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Inter-cohort growth variability and its implication for fishery management of the common sardine (*Strangomera bentincki*) stock off the coast of south-central Chile

Marcelo Feltrim[a,b,d,*], Billy Ernst[c]

[a] Instituto de Fomento Pesquero de Chile – IFOP, Blanco 839, Valparaíso, Chile
[b] Programa Magister en Ciencias mención Pesquerías, Casilla 160-C, Universidad de Concepción, Concepción, Chile
[c] Departamento de Oceanografía, Casilla 160-C, Universidad de Concepción, Concepción, Chile
[d] Grupo de Estudos Pesqueiros – GEP, Universidade do Vale do Itajaí, Rua Uruguai 458, Centro, Itajaí, SC, Brazil

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ABSTRACT

Temporal and spatial variability in somatic growth of small pelagic fish populations has been recently acknowledged in a variety of stocks worldwide. We investigated the inter-cohort variability in length-at-age and somatic growth of the common sardine on the south-central coast of Chile. Using length frequency decomposition analysis of monthly samples from 1990 to 2006, we obtained the mean length-at-age and estimated 15 cohort specific asymptotic growth models (von Bertalanffy) with additional seasonal parameters. Results showed a conspicuous inter-cohort variability in the mean length and growth rate at different life stages throughout the first year of life. Striking anomalies (positive and negative) were observed during the 97/98 ENSO (El Niño South Oscillation), but the mechanisms behind these dynamics are unknown. Nevertheless, we investigated the impact of these variables on the optimal cohort yield. Simulations show that optimal age (month) to begin exploitation varies between cohorts, and a large portion of available cohort is lost by applying fishing mortality in a sub-optimal period. Therefore, monitoring size composition of each incoming cohort and use of an appropriate harvest strategy could help to better manage this resource and optimize fishery benefits.

1. Introduction

The variability in somatic fish growth rates has been studied for an increasing number of populations as a function of gender, temporal and spatial scales (Francis, 1997; Akira et al., 2001; Martins, 2007). Changes in length-at-age have been reported for both demersal, (i.e.: Atlantic cod (*Gadus morhua*), walleye pollock (*Theragra chalcogramma*)), and pelagic fish stocks (i.e. Atlantic mackerel (*Scomber scombrus*), Spanish mackerel (*Scomber japonicus*) and Pacific herring (*Clupea palasii*)). The causes of the changes have been associated to food availability, water temperature, density-dependence, size-selective mortality (natural or fishing), and predation stress (Stokesbury et al., 1999; Akira et al., 2001; Sinclair et al., 2002; Moyle and Cech, 2002; Ali et al., 2003).

This topic has attracted special attention to small pelagic species. Voulgaridou and Stergiou (2003) detected a decrease in the mean length of European sardine during the years 1996 and 2000 and Morimoto (2003) studied the growth patterns of Japanese sardine sampled from 1990 to 1996. The later describes a remarkable increase of class growth rates in the years 1991 and 1992, interpreted as the consequence of a reduction in the population biomass during this period, which describes a density-dependent growth rate. More recently, Takasuka et al. (2007) reported a dome-shaped relationship between water surface temperature and Japanese sardine growth during early life stages, where optimal water temperature for sardine larval growth was around 16.2 °C, and Kim et al. (2006), studying Japanese sardine off Korea, also detected changes in the mean length-at-age one, the results of which he attributed to stock size variations.

In the southeastern Pacific, off the coast of Chile, the small pelagic coastal fish, the "common sardine" (*Strangomera bentincki*), is an abundant and commercially important resource. Its growth has been studied by Cubillos et al. (2001), who described a rapid and seasonal growth, with high growth rates during austral spring/summer (hereafter spring/summer) and decreasing rates during austral autumn (hereafter autumn). The common sardine population has a life cycle synchronized with seasonal variations of environmental conditions in the region (Cubillos et al., 2001). Spawning takes place from June through September (Arrizaga, 1981), a period characterized by downwelling conditions, which benefits eggs and near-shore larvae retention due to predominant winds and onshore circulation (Arcos et al., 2004). Juveniles recruit to fishery in November as 3–4-month old individuals, during a

* Corresponding author at: Universidade do Vale do Itajaí – Rua Uruguai, 458, Centro, Santa Catarina, Brasil. Tel.: +55 47 3341 7824; fax: +55 47 3341 7719.
E-mail address: marfeltrim@univali.br (M. Feltrim).

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period characterized by the onset of the upwelling season in this region (Shaffer et al., 1999). During spring and summer, periods of high food availability, the common sardine grows fast and their length and condition factor increase. In autumn, growth decrease and sardine accumulate fats, storing energy for reproduction in austral winter (hereafter winter). The peak of reproduction matches the downwelling season (August), with sardines showing low level growth rates and condition factors in the previous month (Cubillos et al., 2001).

It is well-known that body length and growth can be correlated to weight, fecundity and even egg-size of fishes (Leal et al., 2009; Daoulas and Economou, 1986). In fisheries management, many biological reference points are estimated using life history parameters, such as those associated with growth dynamics (Beverton and Holt, 1957, 1959; Quinn and Deriso, 1999). For example, the optimal age (month) or length to beginning the exploitation for a resource, usually computed to define the best life period for fish cohort exploitation, will likely vary when estimated using cohort specific growth parameters. Thus, we believe that for small pelagic fish populations the use of cohort specific growth parameters is required to determine better management strategies.

