0.000318	***
zona22	1.47818	0.06958	21.245	< 2e-16	***
zona23	-2.44211	0.06853	-35.633	< 2e-16	***
zona31	1.05252	0.04050	25.990	< 2e-16	***
zona32	2.11085	0.21493	9.821	< 2e-16	***
zona33	0.05815	0.43285	0.134	0.893137	
cb2	0.37892	0.01876	20.195	< 2e-16	***
cb3	0.58653	0.01791	32.739	< 2e-16	***
cb4	0.79996	0.02606	30.698	< 2e-16	***
cb5	0.93938	0.02195	42.790	< 2e-16	***
cb6	1.02521	0.03658	28.028	< 2e-16	***
cb7	0.92175	0.03941	23.391	< 2e-16	***
cb8	1.26067	0.03405	37.022	< 2e-16	***
cb9	1.50346	0.04067	36.963	< 2e-16	***
cb10	1.54649	0.06590	23.466	< 2e-16	***

(Dispersion parameter for binomial family taken to be 1)

Null deviance: 233160 on 205685 degrees of freedom
 Residual deviance: 205585 on 205633 degrees of freedom

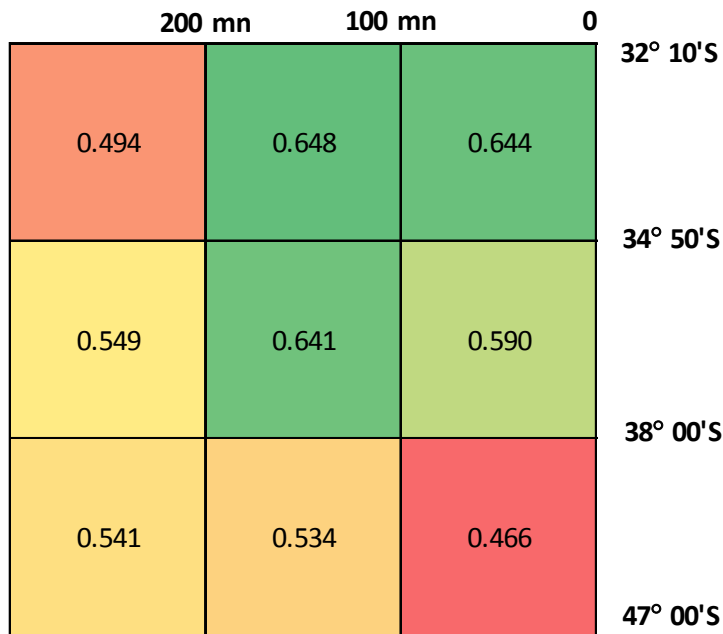


Figure 5. Graphical representation of the area factor in CPUE model. Green color represents highest values and the red the lower value.

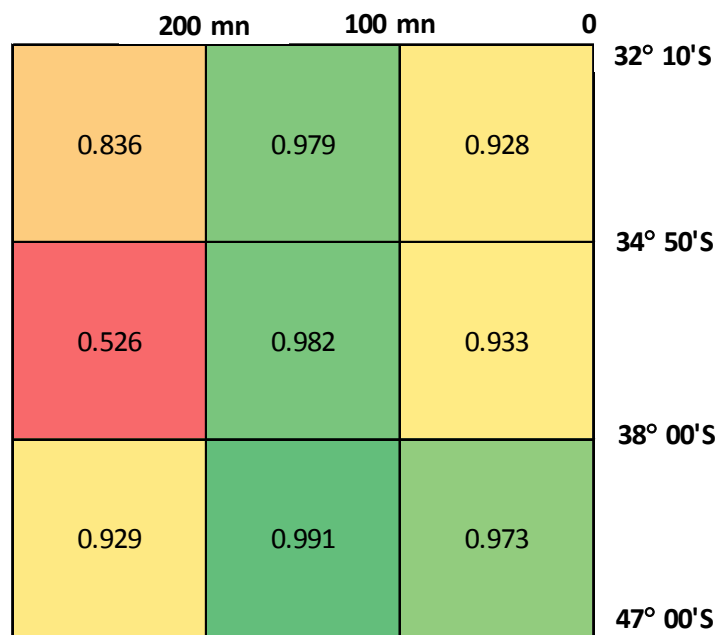


Figure 6. Graphical representation of the area factor in model of catches' success. Green color represents highest values and the red the lower value.

