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Variation in the spawning periods of *Engraulis ringens* and *Strangomera bentincki* off the coasts of Chile: A quantitative analysis

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ABSTRACT

In Chile, anchovy (*Engraulis ringens*) and common sardine (*Strangomera bentincki*) are two commercially important small pelagic fish. In southern Chile (32–41° S), both species coexist and inhabit the coastal zone. In northern Chile (18–25° S), only anchovy is present in the coastal zone. The determine onset, peak, end, and duration of the spawning periods in these small pelagic fish are key factors in population studies and of great interest for fisheries management. The objective of this study is to determine the temporal trends of spawning in these two species. A quantitative method was developed to obtain objective indicators of the spawning periods and the method is a useful tool for comparative studies between populations as well as to study the relationship of spawning periods with other demographic variables affected by fishing or environmental variability. Peak spawning in the three populations was consistent through time but showed changes in the duration of the maximum reproductive period. Anchovy and common sardine of the southern zone show synchrony and a shortening of the duration of spawning periods, probably in response to environmental fluctuations. Anchovy in northern Chile have shown an increase in duration from 1986 that is coincidental with the regime shift reported for the Humboldt Current Ecosystem in the mid-1980s.

1. Introduction

Determination of the onset, peak, end and duration of fish stock spawning periods is critical for population studies and fisheries management. Several studies have shown that larger females with high fecundity and the capability of producing higher quality eggs, exhibit longer and more intense spawning periods (Trippel et al., 1997; Wright and Trippel, 2009; Cubillos and Claramunt, 2009). Consequently, removal of the large females by fishing reduces the stock's reproductive potential (Murawski et al., 2001; Tsikliras et al., 2010; Lowerre-Barbieri et al., 2011). Spawning periods typically show predictable seasonality on an annual cycle (Lowerre-Barbieri et al., 2011), where success is correlated to optimal conditions for survival in the early life-cycle stages (Hjort, 1914; Cushing, 1973). Reproductive seasonality may vary (1) interannually, due to exogenous factors, mainly temperature, (2) spatially in terms of latitude and other habitat factors, and (3) demographically, given the size and age of the spawning stock (Trippel et al., 1997; Wright and Trippel, 2009). Some useful reproductive indexes exist, although there is not a standard method that characterizes the onset, peak, end, and duration of the reproductive period in an annual cycle. Spawning seasonality is usually reported in months, which includes spawning activity and peak spawning, despite a vague definition of the latter (Lowerre-Barbieri et al., 2011). Without a quantitative method, it is also difficult to compare temporal trends among populations or species, especially when indexes exhibit large interannual fluctuations, as in the anchovy (*Engraulis ringens*) and common sardine (*Strangomera bentincki*) off the coasts of Chile. As stated, these are commercially important small pelagic fish. In southern Chile (32–41° S), both species coexist and inhabit the coastal zone. In northern Chile (18–25° S), only anchovy is present in the coastal zone. According to the criteria of Murua and Saborido-Rey (2003), the reproductive strategies of female anchovy

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and sardine can be classified as iteroparous, with asynchronous development and indeterminate fecundity. Similar to other small, pelagic fish, common sardine and anchovy species are fast-growing, but relatively short-lived, approximately 4 years (Aguayo and Soto, 1978; Cubillos et al., 2001), reaching early maturity at the end of the first year (Cubillos et al., 1999) with high rates of natural mortality (Cubillos et al., 2002).

The objective of this study is to determine temporal trends of the spawning periods of common sardine and anchovy.

2. Materials and methods

For fish with indeterminate fecundity, the best index to assess the reproductive activity of a population in an annual cycle is with estimates of daily spawning fraction (S), which is a measure of the fraction of mature females which are spawning on any given day, assuming that remains constant over the sampling interval in which S is estimated (Parker, 1985; Picquelle and Stauffer, 1985), generally a month. From this, it is possible to estimate the frequency of spawning (F), the time between consecutive spawning, and the total number of spawnings (D), which would include a certain time period (month, season, or year). For a month i is:

$$F_i = \frac{1}{S_i} \qquad D_i = S_i \cdot d_i = \frac{d_i}{F_i} \tag{1}$$

where S_i is the daily spawning fraction in month i, and d_i is the numbers of days in month i. In an annual period:

$$D_t = \sum_{i=1}^{12} S_i \cdot d_i \tag{2}$$

where D_t is the number of spawnings in year t. The monthly cumulative spawning per month can be fitted to a sigmoid model (Claramunt et al., 2007):

$$D_i = \frac{a_t}{1 + e^{b_t - c_t \cdot i}} \tag{3}$$

where D_i is the cumulative area under S_i at month i (spawning number until month i); a, b and c are parameters for year t; a is the asymptote (=spawning number in the year t), and b and c are parameters. This is a symmetric sigmoid model, i.e. the inflexion point (spawning peak) coincides with the time at half of the asymptote. If asymmetry is detected in the data, a Gompertz model can be used:

$$D_i = a_t e^{-b_t e^{-c_t \cdot i}} \tag{4}$$

where the inflexion point is reached before 50% of the asymptote; at b/c. We chose these expressions of sigmoid models because in both the asymptote (a) is explicit and then directly obtained.

