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GROWTH PARAMETERS AND MORTALITY RATE OF THE *SCOMBER JAPONICUS PERUANUS* (JORDÁN & HUBB, 1925) ALONG THE PERUVIAN COAST, SOUTH PACIFIC

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ABSTRACT

The growth parameters and the mortality rates of the *Scomber japonicus peruanus* (Chub mackerel) were studied based on monthly data of frequency of fork length classes obtained from commercial landings off the Peruvian coast from 1996 to 1998. The asymptotic body length and growth rate values obtained by the ELEFAN I (Electronic Length Frequency Analysis) ranged from 40.20 cm to 42.20 cm and from 0.38 to 0.39, respectively. The oscillation amplitude was 0.60; the Winter point values varied from 0.50 to 0.60 and the performance index from 2.79 to 2.84. The total mortality rate of the Chub mackerel obtained by the linearized catch curve oscillated between 1.68 and 3.35. The rate of fishing mortality varied from 1.16 to 2.78 and the exploitation rate from 0.68 to 0.84. The annual rate of natural mortality estimated by the Pauly's method ranged from 0.52 to 0.53. The results obtained allow us to conclude that the longevity of the Chub mackerel was slightly over seven years.

RESUMO

Os parâmetros de crescimento e as taxas de mortalidade de *Scomber japonicus peruanus* (cavalinha) foram estudados a partir de dados mensais de freqüência de classes de comprimento provenientes do desembarque comercial ao longo da costa peruana no período de 1996 a 1998. Os valores do comprimento furcal assintótico e da taxa de crescimento obtido pelo ELEFAN I(Electronic Length Frequency Analysis) variaram de 40,20 cm a 42,20 cm e de 0,38 a 0,39, respectivamente. A amplitude de oscilação foi de 0,60; os valores de Winter point variaram de 0,5 a 0,6 e os do índice de performance entre 2,79 e 2,84. As taxas de mortalidade total da cavalinha obtidas pela análise da curva de captura linearizada oscilaram entre 1,68 e 3,35, sendo as variações das taxas de mortalidade por pesca e explotação de 1,16 a 2,78 e 0,68 a 0,84, respectivamente. A taxa anual de mortalidade natural estimada pelo método de Pauly variou de 0,52 a 0,53. Os resultados obtidos permitem inferir que a longevidade da cavalinha foi de pouco mais de sete anos.

Descriptors: Scombridae, Chub mackerel, Growth, Mortality rate, South-Pacific.
Descritores: Scombridae, Cavalinha; Crescimento; Taxa de mortalidade, Pacífico Sul.

INTRODUCTION

Studies of age, growth, mortality rate and exploitation rate are crucial for stock assessment (DULCIC et al., 2007). The growth parameters and the mortality rate are important tools to assessment the exploitation level of the pelagic species (CADIMA, 2000). However, fish stock assessment should be carried out for each stock separately, since an essential characteristic of a stock is that its population parameters remain constant throughout its area of distribution (KAMUKURU et al., 2005; WANG; LIU, 2006). *Scomber japonicus peruanus* "Chub mackerel" is a coastal pelagic species of the Scombridae family that has a wide distribution in the South Pacific Ocean, especially in the coastal waters of Costa Rica, Peru, Chile and Equator, including the Galapagos Island (CHIRICHIGNO; VÉLEZ, 1998).

The distribution of the Chub mackerel in the Peruvian sea is associated with Equatorial Surface Water (DIOSES et al., 2002), being their main spawning ground located to the northern-central region (SANTANDER; FLORES, 1983, CARAMANTÍN, 2001). This species is considered one of the most important fishery resources for the Peruvian economy (IMARPE & ITP, 1996). However, in spite of its widespread occurrence in the Peruvian waters and economic importance, very little is known about the dynamic population of *S. japonicus peruanus*. There are also few studies on growth and mortality of this

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species from off the Peruvian coast (MIÑANO; CASTILLO, 1971; MENDO, 1984; CARAMANTÍN, 2006).

The purpose of this study was to provide information on growth parameters and the mortality rate of *S. japonicus peruanus* along the Peruvian coast from 1996 to 1998.

