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Separation of Norwegian coastal cod and Northeast Arctic cod by outer otolith shape analysis

Christoph Stransky [a,*], Hannes Baumann [b], Svein-Erik Fevolden [c], Alf Harbitz [d], Hans Høie [e,f], Kjell H. Nedreaas [f], Arnt-Børre Salberg [d], Tuula H. Skarstein [c]

[a] *Federal Research Centre for Fisheries, Institute for Sea Fisheries, Palmaille 9, D-22767 Hamburg, Germany*
[b] *University of Hamburg, Institute of Hydrobiology and Fishery Science, Olbersweg 24, D-22767 Hamburg, Germany*
[c] *University of Tromsø, Norwegian College of Fishery Science, N-9037 Tromsø, Norway*
[d] *Institute of Marine Research, P.O. Box 6404, N-9294 Tromsø, Norway*
[e] *University of Bergen, Department of Biology, P.O. Box 7800, N-5020 Bergen, Norway*
[f] *Institute of Marine Research, P.O. Box 1870, Nordnes, N-5817 Bergen, Norway*

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Abstract

For stock assessment purposes, Atlantic cod (*Gadus morhua*) from the coastal and offshore regions off northern Norway is usually allocated to Norwegian coastal cod (NCC) or Northeast Arctic cod (NEAC) by internal morphological features of their otoliths. As this classification is subject to individual interpretation by otolith age readers, this study investigated an alternative objective approach for the separation of the two cod groups, using otolith shape analysis. Several hundred otolith samples from coastal fjord areas along northern Norway and from the Barents Sea were analysed by univariate shape descriptors and elliptical Fourier analysis (EFA). When combining uni- and multivariate descriptors and applying the otolith reader typing as reference, the classification score was 89% for NCC and 90% for NEAC. These results indicate that the internal morphology of the otoliths, evaluated by the age readers, is translated to a great extent to their outer morphology and that otoliths can be allocated to NCC and NEAC by their shapes with high certainty. When genetic typing data (*Pan* I marker) were used as reference, the classification scores were reduced to 83% for NCC and 76% for NEAC when combining uni- and multivariate descriptors and excluding heterozygotes. This implies that differences in otolith morphology cannot directly be linked to genetic structure. Differences in environmental conditions, however, seem to have a considerable influence on how otolith growth increments and consequently otolith shapes are formed. As the various fjord systems in Norway provide local habitats and as differences within the NCC with regard to genetic structure and life-history parameters had been found in earlier studies, variation of NCC otolith shapes between three coastal regions was also examined. The region classification scores for reader-typed NCC varied between 60% and 81%.

Keywords: Stock identification; Otolith shape analysis; Northeast Atlantic; Norway; Atlantic cod; *Gadus morhua*

1. Introduction

There are several stocks of Atlantic cod (*Gadus morhua* L.) in the Northeast Atlantic that are managed as separate units. The largest stock at present is the Northeast Arctic cod (NEAC) which has its nursery and feeding area in the Barents Sea. The Norwegian coastal cod (NCC) is found in fjords and along the coast of Norway. The NCC has been drastically reduced in recent years, and there is great concern that overfishing is taking place (ICES, 2006). In 2006, the NCC stock was also introduced on the national red list of threatened species as a 'near threatened' stock (Kålås et al., 2006). Catch regulations for the NCC have unfortunately had limited effect on preventing unsustainable fishing pressure on the stock, since a mixed fishery with the NEAC, especially during the spawning season, is taking place. Current regulations have also left considerable cod quota for the coastal vessels to be taken at the end of the year, thus resulting in nearly pure NCC catches since few NEAC are close to the coast and available for these fishers at this time of the year. The International Council for the Exploration of the Sea (ICES) has recommended no catch of NCC since 2004 (ICES, 2006), but for social-economic reasons, limited quotas are still given.

* Corresponding author. Tel.: +49 40 38905 228; fax: +49 40 38905 263.
E-mail address: christoph.stransky@ish.bfa-fisch.de (C. Stransky).

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The NEAC stock undertakes long migrations, from the central part of the Barents Sea to the northern part of the Norwegian coast for feeding, to the Lofoten area and as far south as the coast of Møre to spawn, after having reached sexual maturity at an age of approximately 7 years (Bergstad et al., 1987). During these migrations to and along the coast, the NEAC spatially overlaps with the NCC stock. The NCC, which is more typically found within fjords, displays less migratory behaviour (Berg and Pedersen, 2001). The two stocks do not mix randomly at the spawning grounds. Separate groups from the different stocks may stay simultaneously at local spawning grounds within small areas, but NEAC are more abundant in deeper waters (Nordeide, 1998).