A methodological problem is that daily spawning fraction typically is estimated through the number of females with postovulatory follicles; this is time consuming and a biologically intensive histological methodology which can only be applied with samples over short periods, normally at the spawning peak, as it is carried out during the application of the Daily Egg Production Method. However, we propose that there are reproductive indexes, such as gonadosomatic index (GSI) or proportion of active females (PAF), that follow the same temporal S-shape trend and therefore can be used as proxies (Hunter et al., 1985; DeMartini and Fountain, 1981; Parrish et al., 1986; Claramunt and Herrera, 1994; Claramunt and Roa, 2001; Claramunt et al., 2002; Mori et al., 2011). The monthly cumulative area of these proxies can be fitted to a sigmoid model (Eq. (3)). However, researchers must be careful when spawning periods continue into the following calendar year, as with

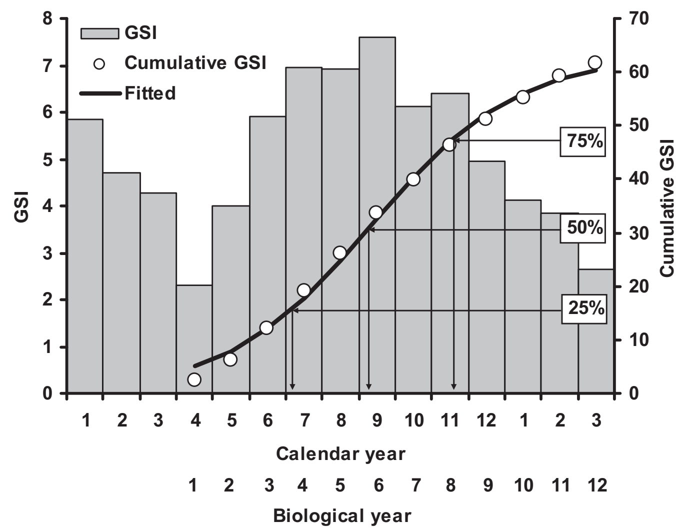

Fig. 1. Description of the proposed methodology for the analysis of the spawning periods. Bars are the monthly average of gonadosomatic index (GSI). Circles are the accumulated GSI and line is a sigmoid model. In X axis a calendar and biological year is showed. Biological year is defined from the month of lowest reproductive activity. The beginning and end of the reproductive period are defined as 25% and 75% of the asymptote. Peak is defined by the inflexion point of the sigmoid model (symmetric or asymmetric).

anchovy and common sardine that begins in June–July and ends in February–March. Therefore, the cumulative area must be based on a biological year, beginning in a month with lowest reproductive activity (Fig. 1). The parameters of the model are estimated by direct minimization of the square errors, assuming Gaussian error, and the selection of the best fit to the data (symmetric or asymmetric model) is made by the lowest error. The onset, peak, and end of the reproductive period are defined according to 25%, 50% and 75% of the asymptote. These quantities can be calculated from Eq. (5) for the symmetric model and Eq. (6) for the asymmetric model:

$$t_X = \frac{b - Ln((1/X) - 1)}{c} \tag{5}$$

and the asymmetric model (Eq. (4)):

$$t_X = \frac{-Ln(-Ln(X)/b)}{c} \tag{6}$$

where X is 0.25, 0.5, or 0.75 (proportion of the asymptote). The criteria of 25% and 75% of the asymptote were adopted arbitrarily as the beginning and end of the maximum spawning periods because this interval represents the sector with the steeper slopes and therefore the period with maximum changes in the reproductive activity and accounts for 50% of the annual spawning. The results are in biological year, to pass to calendar year add the starting month minus one (See X axis in Fig. 1).

We obtained biological data from routine sampling programs by the Instituto de Fomento Pesquero (IFOP; http://www.ifop.cl) and the Instituto de Investigación Pesquera (INPESCA; http://www.inpesca.cl) at main landing ports, including anchovy in the north (18–25° S) and anchovy and common sardine in the south (34–40° S). The sampling design is on weekly base and consisted of random samples from the landings taken almost every day. Each fish was measured (total length) and weighed. The females' ovaries were removed, weighed and classified according to a macroscopic scale of five points: I, virgin immature; II, maturing or recovering; III, mature; IV, hydrated; and V, spawned. The available data covered the period from 1965 to 2011 for anchovy off northern Chile and containing 348,235 individual fish; for anchovy off the southern zone, the data covered the period from 1998 to 2011 and totalled 102,220 females; and for common sardine off the