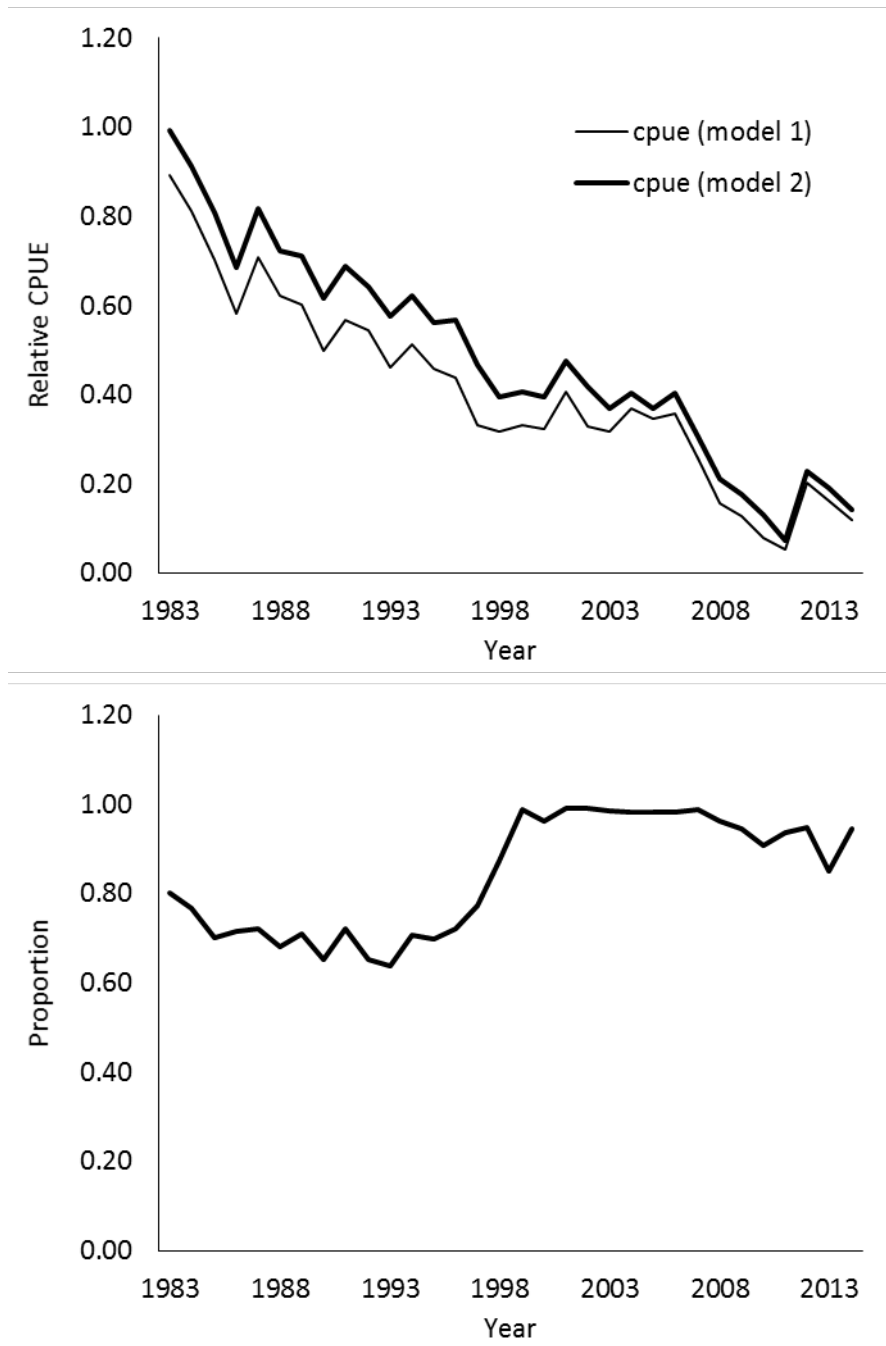


Figure7. CPUE relative (upper panel) and proportion of days with catch (catch success) (lower panel)

3.3. Abundance index

The combination between models (CPUE and success of catches) allowed estimating an annual abundance index, and shows that the population's reduction had been occurring until the mid-1990s (Fig. 8). After a transient stability, in 2006 the population starts a new decline until 2011 and reached the lowest value equivalent to 12% of the CPUE recorded in 1983. The situation occurred in 2012 and referred to the CPUE increase is due to an increase in resource availability within the EEZ. Nevertheless, the overall declining trend has maintained until 2014.