The two stocks have different life-history characteristics. Faster growth of NCC compared to NEAC has been observed for larval, juvenile and adult fish (Van der Meeren et al., 1994; Svåsand et al., 1996; Otterlei et al., 1999). The NCC mature at ages of 5–6 years at lengths of 40–50 cm (Berg and Pedersen, 2001), while NEAC generally mature at 6–8 years of age at 75–90 cm length (Bergstad et al., 1987). Several genetic studies have revealed significant differentiation between NEAC and NCC, indicating that they are genetically distinct populations (e.g., Sarvas and Fevolden, 2005 and references therein). Natural markers and morphological features have also been used to investigate stock-specific differences of Norwegian cod. Body shape differences exist and are well known to fishermen, where NEAC are generally longer and thinner than NCC (Svåsand et al., 1996). Meristic differences between the stocks have also been identified, such as the NCC having lower vertebrae numbers than NEAC (Løken and Pedersen, 1996). Otterlei et al. (2002) found that the otoliths (ear stones) of juvenile NCC are larger than those of NEAC at a given fish length.

In the fisheries assessment, fish from the two stocks are routinely distinguished through otolith morphology (Mjanger et al., 2000). The stock separation criteria developed by Rollefsen (1933, 1934) are still used and are based on differences in shape and relative size of the two innermost translucent zones. The NCC has an even and oval shaped first translucent zone, often looking like "a glowing halo", and a large second translucent zone. The NEAC has an elongated first winter zone with a small bulge on one side, and a smaller second translucent zone (Fig. 1). Fish otoliths that do not show the typical morphology for NEAC and NCC are classified either as uncertain NCC or uncertain NEAC (Jakobsen, 1987). A fifth otolith type has been characterized as "the Svalbard type", which refers to NEAC often found in the Svalbard area with clear translucent bands (Mjanger et al., 2000). Acknowledging that the typing of otoliths is subject to reader-specific experience and inferred variation of stock allocation for the fisheries assessment, Berg et al. (2005) applied digital image analysis to quantify the stock differences in internal otolith morphology. So far, however, it is unclear if the reported differences in the shape of the innermost growth increments are translated to the otolith outline shape of older fish.

Otolith morphometric analyses have previously been used for taxonomic studies and species identification (e.g., Campana, 2004; Stransky and MacLellan, 2005; Schulz-Mirbach et al., 2006). As modern image analysis techniques allow efficient 2D outline analyses of several hundred samples, otolith shapes have been extensively used for stock discrimination (e.g., Cadrin and Friedland, 2005; Stransky, 2005; Turan, 2006). Campana and Casselman (1993) were the first to apply Fourier analysis (see Lestrel, 1997, for a review) of the otolith outlines to investigate intraspecific variation of Atlantic cod. Further studies on cod around the Faroe Islands (Cardinale et al., 2004), Iceland (Jónsdóttir et al., 2006; Petursdottir et al., 2006) and the northern North Sea and west of Scotland (Galley et al., 2006) also reported small-scale differences between cod populations using otolith shape analysis.

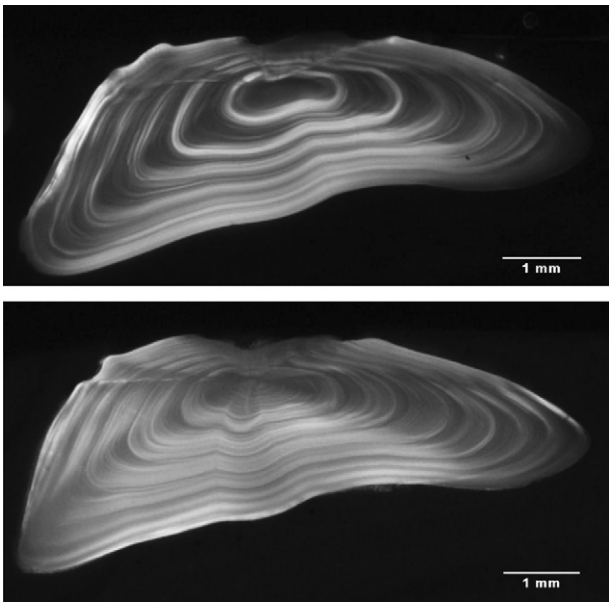

Fig. 1. Otolith thin-section pictures of typical Norwegian coastal cod (upper picture) and Northeast Arctic cod (lower picture). The length of the white bars represents 1 mm of the original otolith size.

By analysing otoliths of Norwegian cod from a selection of distribution areas across all life stages, this study aimed at investigating if there are differences in the outer shape of NCC and NEAC otoliths, allocated by otolith reader types and genetic typing. In the case of consistent differences between stocks, this method would provide an alternative quantitative technique to allocate fish to NCC or NEAC, without the necessity to section the otoliths. As there are indications that NCC may comprise several more or less discrete stocks (Fevolden and Pogson, 1997; Pogson and Fevolden, 2003; Skarstein et al., 2007), and as growth and maturity at age was reported to differ between fjords in northern Norway (Berg and Albert, 2003), variation of NCC otolith shapes between fjord areas was also examined.

2. Materials and methods

2.1. Sampling and selection of material

Cod otoliths from fish randomly sampled in the Barents Sea and the Vestfjorden area (Fig. 2) were selected from the routine survey conducted by the Institute of Marine Research (IMR) in Bergen, Norway, during the winter cruise 2001, and from