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Discriminating stocks of striped red mullet (*Mullus surmuletus*) in the Northwest European seas using three automatic shape classification methods

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ABSTRACT

Stock identification is of primary importance for population structure assessment of economically important species. This study investigates stocks of striped red mullet using three automatic methods of stock identification based on otolith shape and growth marks. Otolith shape is known to be a promising approach for stock identification but interpreting patterns of variance is a difficult problem. In this study, images in reflected and transmitted light were acquired from 800 otoliths sampled in the Northwest European seas from South Bay of Biscay to North Sea. The growth marks are pointed out manually by an expert. The external shape of otoliths was automatically extracted by computer vision process and then three automatic classification methods were compared, two classical state-of-the-art methods based on Fourier descriptors and principal component analysis (PCA), and a recently proposed method based on shape Geodesics. From a methodological point of view, results show that the shape geodesic approach significantly outperforms other classical methods. From a biological point of view, this study shows that the population of striped red mullet in Northwest European seas can be divided in three geographical zones: the Bay of Biscay, a mixing zone composed of the Celtic Sea and the Western English Channel and a northern zone composed of the Eastern English Channel and the North Sea (67% of correct classification rate using both shape and growth pattern information). Moreover, it shows that for a given zone, two subsets of the same year have a lower variability in shape than two subsets from two consecutive years.

1. Introduction

Striped red mullet (*Mullus surmuletus*) occurs along the coast of Europe from the South of Norway (Wheeler, 1978) and the North of the Scotland (Gordon, 1981) to Gibraltar, also along the northern part of West Africa to Dakar, in the Mediterranean and Black Seas. Striped red mullet has been extensively studied in terms of quantity in the Mediterranean Sea and some studies were carried out in the Bay of Biscay (Desbrosses, 1933, 1935; N'Da and Deniel, 1993) that correspond to oldest exploitation areas in the Atlantic Ocean. Within the Atlantic Ocean, there are two main areas where this species is caught in this region: Bay of Biscay and in the Eastern English Channel. This species has been initially exploited by the Spanish fleets along their coast to the Bay of Biscay. Initially considered as a valuable by catch (Marchal, 2008), the development of striped red mullet exploitation and a strong increase in landings along the English Channel and the southern North Sea by French, English and Dutch fleets have been observed since the 1990s. The strong increase of catches is essentially due to French trawlers and supplemented by the Netherlands and United Kingdom fleets which are carried out in the Eastern Channel and the south of North Sea (Mahé et al., 2005). This could be attributed to an expansion of its migration distribution, abundance of this species coupled by the decline of traditionally targeted species in these areas and the sea-water warming trend (Poulard and Blanchard, 2005; Marchal, 2008; ICES, 2010). Reports indicate a steady increase in East English Channel landings reaching ten times recorded landings in 1990 (Marchal, 2008; Carpentier et al., 2009). Striped red mullet is still considered as a non-quota species in the Northeast Atlantic region and evaluation of the level of stock exploitation has only started since 7 years (ICES, 2010).

Stock identification and spatial structure information provide a basis for understanding fish population dynamics and provides reliable resource assessment for fishery management (Reiss et al., 2009). Each stock may have unique demographic properties and responses or rebuilding strategies to exploitation. Biological attributes and productivity of species may be affected if the stock structure and fisheries management are not well considered (Smith et al., 1991).

There are a variety of techniques for stock identification such as genetics and morphometry studies. Genetic studies have been carried out in the Mediterranean Sea (Mamuris et al., 1998a,b; Galarza

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et al., 2009; Apostolidis et al., 2009). In the Gulf of Pagasitikos (Greece sea), the analyses of three molecular markers revealed that this is a panmictic population (Apostolidis et al., 2009). However, on the level of the Mediterranean basin, the siculo-Tunisian Strait seems to be the transition zone between the Mediterranean's eastern and western populations (Galarza et al., 2009). A sharp genetic division was detected when comparing striped red mullet originating from the Atlantic Ocean and from Mediterranean Sea.

Among all available techniques, otolith shape has been proven to be relevant feature for species and/or stock discrimination issues (Campana and Casselman, 1993; Begg and Brown, 2000; Stransky, 2005; Burke et al., 2008; Stransky et al., 2008b). Otolith shape reflects the growth pattern of the fish as well as being markedly species specific. As a result, otolith shape can be used to differentiate stocks of the same species. Another relevant feature for stock identification is the growth law as growth is highly correlated to the environmental conditions and is thus stock specific.

