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Life history of turbot in Icelandic waters: Intra- and inter-population genetic diversity and otolith tracking of environmental temperatures

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ABSTRACT

The stock structure of turbot was investigated between samples from S-Norway, the Irish Sea and the Kattegat, using 12 microsatellite loci and compared to the turbot caught in Icelandic waters. Highly significant genetic differentiation was observed between samples from Kattegat and other areas. Significant genetic differentiation was also observed between the Irish Sea sample on one hand and Iceland and S-Norway on the other hand. No significant genetic differentiation was observed between Iceland and S-Norway. Otoliths of 25 turbot, age ranging from 3 to 19 years, were subjected to nearly 300 mass spectrometry determinations of stable oxygen and carbon isotopes. Oxygen isotope composition ($\delta^{18}O$) in the otolith samples was used to estimate ambient temperature at time of otolith accretion, and yielded estimated temperatures experienced by the turbot ranging from 3 to 15 °C. Overall, the genetic analysis indicates panmixia between turbot in Icelandic and Norwegian waters. While the extensive migration of larvae between Norway and Iceland is unlikely, passive drift of turbot larva from other areas (e.g. Ireland) cannot be ruled out.

1. Introduction

Turbot (*Scophthalmus maximus* Rafinesque 1810) is a marine demersal carnivorous bothid flatfish, that is relatively abundant in European waters from Iceland and Norway (68° N) to Morocco (30° N), including both the Mediterranean (Morgan, 1956) and the Baltic Sea (Aneer and Westin, 1990). Turbot is found in Icelandic waters (Sæmundsson, 1926; Friðriksson, 1938) and is mainly caught along the south and west coast (Fig. 1). Recent information from the Icelandic Fish Market database (http://www.rsf.is/) indicates that the amount of turbot is increasing in the fisheries. From almost being non-existent prior to 1985, annual reported landing is now between 800 and 1500 kg although the species is only caught as a by-catch in coastal fisheries. In this period sold turbot from fish markets in Iceland has increased by over 1000% (http://www.rsf.is). However, little is known about the distribution, migration, stock size and population growth of turbot in Icelandic waters. Understanding the population biology and evolution of highly dispersive marine species requires knowledge of their population structure as well as the biotic and abiotic drivers of neutral and adaptive genetic divergence (Manel et al., 2010).

Genetic population structure of turbot has been analyzed by using haemoglobins, allozymes and microsatellites (Coughlan et al., 1998; Imsland et al., 2003; Nielsen et al., 2004; Bouza et al., 2008). Microsatellites are among the most widely used markers for population genetics and a great number of published microsatellites are available for turbot (i.e. Coughlan et al., 1998; Estoup et al., 1998; Pardo et al., 2007; Bouza et al., 2008). Previous studies of turbot haemoglobins have indicated that in northern Europe is highly structured (Imsland et al., 2003) and genetic differentiation has been reported for turbot in the Baltic and North Seas using microsatellites (Nielsen et al., 2004). However, it is unclear how turbot in Icelandic waters fit into this scenario as little is known

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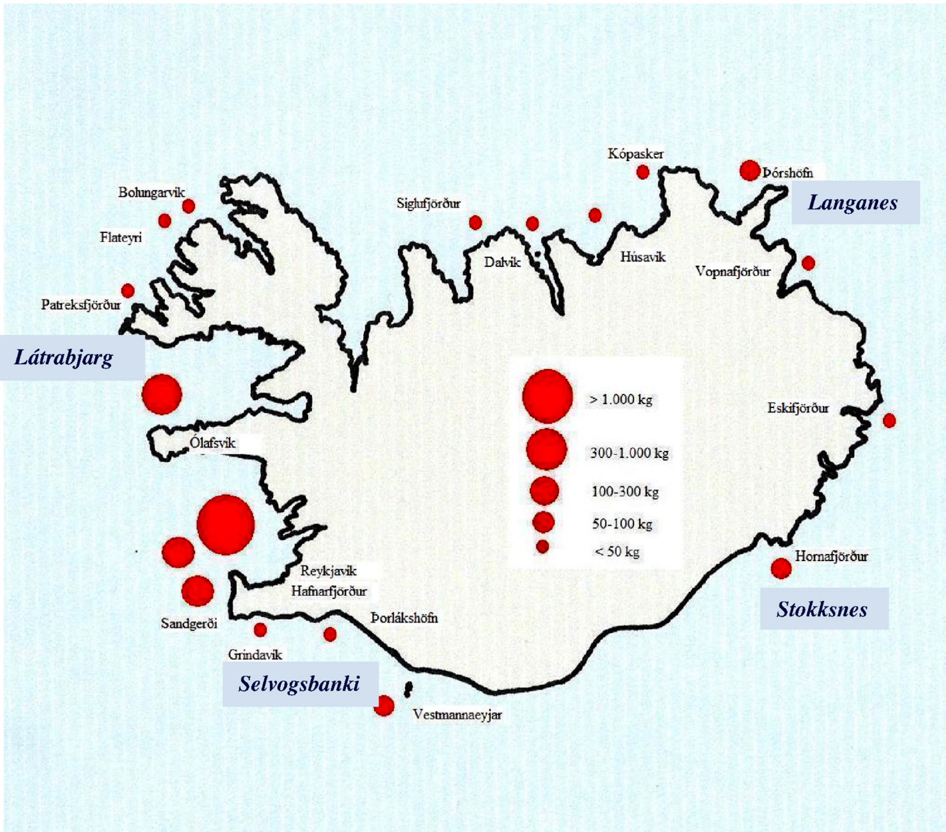

