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

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CPUE of Jack mackerel (*Trachurus murphy*) at the center-south area off Chile 1983-2014.

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Summary

In this work, the jack mackerel CPUE is updated via a Generalized Lineal Model based on the purse seine information at the center-south area off Chile. The fishing effort is defined as haul capacity displaced by day out of port, and several factors 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 the population declined steadily until mid 90's. After a transient stability state, since 2006 a faster declination was observed and the stock depletion had reached the lower value equivalent to 12% of the CPUE recorded in 1983. Although a scale change occurred in 2012 due to an increase in the availability/catchability, the population has continued its declining trend until the present.

1. Introduction

The stock assessment of jack mackerel is the most important scientific activity carried out by the Scientific Committee of the South Pacific Regional Fisheries Management Organization (SPRFMO). This activity implies the analysis of several information sets provided by Member States of this organization, such as the Catch per Unit of Effort (CPUE). CPUE is an abundance index that needs to be updated since it gives an important support to stock assessment models in order to precise the population trend, particularly for recent years.

In order to evaluate the CPUE variability, it is necessary to consider an appropriate statistical analysis that allows the exploration of the main factors that determine this variability, such as the year effect, commonly considered as abundance index. In this report, the CPUE modeling work for jack mackerel, corresponding to the purse seine fleet at the center-south area off Chile (Fleet 2) between 1983 and 2014, is informed.

2. Materials and Methods

The fishing logbooks of the purse seine fleet at the center-south area off Chile from 1983 to 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 distance from the coast: 0-100 nm; 101-200 nm; and >200 nm (Fig. 1). Also, the fleet was composed of 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 in base of quarters. The unit of effort corresponds to the haul capacity displaced by days out of port (m3 x dop) and CPUE is the rate between the catch by trip in tons, and the effort unit.

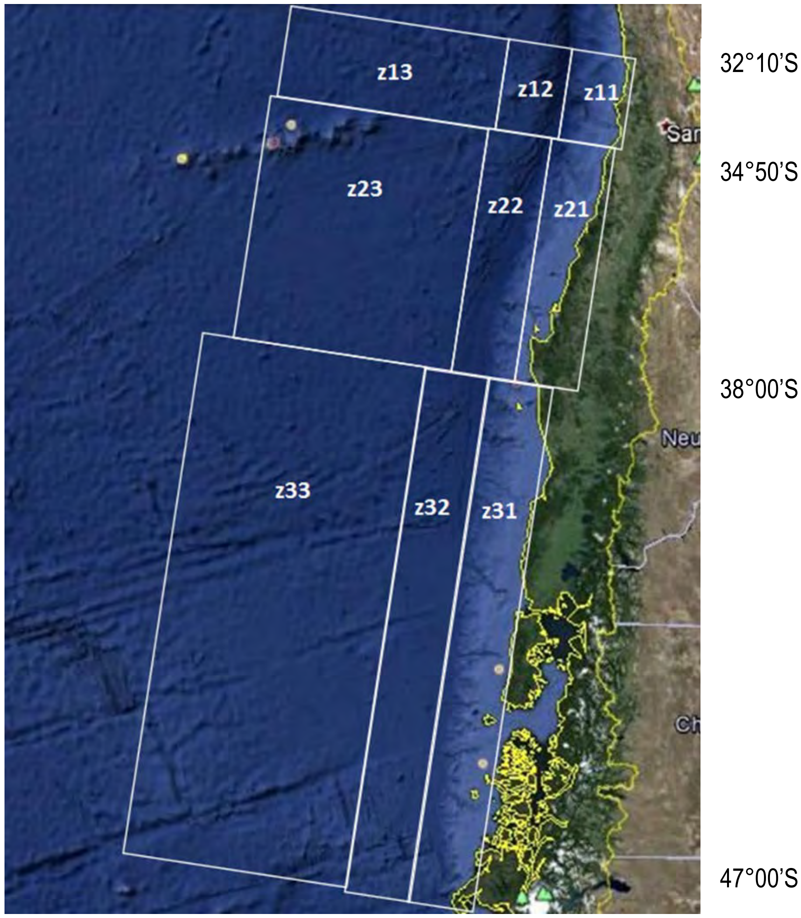


Figure 1. Spatial representation of Jack mackerel fishing zones at the center-south area off Chile.

