Fisheries Research 174 (2016) 210–218

Contents lists available at ScienceDirect

Fisheries Research

journal homepage: www.elsevier.com/locate/fishres

Evaluation of otolith shape as a tool for stock discrimination in marine fishes using Baltic Sea cod as a case study

Karin Hüssy*, Henrik Mosegaard, Christoffer Moesgaard Albertsen, Einar Eg Nielsen, Jakob Hemmer-Hansen, Margit Eero

National Institute of Aquatic Resources, Technical University of Denmark, Jaegersborg Alle 1, 2920 Charlottenlund, Denmark

ARTICLE INFO

Article history:
Received 8 April 2015
Received in revised form 1 October 2015
Accepted 10 October 2015
Available online 22 October 2015

Keywords:
Baltic Sea
Cod
Genetic validation
Otolith shape
Stock discrimination

ABSTRACT

In the Western Baltic Sea two genetically distinct cod stocks "Eastern Baltic cod" and "Western Baltic cod" occur with considerable mixing of stocks. In this study we evaluated the applicability of otolith shape analysis for classification of individuals caught in the mixed stock cod fishery, using SNP (single nucleotide polymorphism) based genetic assignment of otolith shape baselines. We further developed a management aimed approach for mixed stock assignment by robust stochastic baseline selection and posterior bias correction by individual reassignment of the least likely classifications into the alternate stock. Classification criteria selected by Monte Carlo runs of Linear Discriminant Analysis were captured by otolith area and 20 Elliptic Fourier Descriptors of primarily low frequency harmonics. Classification success was considerably lower when using a baseline of spawning individuals only, compared to the better spatial coverage of a combined baseline also including genotyped individuals from the mixed stock area. Furthermore, the inclusion of genotyped individuals balanced the baseline size composition and to a large extent removed a strong size related bias in classification success. These results demonstrate the interplay of environmental, ontogenetic and genetic influences on otolith shape, which complicates the application of otolith shape for stock discrimination in mixed-stock scenarios. Rigours genetic validation and further studies on the temporal dynamics of shape formation are necessary.

1. Introduction

The stock concept is one of the most fundamental in fishery management. With the development of new analytical methods, an ever increasing number of studies have documented the existence of bio-complexity (Ruzzante et al., 2006) with discrete populations within areas previously considered, and managed, as representing a single stock. Mechanical mixing of populations, with limited interbreeding, may result from an overlap in distribution range (Edmonds et al., 1989), for example due to seasonal spawning/feeding migrations (Johnson et al., 1994; Campana et al., 1999, 2000, 2007; Ruzzante et al., 2006). Failure to take stock mixing into account in fisheries management, particularly when the stocks differ in productivity, may lead to sub-optimal exploitation and ultimately over-fishing of some stock components (Begg et al., 1999; Heath et al., 2013). Therefore, efficient stock discrimination methods are needed.

A suite of analytical techniques have been used for stock discrimination, ranging from morphometrics (Elliott et al., 1995) and parasite loading (Braicovich and Timi, 2008) over conventional tagging (Lear, 1984), otolith microstructure analysis (Mosegaard and Madsen, 1996) and otolith microchemistry (Campana et al., 2000, 2007) to molecular tools (Johnson et al., 1994; Ruzzante et al., 1999, 2006; Nielsen et al., 2012) and otolith shape analyses (Campana and Cassleman, 1993). Owing to the higher expenses associated with molecular tools, in combination with the availability of otolith samples from extensive historical archives in fisheries research institutes, otolith shape analysis has recently gained interest among fisheries biologists. Otolith shape is known to depend on a combination of genetic and environmental factors (Cardinale et al., 2004) and separation of populations in both time and space induces divergent otolith shape patterns (Messieh, 1972; Lombarte and Lleonart, 1993). Consequently, otolith shape analyses can be a powerful tool for fish stock management purposes, and is already implemented in stock assessment for example for North Sea

* Corresponding author. Fax: +45 3588 3333.
E-mail address: kh@aqua.dtu.dk (K. Hüssy).

http://dx.doi.org/10.1016/j.fishres.2015.10.010
0165-7836/

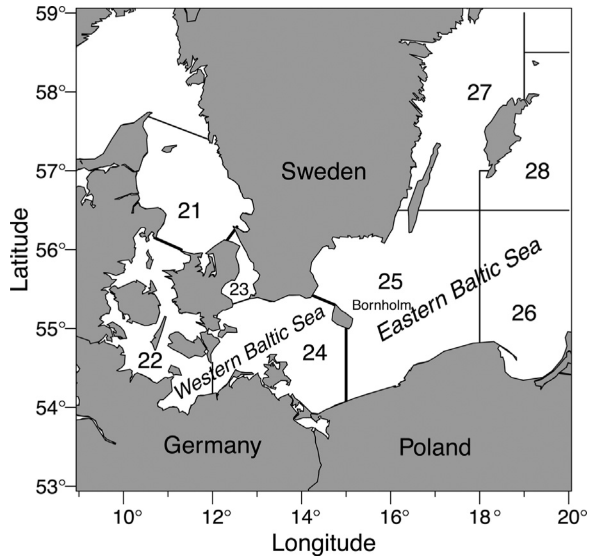

Fig. 1. Map of the Baltic Sea. Numbers indicate ICES subdivisions (SD), thin lines indicate SD boundaries and solid lines the boundaries between the Kattegat, western and eastern Baltic Sea management areas.