In the case of the common sardine, biological recruitment occurs 3–4 months before the onset of the fishing season. This temporal window creates an opportunity to monitor fish size and growth dynamics before start the fishing season, and better define the optimal fishing period. This requires departing from traditional yearly time scale models (De Oliveira and Butterworth, 2004; Feltrim, 2009; Hill et al., 2006).

In this study, we focused our attention on cohort fish length-at-age and growth variability during the first year of cohort life, and assessed the impact on cohort yield under current management practices.

2. Material and methods

2.1. Data

The common sardine stock is distributed along the near-shore coast of south-central Chile, from Valparaíso (30°03′S) to Puerto Montt (41°38′S). The fishery is composed of a purse-seine fleet distributed in three main ports: Constitución, Talcahuano and Corral, with landings concentrated mainly in the central port (Fig. 1).

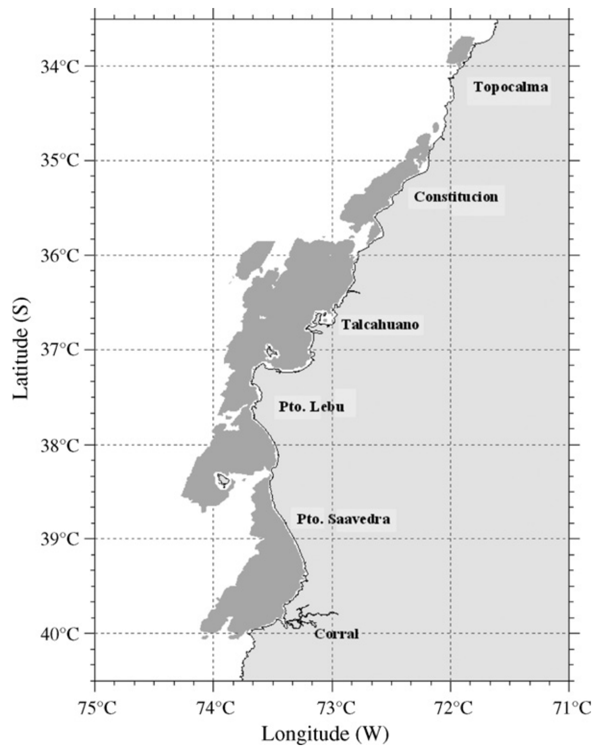

Fig. 1. Distribution of common sardine along the coast off Chile central-south.

Length frequency data was collected from regular purse-seine fishery sampling programs operating in south-central Chile (30–40°S) from 1990 to 2006. Data from July 1990 to December 1997 was obtained from the Chilean Fisheries Research Fund (FIP-"Fondo de Investigación Pesquera") database (Cubillos et al., 1998). For the second period, January 1998 to December 2006, data was obtained from the semi-governmental Institute for Fisheries Development (IFOP-"Instituto de Fomento Pesquero") small pelagic fish monitoring program. The length frequency data we used was previously grouped by month and weighted by the catch to obtain an approximate length frequency distribution of the catch (Tables 1a and 1b).

Table 1a
Length frequency samples sizes (numbers) of common sardine collected by month from fishing sampling programs (1990–1998).

	January	February	March	April	May	June	July	August	September	October	November	December
1990	–	–	–	–	–	–	1052	415	171	382	270	913
1991	2599	2043	2129	1863	783	1785	2520	2595	1803	3110	1994	2225
1992	2182	1922	1049	615	640	278	389	116	427	370	1086	808
1993	973	450	340	183	472	169	1048	966	642	839	2183	1129
1994	1479	677	71	246	338	851	852	842	455	1487	1795	1791
1995	1101	963	2757	1024	1994	617	1267	1873	1462	3258	2006	5447
1996	5003	4767	4523	3487	2409	2579	2961	2408	2462	2624	1006	2971
1997	955	2976	5077	3889	746	1359	150	677	914	1080	–	–
1998	9661	7649	3655	2836	949	1052	4929	3356	1782	1226	5922	4915

Table 1b
Length frequency samples sizes (numbers) of common sardine collected by month from fishing sampling programs (1999–2006).

	January	February	March	April	May	June	July	August	September	October	November	December
1999	8259	11,480	12,030	6238	9343	2539	1353	4212	5660	3243	2865	1094
2000	12,711	12,867	5318	2199	243	–	–	3653	4489	186	117	–
2001	16,366	7999	5702	5517	2520	4037	1910	0	3346	5062	3316	3127
2002	9414	5746	5773	5361	6878	234	1558	574	9904	6706	2839	3957
2003	4765	11,672	7930	3322	963	1358	1695	138	3536	1323	3125	1877
2004	1522	7465	3293	1619	764	805	109	–	1619	1978	3722	1438
2005	393	6824	8420	3159	406	872	522	91	2723	7378	4248	1114
2006	64	18,097	16,195	4658	6244	–	696	142	2461	3380	2926	526