The CPUE analysis was conducted considering a Lineal Generalized Model (GLM; McCullagh & Nelder, 1989). Following the proposal of Stefánsson (1996), Welsh et al. (1996) and Fletcher et al. (2005), data without catches were analyzed independently from 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:

$$\widehat{CPUE}_y = \widehat{CPUE}_y^{+} * \hat{P}_y \qquad (1)$$

$$+$$
$$CPUE_{y,q,cb,z} \quad (2)$$

$$log$$

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

where $\overset{+}{CP\hat{U}E_y}$ is the annual CPUE (y) for days with catch and $\hat{P}_y$is the annual proportion of these days, also 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. ε and σ 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 at the center-south area off Chile

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

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

$$+= exp\left(c1 + Y_y + 0.5\sigma^2\right)$$
$$CP\hat{U}E_y \quad (4)$$

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

3. Results

3.1. Data exploratory analysis

The nominal CPUE showed a steady decline throughout the analyzed period. While the number of trips declined significantly since 1995, the duration of these gradually increased as a result of the expansion of fishing areas (Table 2). The spatial and temporal distribution of fishing effort indicates that together with an increase of catches, fishing effort gradually covers more remote areas far from the coast and, at mid 90's, the fleet had more participation outside the EEZ in 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, a situation that radically changed in the most recent years when the most important fishing areas were within the EEZ and mainly north of 38° S.

In regard to modeling, examination of the data shows a significant correlation between the logarithm of the CPUE average and the logarithm of the variance of the CPUE, in which the slope statistically has a value of two and the intercept a value of zero (p-value <0.025), suggesting that in the GLM a Gamma link function could be considered as initial candidate (Stefánsson, 1996; Brynjarsdóttir & Stefánsson, 2004). (Fig. 2).

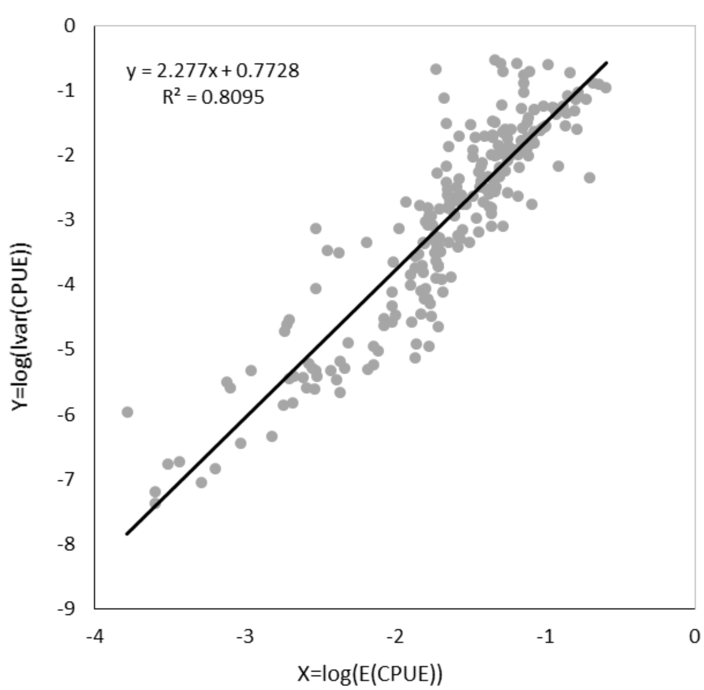


Figure 2. Relationship between log-mean and log-variance of the CPUE of jack mackerel

