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Use of saggital otolith shape analysis to discriminate Northeast Atlantic and Western Mediterranean stocks of Atlantic saury, *Scomberesox saurus saurus* (Walbaum)

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ABSTRACT

The aim of this study was to test the hypothesis that Atlantic saury stocks from the Mediterranean Sea and northeastern Atlantic could be identified by means of saggital otolith shape. Saury is a pelagic fish inhabiting the north Atlantic that undertakes long migrations for feeding and reproduction. A combination of otolith shape indices and elliptic Fourier descriptors are analysed by multivariate statistical procedures. The results obtained show that saury from the Mediterranean Sea and northeastern Atlantic can be distinguished using otolith shape analysis. Whether or not those differences are due to genetic isolation is not tested here but possible drivers of the observed shape variation are explored.

1. Introduction

Sauries are oceanic epipelagic planktivorous. The Atlantic saury, *Scomberesox saurus saurus* (Walbaum) inhabits the North Atlantic and Mediterranean Sea (Sauskan and Semenov, 1968). At least part of the population undertakes seasonal migrations (Dudnik et al., 1981). Saury migrate for feeding purposes to accumulate reserves (Nesterov, 1981), probably for reproduction, which takes place after the migration back from the feeding grounds (Dudnik et al., 1981). Atlantic saury have a protracted spawning period, reproducing throughout the year with peaks during winter in the Mediterranean (Potoschi, 1996) and winter and spring in the Atlantic (Nesterov and Shiganova, 1976). Also, at least in the Atlantic, the spawning ground expands to lower latitudes as water temperature increases (Nesterov and Shiganova, 1976) with spawning taking place along the migration route. Sauries are serial spawners meaning that one female will probably reproduce in different localities as the area suitable for spawning expands. Atlantic saury is a very fast growing, short lived (Agüera & Brophy, in review) species which supports a small scale traditional fishery in southern Italy (Potoschi, 1996), as well as a seasonal fishery in south (Mediterranean) (Abad and Giraldez, 1990; Giraldez and Abad, 1991) and north (Atlantic) Spain. It has been identified as a potentially exploitable species in Ireland (Rihan and Tan, 2010) and Canada (Pohle et al., 1992; Chaput and Hurlbut, 2010).

Most population models assume homogeneity of vital rates and closed life cycles within a stock with young fish produced by previous generations from the same group (Cadrin et al., 2005). Stock identification is of crucial importance in modern fisheries stock assessment and also for understanding the population dynamics of a species in an ecological sense. Stock structure of north Atlantic saury is not clear. It has been generally assumed that there are two different stocks in the northeast and northwest Atlantic (Pohle et al., 1992). There may be more complexity than this simple two-stock model. Nesterov (1974) suggested that spring and autumn spawned fish can be differentiated based on the observation of different distances between scale annuli in fish from both northwestern and northeastern Atlantic. However, studies carried out by Nesterov (1982) based on the distribution of saury during migrations and a study on morphological differences concluded that saury in the northwestern Atlantic can be considered as a single population. There are no references in the literature to saury that inhabit the Mediterranean Sea and it has not yet been established whether this forms part of the northeastern Atlantic population, or is a distinct stock.

The Mediterranean Sea is almost closed, with well-defined limits and with physicochemical characteristics very distinct from those in the adjacent Atlantic. The Almeria–Oran front (AOF), which is the phylogeographical break between the Atlantic and the

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Table 1
Summary of sample data.

Region	Location	Date	n^a	Body size range	Mean body size	SD
North East Atlantic	47°17.5′N 2°32.4′W 46°02.5′N 3°06.5′W 46°24.2′N 4°22.5′W 46°43.1′N 3°44.5′W 46°33.8′N 3°31.0′W 45°51.5′N 3°05.7′W 51°39.0′N 9°49.2′W 51°36.6′N 9°51.0′W	September, 2009	52	160–233	190.6	19.27
West Mediterranean	Off coast Mazarrón (Murcia)	March, 2009	46	165–242	194.9	16.99

[a] Number of individuals from each region used in the study.

Mediterranean (Patarnello et al., 2007) is an oceanographic front generated from Almeria to Oran, resulting from the particular water circulation of the Alboran Sea. The OAF exhibits a pronounced step in temperature (1.4 °C) and salinity (2 psu) (Tintore et al., 1988). Temperature drops at sea fronts have proven to be effective barriers for Atlantic saury, an advantage that has been used in the fishing trials by the USSR in the northwestern Atlantic (Dudnik et al., 1981). It is therefore possible that the AOF acts as barrier to Atlantic saury, preventing, at least to some degree, migrations between the Atlantic and the Mediterranean. The Mediterranean Sea is an oligotrophic sea, however there are areas with substantial organic production (e.g. the Catalan coast, northern Aegean sea and Sicily Straits) (Panardi et al., 2006), those areas within the Mediterranean Sea could support saury during the feeding season; therefore the complete life cycle of saury could take place in the Mediterranean Sea without any mixing of the Atlantic and Mediterranean stocks.