MATERIAL AND METHODS

The growth parameters and the mortality rates of the *S. japonicus peruanus* (Chub mackerel) were studied based on monthly data of frequency of fork length classes obtained from commercial landings along the Peruvian coast (3°23'S-18°20'S and 72°W-84°W) from 1996 to 1998, within the project "Tracking of pelagic resources off the Peruvian coast", which is being carried out at the "Instituto del Mar del Perú - IMARPE" (Fig. 1). The Sea Surface Temperature (SST) was recorded in situ at each one of the sampling areas with a bucket thermometer.

The specimens were caught with industrial purse seine vessel, using mesh sizes of 38 mm. Each time, a random sample of around 40 kg was taken from a vessel before the catch was sorted and landed. The fork length of each individual was measured to the nearest cm and pooled in 1 cm length classes.

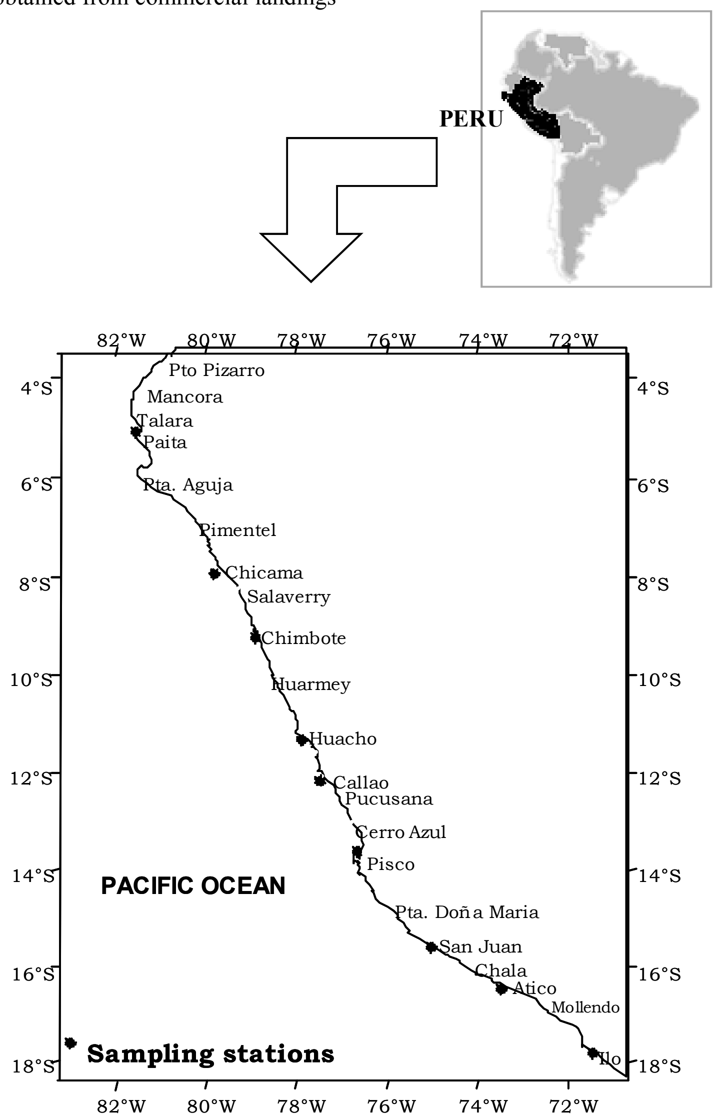

Fig. 1. Location of sampling stations along the Peruvian coast.

The length frequency samples were raised to monthly catch for each sampling area which were summed to account for the total length frequency distribution of the month for the entire area.

The growth rate (*K*) and the asymptotic length fork (Lf_∞) were estimated using the ELEFAN I method (Electronic Length Frequency Analysis), which estimated the parameters of the von Bertalanffy growth curve as a function of the seasonality (PAULY; GASCHUTZ, 1979):

$$Lf = Lf_\infty \{1\text{-}exp\,[-K.\,(t\text{-}to)\text{-}(\frac{CK}{2\pi}).\,(\text{sen}\,2\,\pi\,.(t\text{-}ts))]\}$$

where: Lf_∞ = asymptotic fork length; *K*= growth rate; t_o = theoretical age of fish at zero length; *C* = growth oscillation "amplitude", related with environmental temperature of winter and summer; Winter point (*Wp*) = period of the year where the fish growth is lowest.