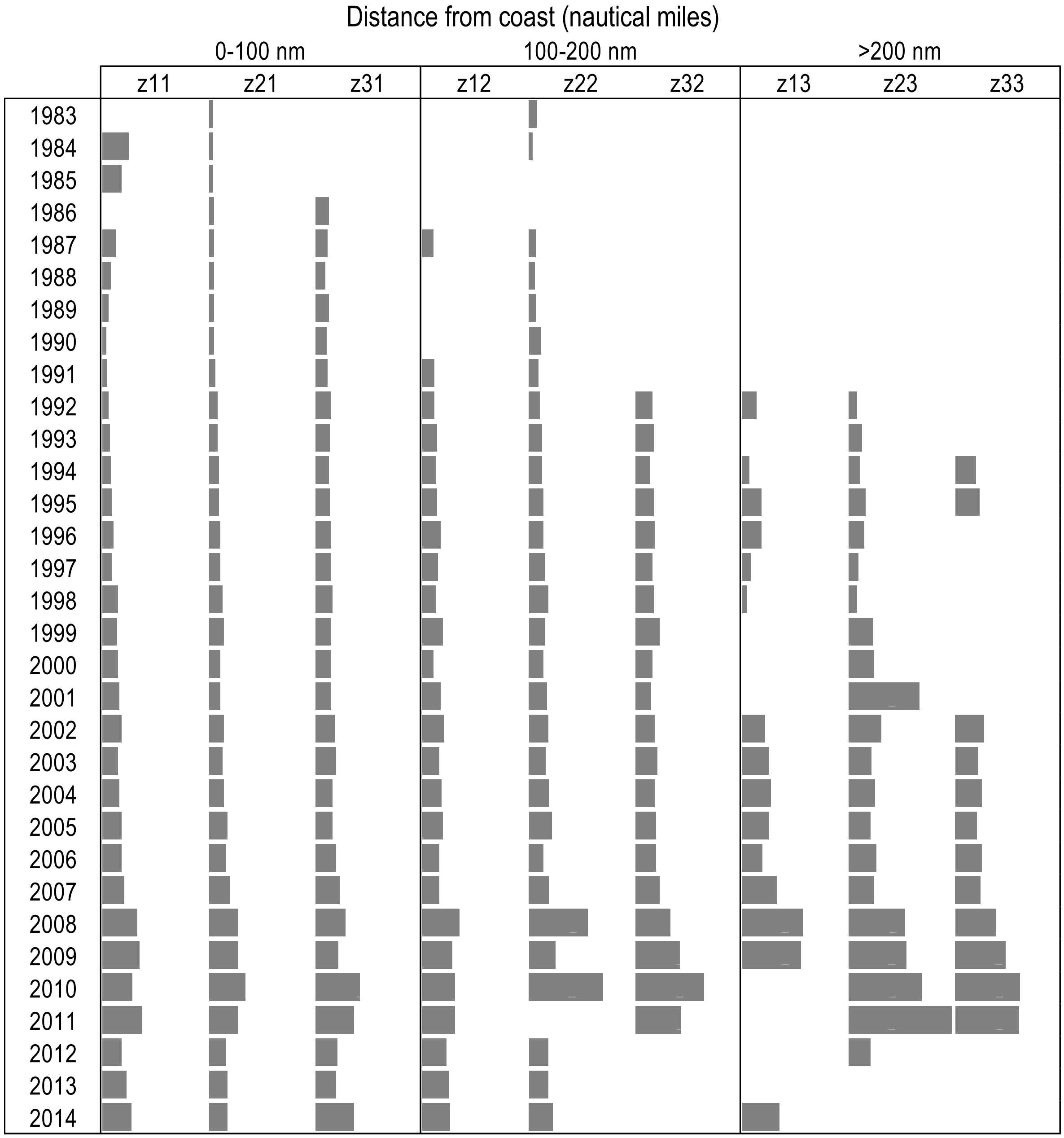
Table 2.

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

Year	Total trips	Trips with catches	Days out 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.

Representation of fishing effort by year and fishing zone. Bars represent the effort's magnitude.



