

## Variability in the weight-, maturity-and reproductive activity-at-length of sardine *Sardine pilchardus* based on acoustic survey data (1992–2012).

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**Summary:** The Iberian sardine (*Sardina pilchardus*) is a short-lived small pelagic fish which has shown wide fluctuations in abundance over the years. High fish availability has followed good recruitment pulses but since the stock has been assessed (from 1978), recruitment has generally declined. We analysed time series of biological data available from fish sampled on-board the spring acoustic surveys carried out in north and northwest Spanish waters (1992-2012). We used Generalised Additive Models to investigate factors affecting growth and maturation, by analysing variation in weight-, maturity- and reproductive activity-at-length over the time series. Final models included significant effects of year, day and location, and different trajectories for males and females in all analyses. Part of the inter-annual variability could be explained by a density dependence effect although this was not the case when models were run by ICES Subdivision and local abundance (derived from the estimates obtained by the acoustic survey) was used instead of stock size. Finally we also explored the effects of SST and zooplankton abundance on sardine growth, maturity and reproductive activity.

**Introduction:** The Iberian sardine (*Sardina pilchardus*) stock, extending from the border between France and Spain to the Strait of Gibraltar has been assessed annually since 1978(ICES, 2014). Stock abundance has fluctuated widely over the assessment period, reflecting the occurrence and periodicity of strong recruitment events. Currently, the biomass of age 1+ fish is near its historical low and an overall decrease in recruitment strength has become apparent (Santos et al., 2012; ICES, 2014). Our understanding of the population dynamics of exploited fish stocks is generally hampered by the lack of good time series but biological data on Iberian sardine are available since the early 1980s (market samples) and since the 1990s (onboard sampling during spring acoustic surveys). Population level changes (e.g. in recruitment) are expected to be mediated through effects at the individual level, e.g. on growth, reproductive output and survival. The available biological data allow us to analyse variability in somatic growth (the length-weight relationship) and reproductive status. A six-point maturity scale is used for sardine, with maturation considered to be complete at stage 3. However, mature individuals become reproductively inactive after the spawning period and consequently, the proportion of “active” individuals (stages 3-5) may be a more useful indicator of reproductive status. In the present study we use biological data from spring acoustic surveys (21 years, 1992-2012) to investigate inter-annual variation in individual growth, maturity and reproductive activity and to determine if there are densodependency effects and whether favourable water temperatures (derived from the temporal loadings of a principal component analysis performed on monthly Sea Surface Temperature, SST) and zooplankton biomass could also help explain this variability.

**Materials and Methods:** The biological data for each fish include weight, length, sex, maturity (6-stage macroscopic scale; Pinto & Barraca, 1958) and age (otolith readings). For each haul, location (latitude, longitude), date and depth were available. Data were collected onboard during annual

spring acoustic surveys in NW shelf waters of the Iberian Peninsula to obtain fishery-independent abundance estimates for pelagic fish. The survey series (21 years of data, 1992-2012) were used to: (1) quantify inter-annual (and seasonal and spatial and sex-related variation) in weight-at-length, maturity (animals were assigned as immature if the maturity class was 1, Silva et al., 2006) and reproductive activity (stages 3, 4 and 5 being considered active, Silva et al., 2006), and (2) determine whether inter-annual variation was related to stock status and/or environment. Gaussian Generalised Additive Models (GAMs) were used for weight and binomial GAMs for maturity and activity. Due to age, maturity stage and depth being correlated with length, the length effect was removed from each using Gaussian GAMs. Models were fitted using forwards or backwards selection to identify main effects, and interactions with sex were investigated. For explanatory variables expected to show simple biological relationships, smoother complexity was restricted using  $k=4$ . Model selection and validation followed standard procedures. To explain inter-annual variability in relation to SSB and environment, two approaches were used: (1) extracting the inter-annual signals in biological response variables using model predictions and running them against SSB and environmental series and (2) rerunning the original models substituting year by SSB (from ICES assessments), SST, zooplankton biomass, or combinations thereof. Zooplankton biomass (ZooB) was measured monthly at two mid-shelf stations (Cantabrian and western Iberian shelf), representing systems with different productivity. SST values were temporal loadings from a Principal Component Analysis of monthly 5x5 km SST data for the NW Iberian shelf (depth < 500m) from 1982 to 2012. The first principal component accounted for >90% of variability. The SST and ZooB series were deseasonalized by subtracting monthly means and averages were derived for the first quarter of each year, around the time of the survey.

**Results and Discussion:** Final models for weight showed significant effects of length, residual age, residual maturity, location, day and year, with sex being included as an interaction with year. Similar results were obtained for maturity and reproductive activity, again with the existence of different trajectories for both sexes. Since a significant location effect was detected, models were also run for each ICES subdivision separately but results showed no consistent patterns and are not discussed further here. Both methods used explain the inter-annual variability gave broadly similar results. There was evidence of a density dependence effect (weight\_at\_length decreased at high SSB). SST showed a positive effect on weight\_at\_length but a negative effect on both maturity\_at\_length and reproductive activity\_at\_length while zooplankton biomass showed a positive effect on all three biological variables. Sardines in the northwestern Iberian shelf are zooplanktivorous (Bode et al., 2004) and therefore food availability is expected to have an effect on biological parameters. The same can be said of temperature, which is known to affect physiological processes in general.

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