Fig. 1. Cumulative landings of turbot in Iceland from 2002 to 2010. Based on data from the Icelandic Fish Markets Database (www.rfs.is). The four sampling areas for otolith analysis are shown in blue. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of the article.)

about its population structure compared to the neighbouring areas.

Stable oxygen isotope analysis of otoliths has previously proven to give useful information of the ambient temperature experienced by fish, allowing reconstruction of seasonal temperatures (Campana, 1999; Morrongiello et al., 2012). The standard corrected ratio of stable oxygen isotopes ^{18}O and ^{16}O ($\delta^{18}O$) in otoliths are inversely related to ambient seawater temperature and $\delta^{18}O$ in the water at the time of otolith accretion, and can be used to estimate previous ambient temperature experienced by the fish to a high degree of accuracy and precision (Høie et al., 2004a). With sufficient otolith growth available for analysis, and clearly identifiable seasonal structures, the seasonal range of temperature variation can be estimated. The accretionary nature of fish otoliths coupled with recent advances in micromilling technology (Høie et al., 2004b) has enabled extraction of high-resolution aliquots of aragonite that represent a time average of a few weeks to months, depending on otolith size and growth. In the present study otolith isotope analysis and high-resolution micromill sampling techniques will be used to estimate the temperature range experienced by wild turbot in Icelandic waters.

Given the sudden increase in annual reported landing of turbot in Iceland, the objective of this study was to incorporate stable isotope analysis of otoliths and genetic methods to improve the basic understanding of life history of turbot in Icelandic waters and to investigate the origin of the present turbot population in Iceland. In the present study turbot collected across four locations North-east Atlantic Ocean was analyzed using genetic analysis. Further, was isotope analysis of otoliths from turbot sampled in Icelandic waters used to estimate temperature range of turbot collected across several locations around Iceland.

2. Materials and methods

2.1. Genetic analysis across North-east Atlantic Ocean

A total of 201 individuals were collected at several locations in the North-east Atlantic Ocean in the years 1998–2011 (Table 1). Muscle and fin clips samples were collected from each individual and conserved in 99% ethanol. Samples were genotyped at 12 microsatellite loci [Sma-USC10, Sma-USC18, Sma-USC19, Sma-USC24, Sma-USC26, Sma-USC27, Sma-USC34, Sma-USC36 (Pardo

Table 1
Sampling information and environmental information for turbot used in genetic analysis across North-east Atlantic Ocean.

Sampling area	Latitude	Longitude	Sampling time	N	Winter SST	Summer SST
S-Norway	57.47 N	6.26 E	2011	45	6.1	12.8
Irish Sea	53.62 N	5.10 W	1998–2000	28	7.9	13.6
Kattegat	56.50 N	11.30 E	2009–2010	58	2.7	16.1
Iceland	63.2–64.0 N	14.0–25.2 W	2009–2011	70	5.9	12.3

SST, mean sea surface temperature (°C) (source: http://ocean.ices.dk/data/surface/surface.htm) in the sampling period for each sampling area.
Sampling latitude and longitude reflect sampling position midpoint.