There are many techniques appropriate for studying stock structure. Geometric morphometrics is one of them. Geometric outline methods quantify boundary shapes so that patterns of shape variation within and among groups can be evaluated (Cadrin, 2005; Cadrin and Friedland, 2005). The application of this technique to otolith analysis is an important tool in the study of fish populations. Otoliths are recorders of growth and their structure and development are influenced by external environmental conditions as well as the physiological state of individual fish (Campana and Neilson, 1985); these characteristics can vary between populations, therefore otoliths may show characteristics that are stock specific. Variation in otolith shape is widely used for discriminating between fish stocks (Bird et al., 1986; Campana and Casselman, 1993; Torres et al., 2000; DeVries et al., 2002; Tracey et al., 2006; Mérigot et al., 2007; Burke et al., 2008; Duarte-Neto et al., 2008). A few studies have used otolith shape to successfully differentiate between Atlantic and Mediterranean fish. Tuset et al. (2003) discriminated between Atlantic and Mediterranean stocks of the comber (*Serranus cabrilla*) while Stransky et al. (2008) separated Mediterranean and Atlantic stocks of horse mackerel (*Trachurus trachurus*), although these are not genetically isolated stocks (Abaunza et al., 2008).

The aim of this study was to analyse otolith shape variability in Atlantic saury from the north east Atlantic and Mediterranean Sea, and to examine its potential to elucidate stock structure.

2. Materials and methods

2.1. Sampling

Samples of saury were obtained from southwest Ireland, Bay of Biscay and south east Spain during the year 2009. Sampling details are summarised in Table 1 and Fig. 1. Saury samples used in this study were caught in different seasons. Information from otolith microstructure showed that they also hatched in different seasons (Agüera & Brophy, in review): spring in the case of the Atlantic samples and autumn in the case of the Mediterranean samples. All the samples were taken using purse seine nets of 22 mm mesh. In the Bay of Biscay and the Mediterranean, fish were concentrated and attracted to the fishing vessel using lights. Atlantic samples were taken in different nights during the month of September. A single sample was collected from the Mediterranean during one night.

Body size (BS) was measured to the nearest millimetre from the point where the lower jaw begins to elongate into the beak to the posterior end of the muscular knob at the base of the caudal peduncle. The weight of each fish was recorded to the nearest 0.1 g. Saggital otoliths were removed, cleaned of membranes and tissues and stored dry. Only left otoliths that did not show any clear distortion or damage were used. Differences in shape between left and right otoliths have been previously reported (Potoschi, 1996), so when the left otolith was damaged or not present the specimen was discarded. A total of 98 left otoliths were used in this study, 52 from the Atlantic and 46 from the Mediterranean. According to results from otolith increment analysis all the specimens included in this study are in the 0+ age class (i.e. less than one year old) (Agüera & Brophy, in review).

2.2. Image acquisition and feature extraction

The otoliths were photographed using a QIMAGE Retiga 2000R digital camera attached to an Olympus SZX10 Stereomicroscope. The magnification was kept constant at 4× for all the otoliths photographed. The images were captured and segmented: binarising and partitioning the picture into areas that are easier to analyse, in this case with the objective of differentiating the otolith from the background. Image-Pro v6.3. software was used for segmentation.

Measurements (Table 2) of each otolith as well as the resulting size based shape indices (Table 2) were extracted and calculated using Matlab v2009b and Matlab Image Processing Toolbox function RegionProps on the segmented images. Area (A) is the total number of white pixels in the binary otolith image; perimeter (P) is the number of pixels in a 1 pixel wide outline enclosing the white area. Otolith length (OL) and otolith width (OW) are measure as the major axis and minor axis, respectively, of an ellipse with the same normalised second moment as the otolith outline (Gonzalez et al., 2004). The use of a constant amplification and image acquisition set-up make it possible to use pixels as measurement units; this avoids the introduction of extra error due to the transformation from pixels to another measurement unit.

Ten elliptic Fourier harmonics were calculated using the software SHAPE v1.3 (Iwata and Ukai, 2002). Elliptic Fourier Descriptors (EFDs) can delineate any type of shape with a closed two-dimensional contour (Kuhl and Giardina, 1982). They use an orthogonal decomposition of a curve into a sum of harmonically related ellipses that can be combined to reconstruct an approximation of the closed curve. EFDs have been effectively applied to the analysis of various biological shapes in animals (Iwata and Ukai, 2002), including otoliths (Tracey et al., 2006; Burke et al., 2008;