The theoretical age at which the fish has mean length zero (t_o) was estimated by Pauly's (1979) formula:

$$log\,(-t_o) = -0.392 - 0.275\; log.\, Lf_\infty - 1.038\; log\, K$$

The Index of growth performance (ϕ) (PAULY; MUNRO, 1984) was calculated using the following equation: $\phi = log\,K + 2\,log\,Lf_\infty$; where: Lf_∞ and *K* are the growth parameters of the von Bertalanffy equation.

The total mortality (*Z*) was estimated by means of the catch curve based on fork length frequency class, converted into age groups, and the growth parameters Lf_∞ and K of von Bertalanffy's curve (SPARRE; VENEMA, 1997). The equation utilized was:

$$Ln\,C\,\frac{(Lf_1,Lf_2)}{\Delta t\,(Lf_1,Lf_2)} = C - Z\,t\,\frac{(Lf_1 + Lf_2)}{2}$$

where: *C* is the number of the specimens caught in determined length range; *Z* is the total mortality and Δt the mean time in which the fish grows since the fork length Lf_1 to Lf_2.

The natural mortality (*M*) was estimated using the Pauly's (1980) empiric formula: $M = 0.8\,exp\,[-0.0152 - 0.0279\,Ln\,Lf_\infty + 0.6543\,Ln\,K + 0.463\,ln\,T]$; where: *T* is the annual mean water temperature value, which was 17°C for the given sampling area.

Fishing mortality (*F*) was estimated from the difference between the total mortality (*Z*) and the natural mortality (*M*). The exploitation rate (*E*) was calculated as a function of: $E = F/Z$ (SPARRE; VENEMA, 1997).

The Chub mackerel longevity was obtained using the Pauly and Munro (1984) equation: $T_{max.} = 3/K$; where *K* is the growth rate.

Results

The Sea Surface Temperatures (*SST*) recorded during the period of the study ranged from 16.06 (1996) to 25.90ºC (1998), being higher in June and December 1997 and January-April 1998, and lowest in June-October 1996 and September-November 1998. Similar values of SST were registered in January-February 1996 and 1997 (Fig. 2).

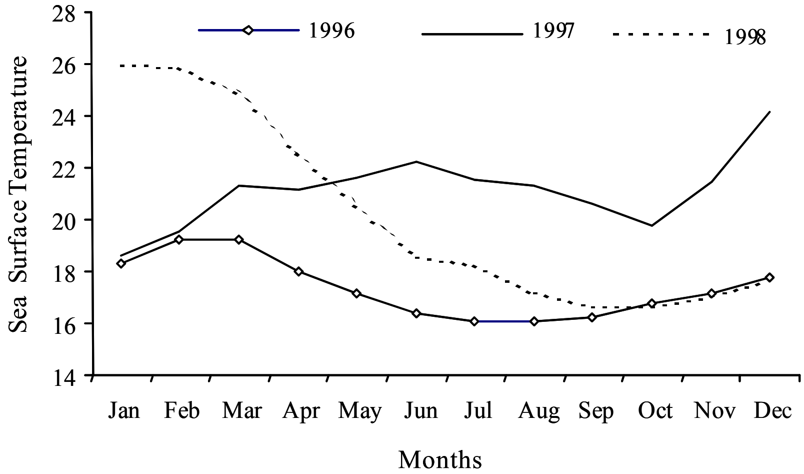

Fig. 2. Monthly values of the Sea Surface Temperature in the Peruvian coast from 1996 to 1998.

A total of 3 363 361 specimens of *S. japonicus peruanus*, ranging from 10 cm to 39 cm *FL* were collected between January 1996 and December 1998 (Table 1).

The values of the asymptotic length (Lf_{∞}) and the growth rate (K) varied from 40.20 cm to 42.20 cm, and from 0.38 to 0.39, respectively. The results obtained showed that the oscillation amplitude was 0.60. The Winter point values varied between 0.5 and 0.6, whereas the performance index ranged from 2.79 to 2.84 (Table 2).