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 than 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 1%.

On the other hand, 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). The year effect was the most important factor but explains only 7% of the total residual deviance. The residual's graph shows that while both models have a symmetric distribution (Fig. 3, 4), in model 2 the overlap of the expected theoretical quantile on the line seems to be higher, ratifying that the best link function in the model is the Gamma function.

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, with CPUE being 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 are located north of 38°S and within the EEZ, while in oceanic areas the highest abundances are located south 34°50´ S (Fig. 5). Regarding the catch success, the highest values are found between 100 and 200 nm, as well as within the 100 nm but south of 38°S. Historically, the zone between 34°50'S and 38°00'S, outside the EEZ, has the lowest probability of success (52%) (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, with the exception of 2012, when the CPUE increased as the result of the operation within the EEZ. Meanwhile, the annual signal of capture success shows three periods: the first from 1983 to 1996 with an average of 70% catch's success; a second period extending from 1997 to 2000 when a sustained increase in catch success occurred; and the third period from 2001 onward 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%

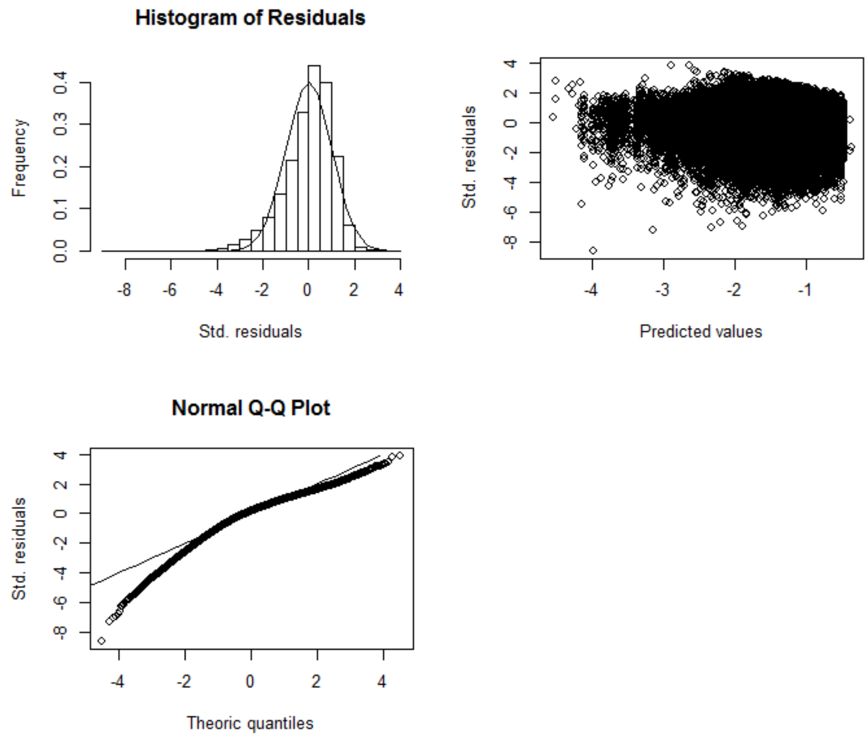


Figure 3. Diagnostic of residuals GLM, CPUE data, Model 1

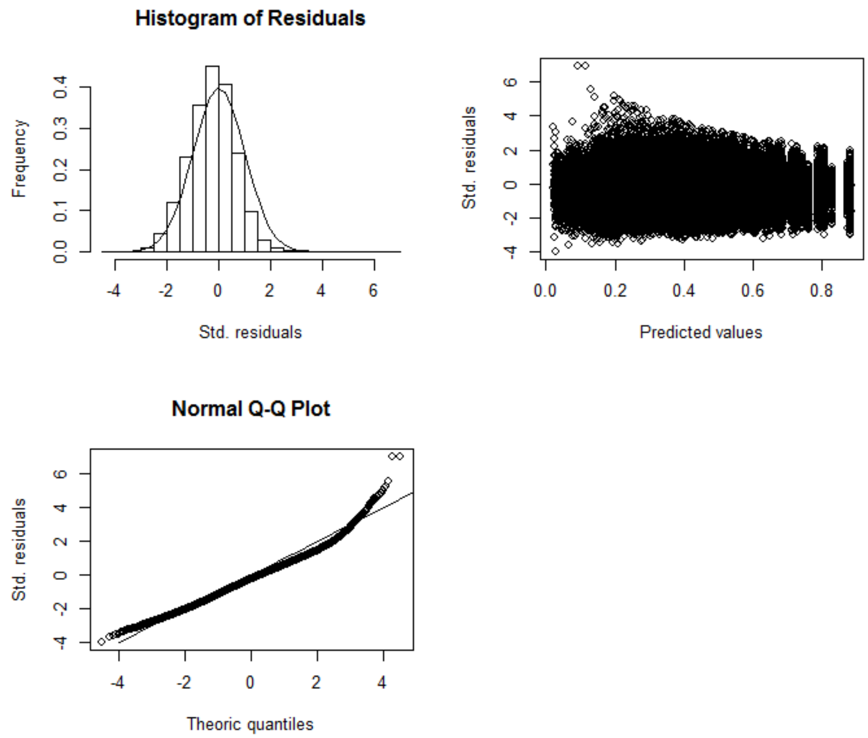


Figure 4. Diagnostic of residuals GLM, CPUE data, Model 2

Table 5.

