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Analysis of the CPUE in the Jack Mackerel Fishery in centre-southern Chile

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1. Introduction

Between 1981 and 1997, the purse seine fleet of the jack mackerel fishery in the center-south zone of Chile showed a steady growth. It reached a 189-vessel peak, accounting for 130 thousand m^3 of hold capacity. Further adjustments in catches, caused by the stock reduction and new effort control measures, led to a strong reduction of the fleet and the replacement of vessels with larger, more efficient, and more autonomous ones. Up to the late 1990's the fleet was constituted by vessels with hold capacities below 450 m^3, and recorded a high number of trips lasting one day in average. However, as the fleet expanded its area of operation (Figure 1) and further larger well-equipped vessels entered the fleet, trip frequency decreased but longer lasting.

On the other hand, the CPUE is assumed to be proportional to the exploitable abundance, and is often an index used in stock assessment. The lack of indices to adjust the stock assessment model used in the JMSG-SGW-SPRFMO for the most recent years in the center-southern zone is a key issue; in this context, the CPUE series of this fleet has been updated through GLM statistic modeling.

2. Methodology

Daily logbook records of the industrial purse-seine fleet in the center-south of Chile for the years 1981-2011 were analyzed. On the basis of the changes and increases of operation areas of the fleet over time, the studied zone considered three latitudinal strata between 32°10'S and 47°00'S, and three distance ranges from the coast: 0-100nm; 100-200nm; >200nm (Figure 2).

The fleet was grouped into ten hold capacity strata: <250 m3; 250-350 m3; 350-500 m3; 500-600 m3; 600-750 m3; 750-850 m3; 850-910 m3; 910-1100 m3; 1100-1500 m3 and 1500-1850 m3, while the clear seasonality of the fishery allowed stratifying the months of operation, splitting them into quarters: January-March, April-June, July-September, and October-December. The analysis measures the effort as a displaced hold capacity by the days out of port (m3).