The growth curves indicated the presence of seven complete cohorts and one cohort constituted by a few months. Assuming that each cohort corresponds to one year old, it is possible to suggest that the Chub mackerel longevity is slightly over 7 years (Fig. 3).

Tabela 1. Monthly catch at fork length class values of *S. japonicus peruanus* from 1996 to 1998.

Length class	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
10								38		22	58	
11								153		136	360	2
12								115	11	460	1092	33
13								38	11	2325	2717	201
14						1	2	0	11	2765	4704	282
15		1	5			22	26	73	11	1440	9104	466
16	3	149	12	2	42	3	93	174	404	352	7185	942
17	2062	208	86	11	1092	1508	62	423	96	244	7487	1592
18	3993	442	322	40	539	1596	189	530	259	361	4861	3314
19	85	936	486	50	600	1835	548	396	310	606	2785	4640
20	728	1045	299	27	332	1121	793	789	1186	1323	2969	6756
21	2072	1165	96	34	674	1129	959	1159	3003	2694	6165	11675
22	1419	1368	37	166	431	1298	933	757	4679	3252	16416	15139
23	1983	831	168	741	464	674	2388	963	2936	3619	13261	25265
24	5288	2057	672	3229	591	982	3772	2576	4929	5825	11087	24553
25	2546	7712	2017	4407	913	2584	7258	9845	9614	9595	93675	31315
26	12713	38205	7164	5837	3893	4602	10527	22769	24963	23622	82752	46468
27	96081	75009	10091	6268	9118	6873	12204	36998	49405	47288	93518	88572
28	115092	72457	8727	5083	11951	9107	10593	40358	62284	60587	173766	146703
29	59537	45393	4101	4306	8537	5482	4897	33831	48303	63029	217537	93492
30	20402	22090	1597	2596	4283	2062	1666	18177	25614	36638	252073	52592
31	5418	11547	683	1390	2225	1358	1335	10858	13970	16993	78006	19460
32	2660	7290	470	897	1135	1311	614	6290	9879	11083	49984	10995
33	1510	3678	243	410	628	619	140	3576	5562	5047	18644	3378
34	359	1322	125	118	198	172	77	1483	2142	2187	2113	2879
35	60	538	39	24	18	98	35	400	869	749	425	83
36	51	267	7			19		43	519	482	388	21
37	111	69							117	125	67	38
38	60	3							33	45	5	
39	15	7	7						22		90	
Total	334247	293789	37453	35636	47663	44458	59111	192814	271141	302896	1153296	590856
Standard deviation	70873	60435	8015	7700	10445	9329	12855	41233	54839	62274	232353	123347

Table 2. Growth parameters of *S. japonicus peruanus* obtained by ELEFAN I method from 1996 to 1998. Asymptotic fork length (Lf_{∞}); growth rate (K); growth oscillation Amplitude (C); Winter point (Wp); growth performance index (ϕ); sample size (n).

Years	Lf_{∞}	K	C	Wp	ϕ	Sample size
1996	40.20	0.38	0.60	0.60	2.79	n =178067
1997	42.20	0.39	0.60	0.50	2.84	n =720608
1998	41.50	0.39	0.60	0.5	2.83	n =2464686
Mean	41.30	0.39	0.60	0.53	2.82	n =3363.361
Standard Deviation	1.01	0.01	0.00	0.06	0.03	