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

```
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 ***
---
(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 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
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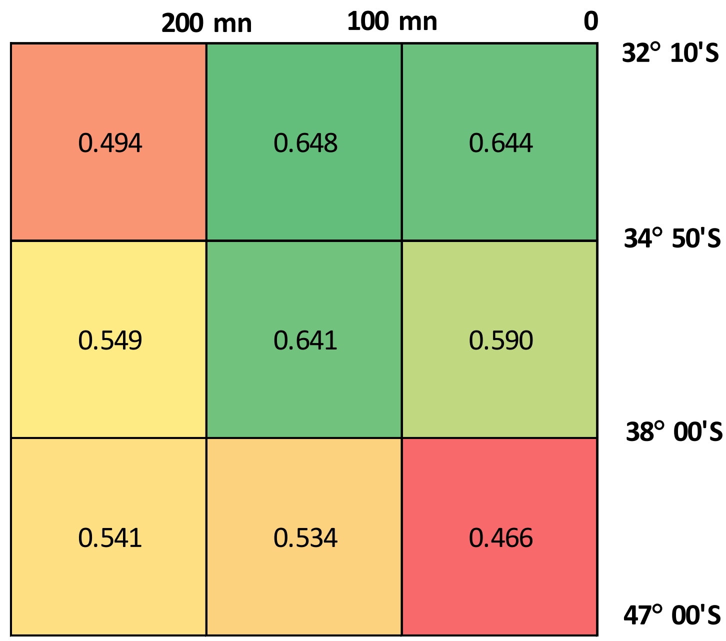

Figure 5. Graphical representation of the area factor in the CPUE model. Green represents highest values and red the lowest values.

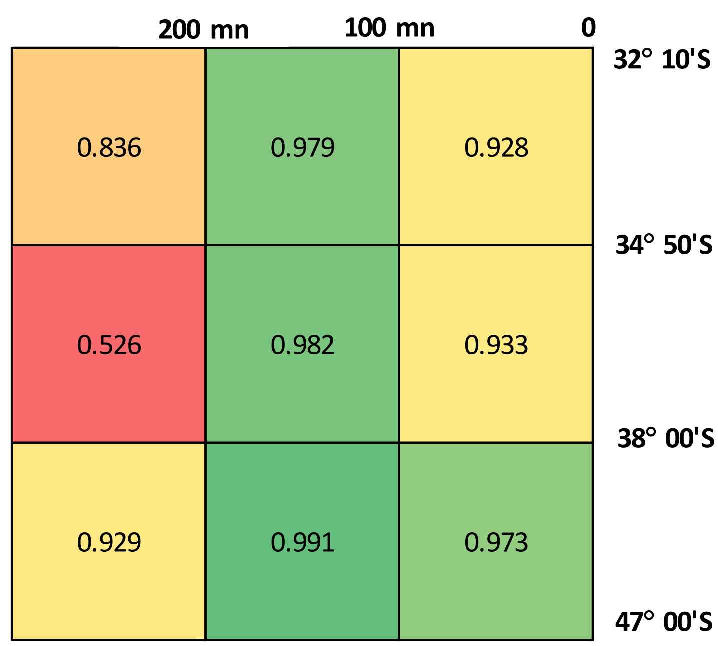

Figure 6. Graphical representation of the area factor in model of catches's success. Green represents highest values and red the lowest values.

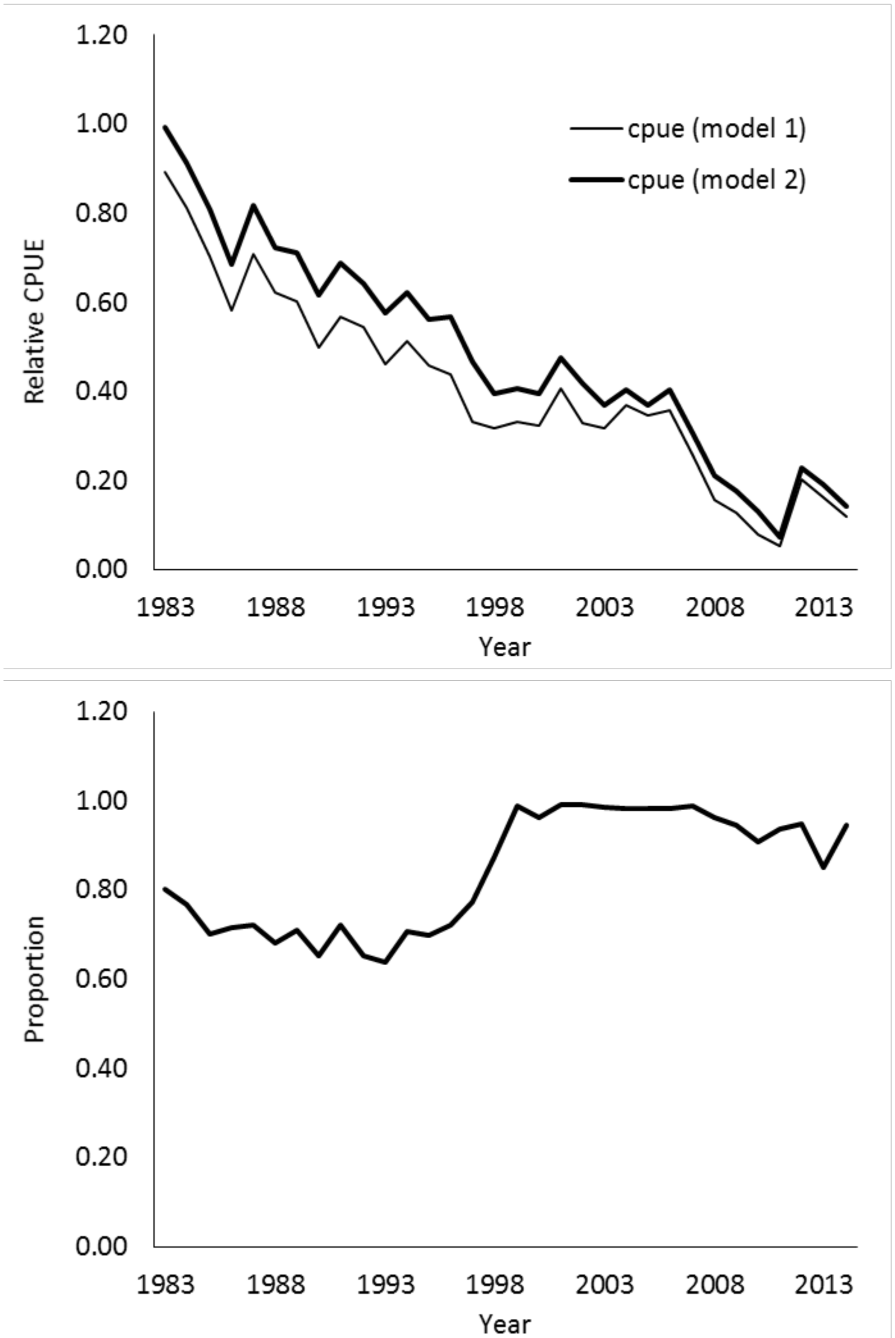

Figure 7. CPUE relative (upper panel) and proportion of days with catch (catch success) (lower panel)

3.3. Abundance index