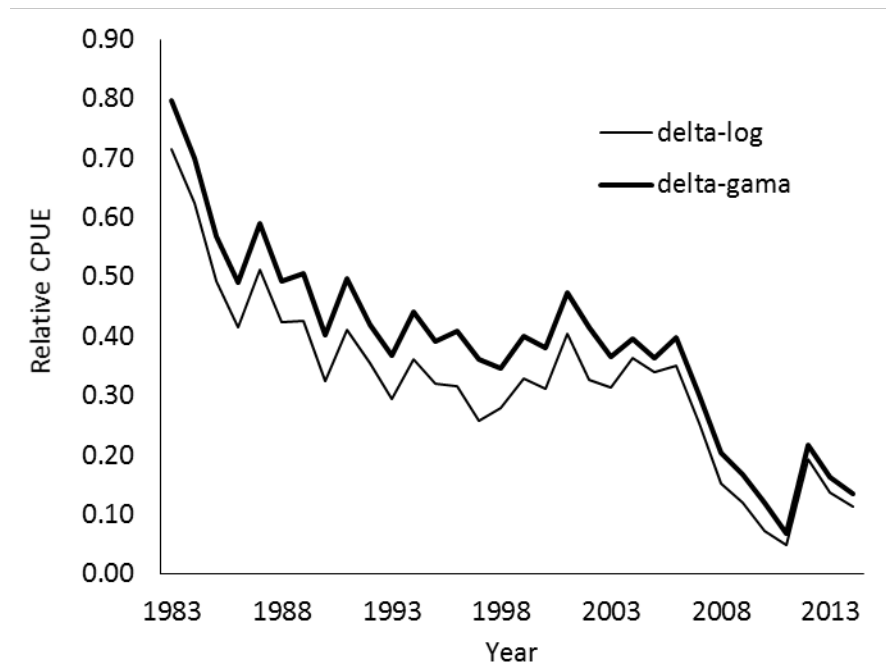


Figure 8. Abundance index of jack mackerel 1983-2014.

4. Discussion

The jack mackerel CPUE as abundance index at center-south area off Chile was updated. The methodology was similar to the one used by Caballero *et al* (2013), who used the daily deployment of hold capacity as an effort unit. In this sense, the days out of port represent in a better way the deployment of fleet capacities to achieve catches, and secondly, the hold capacity generates a measure of pre-standardized effort, because is well known that in in purse seiners, the fishing power is proportional to the hold capacity.

The analysis allowed the identification of the spatial patterns in this fishery, where is observed that the main density of jack mackerel is located north of 38S and within the EEZ, while in terms of capture success, the highest scores are recorded among 100 nm - 200 nm along the entire area of analysis.

Moreover, catch success showed a significant change from around 1999, where the catch success has remained at 96% due to adjustment in the fleet at the end of 90's, and by the enactment of the Fishing Act where the maximum catch per vessel owner was established in 2001. The above situation determined an important reduction in the number of vessels along with the increase in the fleet efficiency, despite that fishing grounds were located farther and with this the increase of number of days out of port between 2008 and 2011.

The abundance signal indicates that jack mackerel after a sharp decline until 1998, remained temporarily stable population levels until 2006, and then experienced a significant reduction in population that has remained to date. Nevertheless the above, the change of scale in CPUE since 2008, should be understood as a change in the catchability of jack mackerel, due that its main fishing areas were concentrated within the EEZ and north of 38°S, area precisely identified with higher density and catch probability.

Finally, and while the abundance index from the acoustic surveys are not improving, the CPUE will continue being the main abundance index in the stock assessment. Due this, it is important to maintain a rigorous analysis in this sense and the statistical modeling is crucial to obtain an adequate index for stock assessment purposes.

5. Bibliography

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