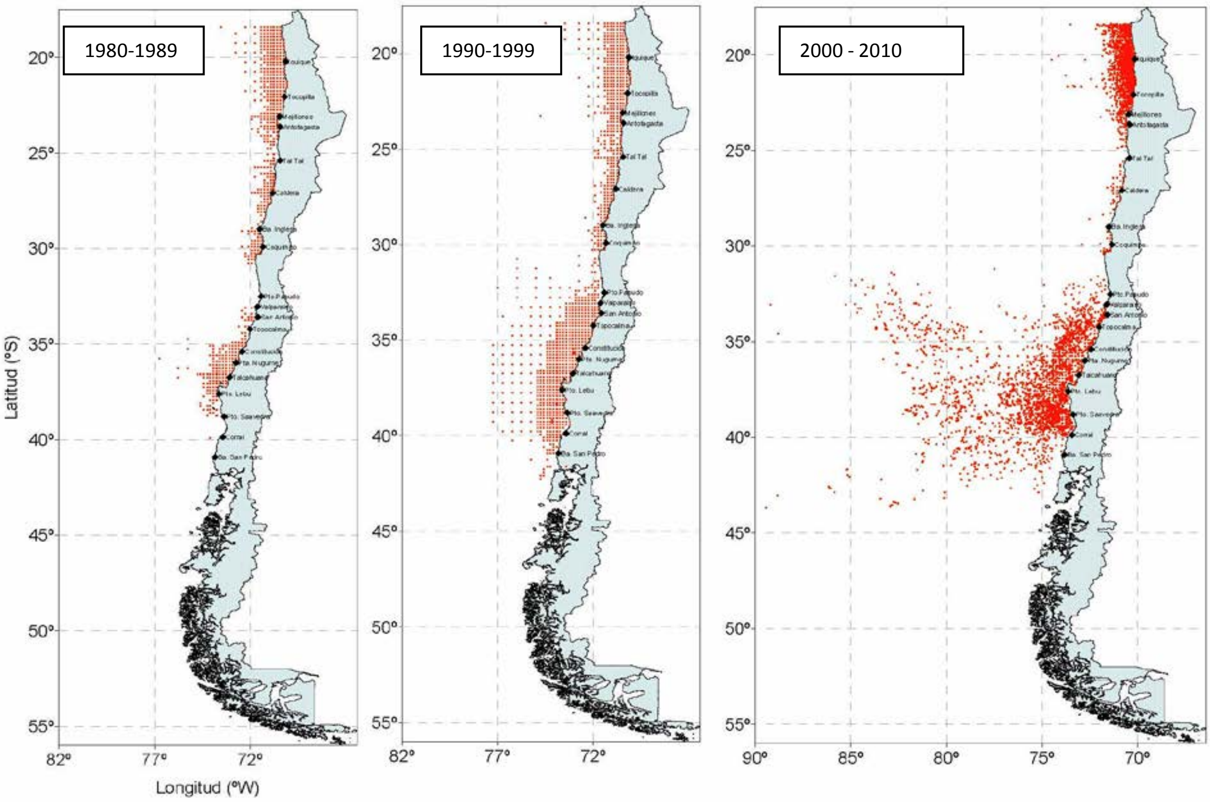

Figure 1. Distribution of the Chilean jack mackerel fishery and its spatial expansion

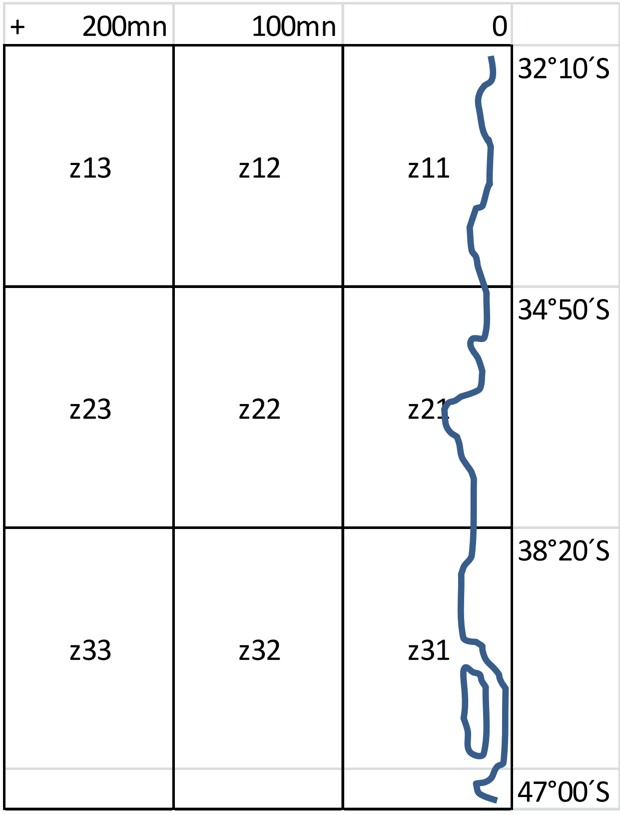

Figure 2. Spatial representation of the stratification of the studied zone

Generalized Linear Models (GLM; McCullagh & Nelder, 1989) were used to standardize the CPUE. Following this approach, CPUE is predicted as a linear combination of explanatory variables, and the ultimate objective is to estimate the annual effect. There are several alternatives for modeling catch rates (CPUE) through GLM; their use depends on the characteristics of the variable to be modeled. In this context, normal delta and delta gamma models were assessed (Pennington, 1983; Ortiz y Arocha, 2004), which allow separated modeling of the successful catch rates and the number of catch successes, where the index is obtained as the product between the proportion of fishing successes and the index estimated for the rates of fishing with catch (Lo et al, 1992) and tweedie models (Dunn y Smyth, 2005; Shono, 2008a; Tascheri *et al.*, 2010), which make possible to model successful catch rates and the number of catch successes jointly. A deviance analysis was conducted to assess the importance of each main effect.

The CPUE with non-zero catch was modeled as:

$$\ln(CPUE)_{i,j,k,l} = g^{-1}(\mu + \alpha_i + \beta_j + \gamma_k + t_l + \varepsilon_{i,j,k,l}) \quad (1)$$

Where g is the link function, μ is the intercept, α_i is the year factor, β_j is the quarter, γ_k is the zone factor, t_l is the hold range factor, and $\varepsilon_{i,j,k,l}$ is the random error component.