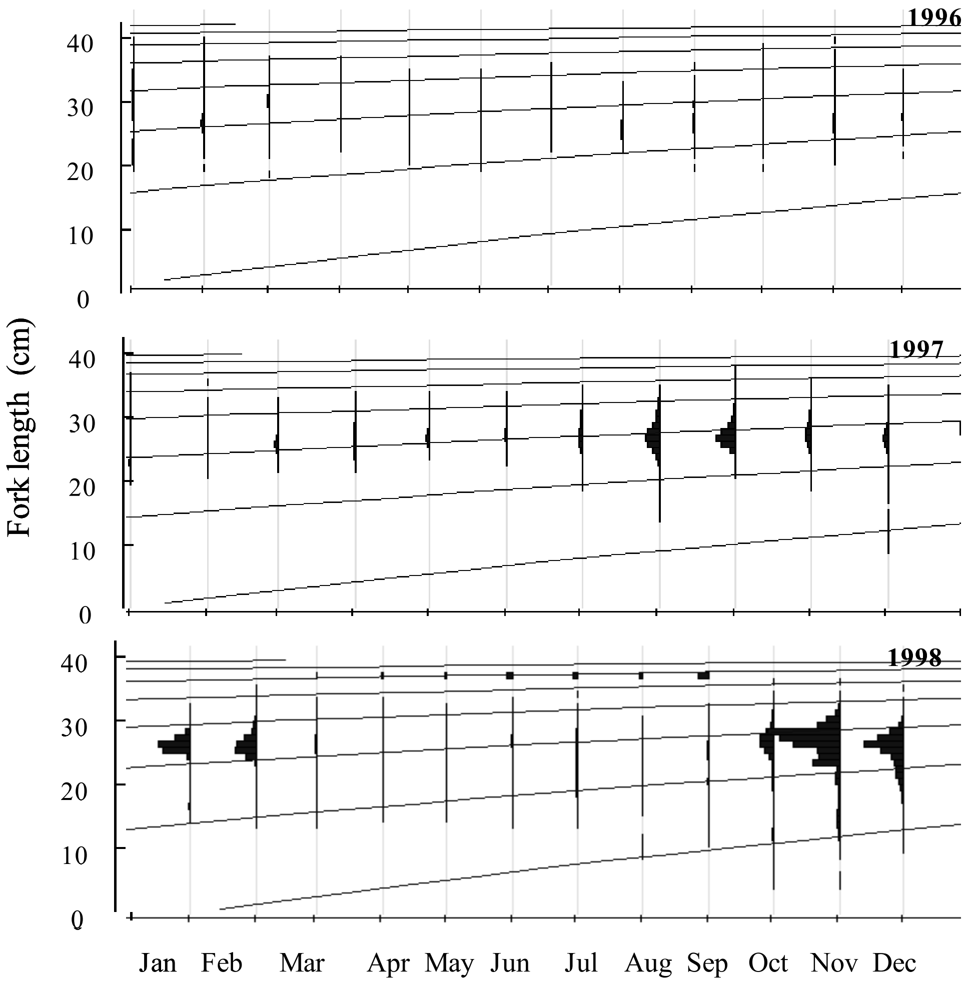

Fig. 3. Growth curves of *S. japonicus peruanus* estimated by ELEFAN I method from 1996 to 1998.

During the study period 1996-1998, the age at which the Chub mackerel had length zero (t_o) was -0.39 year to -0.40 year (Table 3). The results also showed that the total mortality of the species obtained from the linearized catch curve ranged from 1.68 to 3.35, being the mean value 2.53 (Table 4). However, the natural mortality annual rate (M) estimated by Pauly's empiric formula oscillated between 0.52 and 0.53 (Table 4).

The fishing mortality rate (F) of the Chub mackerel estimated on annual basis, varied from 1.16 to 2.78, being the mean value 2. In contrast, the exploitation rate (E) ranged from 0.68 to 0.84, with mean value 0.77 (Table 4).

The mean longevity of the Chub mackerel estimated by Pauly's method from the period 1996 to 1998 was 7.77 years (Table 4).

Table 3. Theoretical annual age values at length zero (*to*) of *S. japonicus peruanus* from 1996 to 1998.

Years	t_o
1996	-0.40
1997	-0.39
1998	-0.39
Mean	-0.39
Standard Deviation	0.01

Table 4. Total annual (Z), natural (M), fishing (F), exploitation (E) mortality rates and longevity of *S. japonicus peruanus* from 1996 to 1998.

Years	Z	M	F	E	Longevity
1996	1.68	0.52	1.16	0.68	7.90
1997	2.56	0.52	2.13	0.80	7.70
1998	3.35	0.53	2.78	0.84	7.70
Mean	2.53	0.52	2.00	0.77	7.77
Standard Deviation	0.84	0.01	0.82	0.08	0.12

DISCUSSÃO

Growth is an increase of body size resulting from production of new tissues. This process during a particular period result in formation of growth marks on hard parts of the fish species: scales, opercula bones, spines, vertebrae, teeth and otoliths (BERTALANFFY, 1957; BEAMISH; MCFARLANE, 1983; CAMPANA, 2001; MANCERA-RODRÍGUEZ; CASTRO-HERNÁNDEZ, 2004). The body size is an important variable in fisheries ecology as it provides a basis for predicting life history features, including maturity, longevity and mortality rates (FROESE; PAULY, 2000; CHOAT et al., 2006).