In the present study, the stock identification was investigated with two methods based either on otolith shape or on growth marks (and both information). Images in reflected and transmitted light were acquired from 800 otoliths sampled in the Northwest European seas from South Bay of Biscay to North Sea. Growth marks have been pointed out manually by an expert. External shapes were extracted by computer vision process and then three automatic classification methods were compared, two classical state-of-the-art methods based on Fourier descriptors, principal component analysis (PCA), and a recently proposed method (Nasreddine et al., 2009) based on shape geodesics.

2. Materials and methods

2.1. Otolith datasets

Striped red mullet otoliths were extracted from fish randomly sampled from the southern bay of Biscay to the North sea. The study area was divided into six geographic sectors: the NS (North Sea; ICES Division IVab), the EEC (Eastern English Channel; ICES Division VIId), the WEC (Western English Channel; ICES Division VIIe), the CS (Celtic Sea; ICES Division VIIh), the NBB (North Bay of Biscay; ICES Division VIIIa) and the SBB (South Bay of Biscay; ICES Division VIIIb) (Fig. 1). All sampling were collected from September to December 2009 except the EEC otoliths which were collected from October to November 2007 and 2008.

The otoliths were selected from the routine surveys on board the RV "Thalassa" and RV "Gwen-Drez" conducted by the Ifremer Institute (France) and from fisheries markets. Fish were caught by otter trawl, bottom pair trawl and set gillnets. Both sagittal otoliths were removed and cleaned before drying and storing in paper envelope. One otolith per fish was examined using a light microscope connected to a video camera and a dedicated image-analysis system TNPC (digital processing for calcified structures) developed by Ifremer, ENIB and Noesis society.

Images of whole otoliths have been acquired using both transmitted and reflected lights. From 800 otoliths coming from six different stocks of striped red mullet (Fig. 1), four different image datasets will be considered:

Dataset (1): 600 otoliths sampled from six different stocks (100 otoliths per stock):
- NS: North Sea (IVab) – 2009
- EEC08: Eastern English Channel (VIId) – 2008
- WEC: Western English Channel (VIIe) – 2009
- CS: Celtic Sea (VIIh) – 2009
- NBB: North Bay of Biscay (VIIIa) – 2009
- SBB: South Bay of Biscay (VIIIb) – 2009

Dataset (2): 700 otoliths: the 600 otoliths of dataset (1) with 100 other otoliths from Eastern English Channel but of a different year:
- EEC07: Eastern English Channel (VIId) – 2007

Dataset (3): 200 otoliths: those from Eastern English Channel (VIId) over the two consecutive years 2007 and 2008:
- EEC07: Eastern English Channel (VIId) – 2007
- EEC08: Eastern English Channel (VIId) – 2008

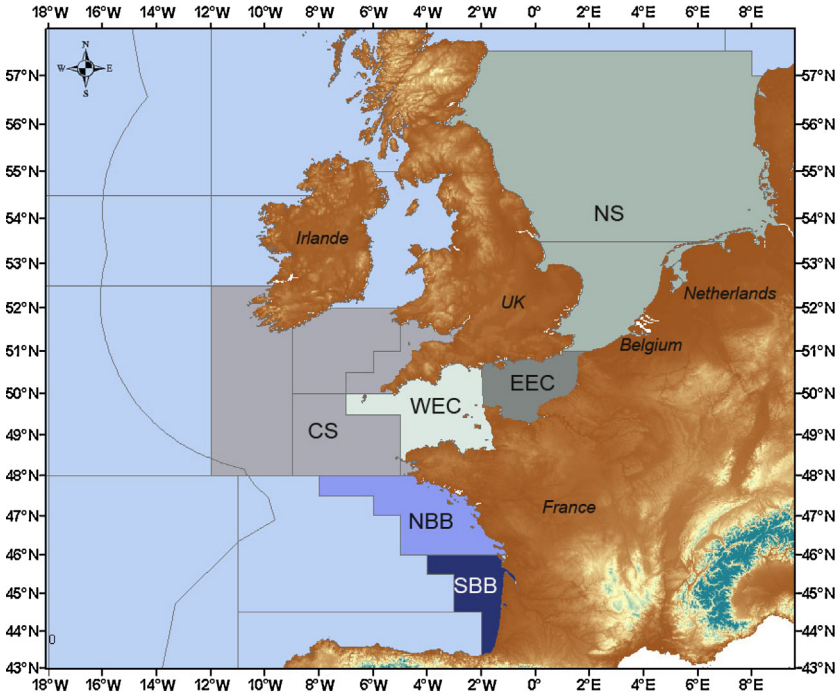

Fig. 1. Map of the stocks of striped red mullet involved in this study.