As a mean to incorporate trips without catch, it was modeled a catch success probability (p), which corresponds to the quotient between days with non-zero catch and total days fishing for jack mackerel. The model follows a binomial distribution and a "Logit" link function is used to relate *p* with the predictors.

$$\ln\left(\frac{p}{1-p}\right)_{i,j,k,l} = \mu' + \alpha'_i + \beta'_j + \gamma'_k + t'_l + \varepsilon'_{i,j,k,l} \qquad (2)$$

Where μ' is the intercept; α'_i the year factor; β'_j the quarter; γ'_k the zone factor; t'_l the hold range factor; and $\varepsilon'_{i,j,k,l}$ the random error component. Thus, the annual value of the CPUE corresponds to the product between the expected CPUE for non-zero catch and the probability of catch success (p).

3. Results

Three CPUE model series, which are likely to be used in the stock assessment, are presented. The results of the deviance analysis indicate that all the factors were significant, where the factor Year presents the highest level of explanation to the deviance (Table 1, 2 and 3). The residuals behavior and coefficient estimates for the best model (Gamma) are shown in Table 4 and Figure 3.

The proportion of days out of port, or catch success, shows a significant increasing tendency from 1995 to 1999, as a consequence of the higher efficiency of the fleet in response to the depletion of the resource and the gradual movement of fishing grounds further away, followed by a stable period in which 98% of trips registered fishing (Figure 4). Figure 5 and Table 5 provides CPUE performance as an index of biomass for three GLM models, which present a slight difference on scale, but maintain a similar tendency in terms of its behavior pattern.

Table 1.

Percentage of deviance explained by each factor in each fitted model (CPUE).

	G.L.	Binomial R^2 : 13 %	Lognormal R^2 : 18 %	Gamma R^2 : 20 %	Poisson (composite) R^2 : 15 %
Year	30	30.6	78.8	82.4	81.9
Quarter	3	11.8	15.9	9.1	10.7
Hold Capac.	9	13.4	3.7	6.2	3.3
Zone	9	44.2	1.5	2.3	4.1

Table 2.

Deviance analysis based on a Gamma link function (for non-zero catch data)

	Df	Res.Dev	delta dev.	% dev. Expl	AIC	p-value
Cte	1	153600	-	-	37751	-
Year	30	128078	25521	82.4	7291	< 0,001
Quarter	3	125262	2816	9.1	3605	< 0,001
Hold Capac.	9	123345	1917	6.2	1067	< 0,001
Zone	9	122635	710	2.3	130	< 0,001

Table 3.

Deviance analysis for catch success (proportions of non-zero catch data)

	Df	Res.Dev	delta dev.	% dev. Expl	AIC	p-value
Cte	1	248652	NA	NA	248654	-
Year	30	238839	9813	30.6	238901	< 0,001
Quarter	3	235069	3770	11.8	235137	< 0,001
Hold Capac.	9	230782	4287	13.4	230868	< 0,001
Zone	9	216612	14170	44.2	216716	< 0,001

Table 4.