Growth or changes in size of fish can be best evaluated on rate basis, therefore, a temporal measurement such as age is essential in growth studies. Age data can usually be obtained by counting annual increments of hard part caused by the response of the fish to strong fluctuations in environmental conditions. In warmer areas, such changes are less pronounced and it is therefore difficult to use a seasonal ring for age determination (SPARRE; VENEMA, 1997). In this case, the analysis of length-frequency data has been widely used for tracing the survival and growth of fish by identifying cohorts or age groups (BHATTACHARYA, 1967; PEREIRO, 1992).

The utility of length frequency analysis for age determination compared to other methods using hard structures is a contentious issue (HILBORN; WALTERS, 1992). Although, length frequency analysis method is of widespread use at the present time, some studies did not fulfill its requirements (CAMPANA, 2001). Iversen (1996) mentioned some limitations about length-frequency methods for age determination such as "....The method should be used for relatively short time spawning season fishes, the technique requires big samples with wide size range and the age at first capture should be known to detect the age of first modal group. Nevertheless, it was possible to mitigate some limitations in this study, since the analyzed samples were representative and was possible to separate efficiently the overlapping of length modes".Physical environment is an essential factor in regulating marine fish populations (CUSHING, 1982). In general, growth may be influenced by several factors such as density, temperature, salinity, reproductive cycle and food availability (FREÓN; MISUND, 1999; SWAIN et al., 2003; LAPPALAINEN et al., 2005; DULCIC et al., CARAMANTÍN-SORIANO ET AL: GROWTH PARAMETERS AND MORTALITY RATE 2007). Temperature is one of the factors influencing the metabolism, growth and natural mortality of several fish species (PAULY, 1980; MARTINEZ-PALACIOS et al., 1996; ROBARDS et al., 2002; WILLIAMS et al., 2007). It has been reported that the sea water temperature also affect the recruitment and, hence, fish stock abundance (CARDINALE; YELM, 2006).

In Argentinean sea waters, the growth of *S. japonicus* is influenced by the higher water temperature (PERROTA et al., 2001. These results coincide with that reported by Robards et al. (2002). However, extremely high or low temperatures can have negative effect on the growth and mortality of the first stage of life in *S. japonicus* (HWANG; LEE, 2005).

Remarkable variations of temperatures due to El Niño event may influence the annual growth rate of the pelagic species (PARRISH et al., 1985; ARNTZ; BERNAL, 1996). According to Kikkawa et al. (2001), the age and the growth rate of *Thunnus obesus* from the equatorial western Pacific Ocean was influenced during El Niño events. The results obtained in the present study did not show great variation in the growth parameters of *S. japonicus peruanus* during 1997-1998 El Niño events (Table 2), probably, due to the low variations of the catch composition at fork length obtained during that event.

In general, the seasonal growth of fish might be related to their life-cycle, spawning time, feeding regimes and the metabolic costs of different activities (PAULY, 1979; MOREAU, 1987; PAJUELO; LORENZO 2001). This seasonality of the growth in pelagic fishes has close relation with the growth parameters Winter point (*Wp*) and oscillation Amplitude (*C*), (PAULY; TSUKAYAMA, 1983; CUCALÓN-ZENCK, 1999; BELLIDO et al., 2000). According to Pauly and Tsukayama (1983), the values of the oscillation Amplitude are related with environmental temperature of winter and Summer, which appear to be related to reproduction and food abundance. Palomares et al. (1987) based on *Wp* (0.7) and *C* (0.27) values obtained to *Engraulis rigens* from Peruvian coast concluded that their growth is slower in winter, when their main spawning peak is taking place.

The results obtained in the present study, revealed that the growth of *S. japonicus peruanus* was slower in summer by approximately 60% (Table 2) with respect to the average growth. Coincidentally, the reproductive activity of the species is more intense in this season of the year, since it has a partial spawner with a period of reproductive activity between August to March (MENDO, 1984; CARAMANTÍN,-SORIANO, 2001).