herring (ICES, 2013a). The primary analytical tool used for spatial and temporal discrimination of stocks and populations (e.g. Bolle and Begg, 2000; Cardinale et al., 2004; Mérigot et al., 2007) has been based on the Fourier Series Shape Analysis (Bird et al., 1986), and has been applied for various species, such as cod and herring. For cod, most of the previous studies were designed to map the geographical distribution of populations and/or stock components in the Northwest Atlantic (Campana and Cassleman, 1993), the Northeast Atlantic (Stransky et al., 2008), Iceland (Petursdottir et al., 2006; Petursdottir et al., 2006), Scotland/Ireland (Galley et al., 2006) and the Baltic Sea (Paul et al., 2013). The objectives of these studies were to evaluate the impact of genetic and/or environmental conditions on otolith shape and their usefulness as stock discrimination tool. Even though these studies found highly significant differences in otolith shape when comparing cod captured in their spawning areas, none of them have addressed the application of this approach for management purposes in an area with mixed stocks. In this study, the applicability of otolith shape analysis for the identification and estimation of stock proportions in management situations where biological populations mix (i.e. a mixed stock scenario) is examined using the example of Baltic Sea cod.

Cod are generally distributed throughout the Baltic Sea (Bagge et al., 1994), and is assessed and managed as two distinct populations, one east of the island of Bornholm (ICES Subdivisions (SD) 25–32), the other from west of Bornholm to the Sound and the Danish Belts (ICES SDs 22–24) (Fig. 1). The two populations differ with respect to morphometric characteristics as well as genetic variation (Bagge et al., 1994; Nielsen et al., 2003, 2005). However, as part of their seasonal cycle, adult cod, for example in the Arkona Basin (SD 24) undertake distinct and highly complex migrations, targeting specific feeding and spawning areas which may cross management and environmental boundaries (i.e. into SD 25) (Aro, 1989; Berner and Borrmann, 1985; Berner, 1967; Otterlind, 1985). Spawning migrations of cod tagged east of Bornholm (SD 25) to the Arkona Basin (SD 24) also occur (Aro, 1989; Nielsen et al., 2013). These studies suggest that eastern and western Baltic cod stocks co-occur in the Arkona Basin (SD 24). Thus, interactions between populations in the western Baltic Sea are highly dynamic and provide a valuable scenario for assessing methods for stock discrimination under complex scenarios of relevance to fisheries management. The abundance of eastern Baltic cod in SD 25 has substantially increased in recent years (Eero et al., 2012a), while that of the western Baltic cod in SD 22 is low (ICES, 2013b). A relatively high abundance of cod currently found in SD 24, belonging to the management area of the western cod, is considered to be due to spill-over of the eastern cod (Eero et al., 2014; ICES, 2013b). In order to be able to account for this stock mixing in fisheries management to avoid depletion of the cod of western origin, an efficient stock discrimination tool is needed.

Table 1
Summary of the sample collection.

Stock	Area (SD)	Sample type	Month	*n* Otoliths	*n* Genetics
Western	22	Spawning	March/April	410	148
Eastern	25	Spawning	June/July	854	74
		Spawning	August	411	14
Unknown	24	Spawning	May	207	207
		Spawning	June/July	937	407
		Non-spawning	June/July	121	121
Total				2940	971

The objective of this paper is to evaluate otolith shape as a methodology for stock discrimination in an area with potential mixing of two neighbouring stocks. This evaluation relies on validation through genetic assignment and includes a general evaluation of the traditional otolith shape analysis setup as well as an assessment of the impact that the selection of baseline samples has on the applicability of this method to the mixed stock. Since management does not need correct individual classification but rather relies on unbiased and precise estimates of proportions of each stock, classifications were statistically corrected to reflect the true underlying proportions and the conditions for optimal selection of baselines were analysed.

2. Materials and methods

The otolith shape based stock discrimination relies on the definition of stock-specific otolith shapes derived from baseline reference samples consisting of individuals known to belong to a specific stock. Otolith shapes as silhouette outlines from these baseline samples are extracted from digitised images using image processing techniques and parameterised through Elliptic Fourier Analysis (EFA) to derive stock classification criteria by Linear Discriminant Analysis. In this study we used two different types of baselines, one based on the traditional "spawning stock" baseline (see Section 2.1) and one also including all genotyped individuals from the mixed stock area, the "combined" baseline (see Section 2.2). The performance of the two baselines was tested by comparison of otolith shape based classifications with genetically identified stock of origin in a mixed stock sample.

2.1. Samples for "spawning stock" baseline

For each stock, individuals were collected on the known spawning grounds during the spawning season in 2011 (Fig. 1). For eastern Baltic cod the only spawning area with hydrographic conditions suitable for egg survival is the Bornholm Basin (SD 25), with a spawning season from May to September (peak spawning season June/July). The main spawning grounds of the western Baltic cod are the Kiel Bay and the Danish Straits (SD 22) where the main spawning season is restricted to March/April. In the Arkona Basin (SD 24), efforts were made to cover both the Eastern and Western stocks' main spawning season, but spawning individuals were only found in May/June and none in March/April. Samples were collected from scientific research cruises and from market sampling. Each fish was identified with an individual number and standard biological data were collected (total length, sex, maturity stage). Only individuals