Coefficient of GLM for a Gamma link function

Parameter	Estimate	Std. Error	t value	Pr(>|t|)	Parameter	Estimate	Std. Error	t value	Pr(>|t|)
(Intercept)	-0,622489	0,396658	-1,569	0,11657	Cat.quarter2	0,099155	0,005994	16,542	< 2e-16
Cat.year1982	0,399195	0,397276	1,005	0,31498	Cat.quarter3	-0,072897	0,006518	-11,184	< 2e-16
Cat.year1983	0,40428	0,396036	1,021	0,30734	Cat.quarter4	-0,365925	0,007723	-47,379	< 2e-16
Cat.year1984	0,318399	0,396063	0,804	0,42145	Cat.holdCap2	-0,004881	0,010299	-0,474	0,63553
Cat.year1985	0,200597	0,396054	0,506	0,61251	Cat.holdCap3	-0,059624	0,009616	-6,2	5,65E-10
Cat.year1986	0,036531	0,396044	0,092	0,92651	Cat.holdCap4	-0,204946	0,01274	-16,087	< 2e-16
Cat.year1987	0,207792	0,396053	0,525	0,59982	Cat.holdCap5	-0,244819	0,010939	-22,381	< 2e-16
Cat.year1988	0,098822	0,396069	0,25	0,80297	Cat.holdCap6	-0,398467	0,014973	-26,612	< 2e-16
Cat.year1989	0,083485	0,396074	0,211	0,83306	Cat.holdCap7	-0,371991	0,015805	-23,537	< 2e-16
Cat.year1990	-0,073743	0,396063	-0,186	0,8523	Cat.holdCap8	-0,322027	0,013084	-24,612	< 2e-16
Cat.year1991	0,039792	0,396081	0,1	0,91998	Cat.holdCap9	-0,43411	0,013596	-31,93	< 2e-16
Cat.year1992	-0,031794	0,396115	-0,08	0,93603	Cat.holdCap10	-0,475743	0,015738	-30,23	< 2e-16
Cat.year1993	-0,15425	0,396127	-0,389	0,69698	Cat.zone11	0,077857	0,026277	2,963	0,00305
Cat.year1994	-0,081207	0,396131	-0,205	0,83757	Cat.zone12	-0,011755	0,032067	-0,367	0,71395
Cat.year1995	-0,172646	0,396131	-0,436	0,66296	Cat.zone13	-0,339881	0,04277	-7,947	1,93E-15
Cat.year1996	-0,164705	0,396169	-0,416	0,6776	Cat.zone21	-0,016107	0,024995	-0,644	0,51929
Cat.year1997	-0,363854	0,39615	-0,918	0,35837	Cat.zone22	-0,030679	0,027542	-1,114	0,26533
Cat.year1998	-0,53894	0,396298	-1,36	0,17385	Cat.zone23	-0,218583	0,032814	-6,661	2,72E-11
Cat.year1999	-0,471733	0,396428	-1,19	0,23406	Cat.zone31	-0,248363	0,025686	-9,669	< 2e-16
Cat.year2000	-0,504245	0,396435	-1,272	0,20339	Cat.zone32	-0,235791	0,033056	-7,133	9,87E-13
Cat.year2001	-0,278889	0,39645	-0,703	0,48177	Cat.zone33	-0,289752	0,034888	-8,305	< 2e-16
Cat.year2002	-0,470158	0,396525	-1,186	0,23574					
Cat.year2003	-0,592741	0,396588	-1,495	0,13502					
Cat.year2004	-0,512878	0,396631	-1,293	0,19598					
Cat.year2005	-0,605167	0,396751	-1,525	0,12718					
Cat.year2006	-0,513304	0,396823	-1,294	0,19583					
Cat.year2007	-0,789226	0,396823	-1,989	0,04672					
Cat.year2008	-1,162,641	0,397485	-2,925	0,00345					
Cat.year2009	-132,549	0,397309	-3,336	0,00085					
Cat.year2010	-1,601,242	0,399304	-4,01	6,07E-05					
Cat.year201	-2,169,451	0,398504	-5,444	5,22E-08					