According to Perrota (1993) and Kiparissis et al. (2000) the growth of S. *japonicus* is relatively variable being their growth rate from 0.17 to 0.47 (MORALES-NIN, 1988; DAWSON, 1986; GLUYAS-MILLÁN;QUIÑONEZ-VELAZQUEZ, 1997; CUCALÓN-ZENCK, 1999).

Mendo (1984), based on otoliths analysis, concluded that in the Peruvian coast the asymptotic body length and growth rate of *S. japonicus peruanus* were 40.6 and 0.41 respectively. In the present study, the mean asymptotic body length (41.30) and growth rate (0.39) of Chub mackerel from the same area agreed with data reported by that author.

Errors in the estimative of the growth fish parameters (Cf_∞ e K) can be evaluated using the growth performance Index (ϕ) (PAULY; MUNRO, 1984).

According to Moreau et al. (1986), species within the same family are expected to have similar ϕ values. Cucalón-Zenck (1999), using fork length frequency data of *S. japonicus peruanus* from the Gulf of Equator from 1989 to 1996, obtained a mean performance Index of 2.95. The value of ϕ (2.82) found in the present study is a strong indication that the Chub mackerel of these two regions would belong to the same stock.

Aguayo and Steffens (1986), Dawson (1986), Menz and Pizarro (1988) and Cucalón-Zenck (1999) reported that the Lf_∞ and K values of *S. japonicus peruanus*, from the Equator and Chile regions, ranged from 38 cm to 45 cm and 0.16 to 0.41, respectively (Table 5). The results obtained in the present study ($\overline{\mathrm{L}}f_\infty$ = 41.30 cm and $\overline{K}$ = 0.39) are well within the range reported by various authors in other areas of the eastern Pacific (Table 5).

Table 5. Growth parameters of *S. japonicus peruanus* obtained by different authors.

Authors	Growth parameters Lf_∞	K	ϕ	Method/Area
Mendo (1984)	40.60	0.41	2.92	Direct-Peru
Aguayo & Steffens (1986)	44.40	0.16	2.58	Direct-Chile
Dawson (1986)	40.50	0.21	2.62	Direct-Equador
Menz & Pizarro (1988)	38.00	0.41	-	Indirect-Equador
Cucalón-Zenck (1999)	45.00	0.37	2.95	Indirect-Equador
Present study	**41.30**	**0.39**	**2.82**	**Indirect-Peru**

The values of total mortality rate, fishing and exploitation suggest that in those years *S. japonicus peruanus* was over-exploited and nearing its maximum capacity, since its mean exploitation rate was 0.77. This may be confirmed by the fact that a remarkable increase in Chub mackarel abundance of juvenile has been observed (ÑIQUEN; BOUCHON, 2004; CARAMANTÍN, 2006).

In relation to the rate of natural mortality of *S. japonicus peruanus* in Peruvian waters, the results obtained (0.52) seem to confirm the findings of Oldepesca (1986) and Perrota (1993), who found for *S. japonicus* from Argentina and Equator sea values ranging from 0.40 to 0.54.

The magnitude of *K* has a direct relationship with the lon longevity of any fish (PAULY, 1980). This becomes obvious if we consider that the oldest fishes in a given exploited stock, in nature, generally reach about 95% of their asymptotic length (TAYLOR, 1958). Our findings suggested that the largest specimen of Chub mackerel found in the samples was probably the oldest fish, since that length (*Cf* =39 cm) as mean asymptotic length (*Cf* = 41.30 cm) were very close.

Gluyas-Millán and Quiñonez-Velázquez (1997) based on the analysis of the otholits concluded that the longevity of *S. japonicus* can reach up to 9 years in the Gulf of California, and 8 years in the Equator region (CUCALÓN-ZENCK, 1999). These conclusions are in accordance with our findings because the mean longevity of *S. japonicus peruanus* was 7.77 years.

The results obtained in the present study emphasize that the control of fish landings, better enforcement of legislation and continued monitoring in the coastal environment are very important and necessary for sustainable fisheries (FAO, 2007).

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