The combination of models of CPUE and success of catches allowed to estimate an annual abundance index, and showed that the population's reduction had been occurring until the mid 90s (Fig. 8). After a transient stability, in 2006 the population started a new decline until 2011 and reached the lowest value equivalent to 12% of the CPUE recorded in 1983.

The increase of the CPUE occurred in 2012 is the result of an increase in resource availability within the EEZ. Nevertheless, the overall declining trend maintained until the present (i.e. 2014).

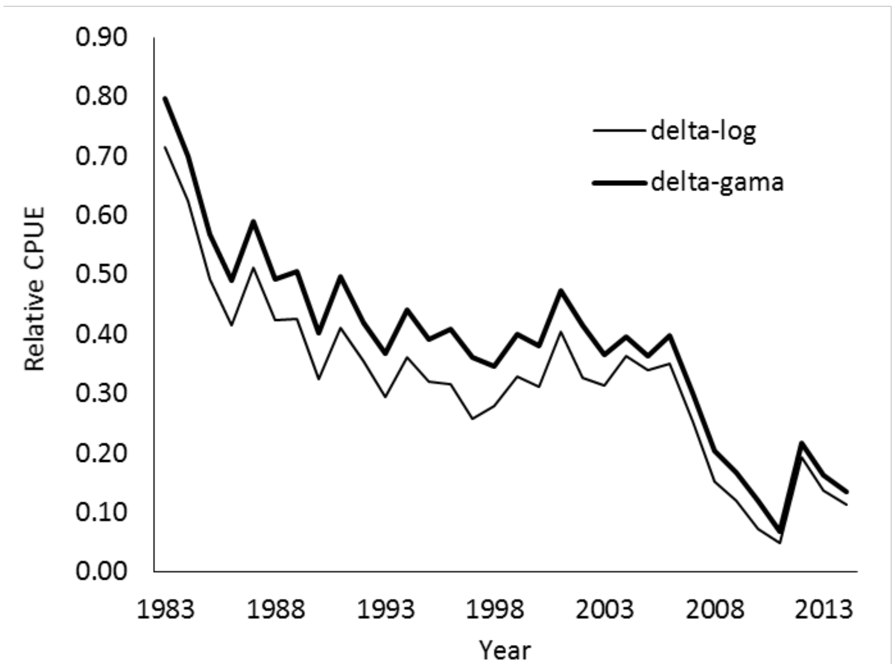

Figure 8. Abundance index of jack mackerel 1983-2014.

4. Discussion

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

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

Moreover, catch success showed a significant change around 2000-2001 when reached values close to 96% due to adjustments in the fleet at the end of the 90's, and also to the enactment of the Fishing Act (2001) which established the measure known as Maximum Catch per Vessel Owner. This situation determined an important reduction in the number of vessels along with the increase in the fleet efficiency, despite the fact that fishing grounds were located farther and the number of days out of port between 2008 and 2011 increased.

The abundance signal indicates that after a sharp decline until 1998, the jack mackerel stock remained temporarily at stable levels until 2006, and then experienced a significant reduction which maintains to date, although an important change in availability was observed in 2012.

5. Bibliography

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