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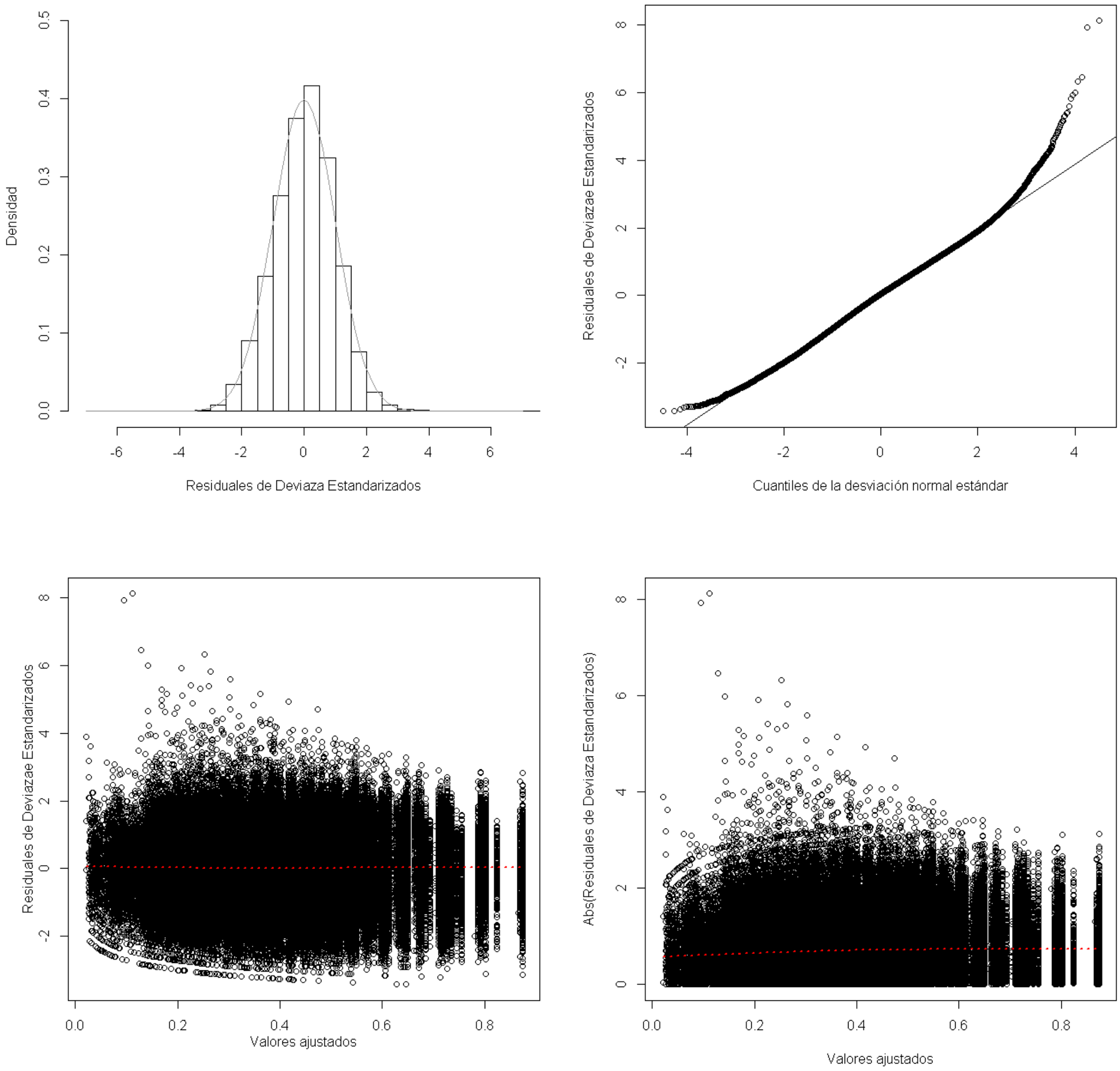

Figure 3. Behavior of residuals in a GLM based on a Gamma link function.

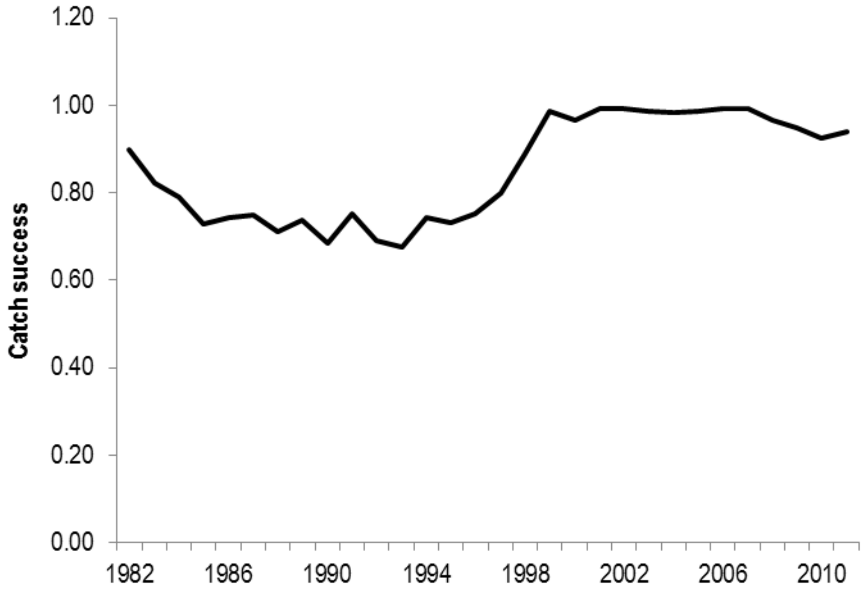

Figure 4. Proportion of days out of port with catches (catch success) of jack mackerel in the center-southern zone of Chile.

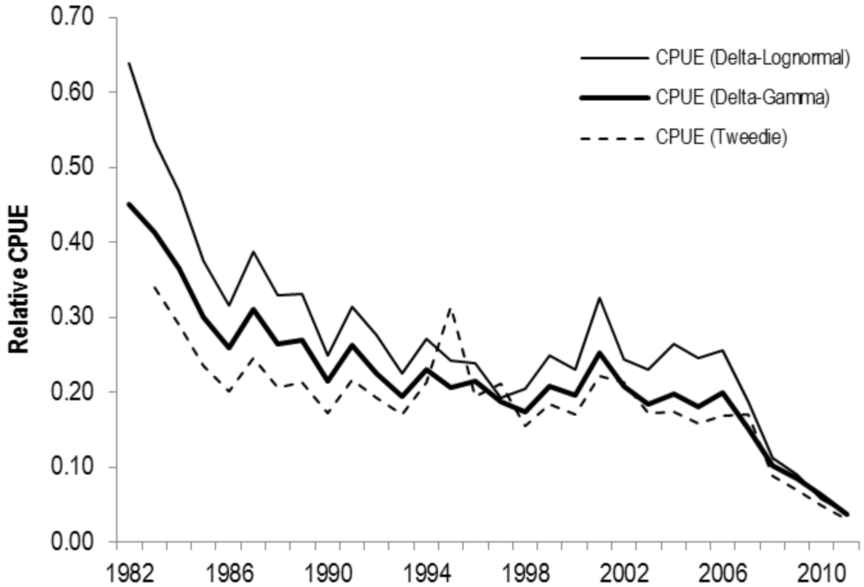

Figure 5. CPUE of jack mackerel in the south-center zone of Chile for three GLM models

The three indices show that the exploitable population or stock of the resource steadily declined until 1998, followed by a slight stabilization and recovery up to 2006. The situation of the last five years reveals a significant decline of the CPUE, as a response to the clear population depletion and is consistent with what had been observed in the fishery. Regarding the indices, there are no comparative advantages between the one or the other; therefore, considering the flexibility of the gamma distribution, the delta-gamma model is proposed to be used for stock assessment.

Table 5.

Expected proportion of non-zero catches (catch success), and the CPUE (delta model) for each GLM.

Year	Catch success (p)	CPUE (Delta-Lognormal)	CPUE (Delta-Gamma)	CPUE (Tweedie)
1982	0.899	0.639	0.450	-
1983	0.821	0.534	0.413	0.339
1984	0.790	0.468	0.365	0.290
1985	0.730	0.376	0.300	0.235
1986	0.742	0.316	0.259	0.201
1987	0.748	0.387	0.310	0.246
1988	0.712	0.330	0.264	0.206
1989	0.738	0.332	0.270	0.213
1990	0.685	0.250	0.214	0.171
1991	0.752	0.313	0.263	0.216
1992	0.691	0.276	0.225	0.193
1993	0.676	0.225	0.195	0.170
1994	0.742	0.272	0.230	0.212
1995	0.730	0.242	0.207	0.314
1996	0.751	0.239	0.214	0.194
1997	0.800	0.192	0.187	0.211
1998	0.890	0.205	0.174	0.155
1999	0.987	0.249	0.207	0.183
2000	0.965	0.230	0.196	0.170
2001	0.991	0.325	0.252	0.221
2002	0.992	0.244	0.208	0.213
2003	0.986	0.229	0.183	0.173
2004	0.985	0.264	0.198	0.174
2005	0.985	0.246	0.181	0.158
2006	0.993	0.255	0.200	0.169
2007	0.991	0.187	0.151	0.170
2008	0.966	0.112	0.102	0.088
2009	0.948	0.089	0.085	0.070
2010	0.924	0.058	0.063	0.049
2011	0.940	0.039	0.036	0.029

4. Conclusions

CPUE modeled in terms of the catch per displaced hold capacity by day reflects the decline of the jack mackerel stock, which started in the early 80s. Nonetheless, an apparent recovery of the population or an improved efficiency allowed stability in the indices between 1998 and 2006, to further show a rapid decline up to the most recent year

5. References

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