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# Variations in length and growth of Greenland Halibut juveniles in relation to environmental conditions

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ABSTRACT

Greenland Halibut (*Reinhardtius hippoglossoides*), especially juveniles, are abundant in the St. Lawrence estuary, where oxygen levels are very low (18–25% saturation). Current data suggest that juveniles may be sedentary in this region. We investigated the relative importance of oxygen for juvenile growth in different areas occupied by juveniles in the estuary and Gulf of St. Lawrence (EGSL). More specifically, we examined the mean size-at-age for 1- and 2-year-old juveniles as well as the growth rate in different areas in relation to oxygen, depth, temperature, and juvenile density. Overall, oxygen concentration was found to affect juvenile Greenland Halibut growth: growth rate varied inversely with dissolved oxygen levels and significantly decreased when oxygen conditions were below 80 μmol/L (∼25% saturation). Temperature did not affect juvenile growth rates within the range found in these areas (4.95–5.14 °C). Mean lengths in 1- and 2-year-old juveniles (17 and 27 cm, respectively) as well as length increment estimates from 1 to 2 years old in the EGSL were much higher than those observed in other populations of Greenland Halibut. Length increment from ages 1 and 2 ranged between 8 and 12 cm for temperatures varying from 3.7 to 5.5 °C. We found the highest abundance of juveniles in bottom waters characterized by low oxygen concentrations and also found that there was continuous juvenile growth over the year; these observations suggest that the negative impacts of dissolved oxygen should be limited and/or largely compensated by other physical or biological characteristics of the EGSL, such as food abundance, food availability, and/or predator density.



## 1. Introduction

Climate change is expected to have impacts on the biology and ecology of marine organisms and ecosystems (Brierley and Kingsford, 2009). Changes in the physical (temperature, ocean current patterns) and biogeochemical (oxygen content, primary productivity, plankton community structure) conditions of different marine ecosystems are expected to lead to strong shifts in species distribution, phenology, and marine fisheries productivity (Edwards and Richardson, 2004; Richardson and Schoeman, 2004; Perry et al., 2005; Hiddink and Hofstede, 2008; Rosa and Seibel, 2008; Cheung et al., 2010; Pörtner, 2010). In particular, pronounced changes are expected in the distribution and abundance of marine fishes (Cheung et al., 2013) along with modifications in their growth, survival, and reproduction (Beaugrand et al., 2002, 2003). Development and growth, and thus organism size, are affected by temperature, oxygen level, and other factors such as resource availability (Irie and Fischer, 2009; Pauly and Kinne, 2010). Recently, Daufresne et al. (2009) and Sheridan and Bickford (2011) showed that rising temperatures associated with a reduction in oxygen availability result in reductions in body size of marine fishes. A recent model examining the integrated changes in ecophysiology and distribution of 600 species of exploited demersal marine fishes around the world demonstrated that the assemblage-averaged maximum body weight could experience a global reduction of 14–24% from 2000 to 2050 based on a high-emission scenario of anthropogenic greenhouse gases (Cheung et al., 2013). About half of this reduction in size is due to changes in distribution and abundance while the remainder is linked to physiological modifications.

A hypoxia trend in bottom waters (>150 m) of the lower St. Lawrence estuary was observed between 1930 and the mid-1980s, with dissolved oxygen (DO) levels decreasing by half in the deep-water layers. This was mainly due to (1) an increase in the proportion of warm, oxygen-poor North Atlantic central water coming into the system, (2) an increase in organic matter flow into the surface layer, and (3) an 11–27% increase in the rate of

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bacterial respiration (Gilbert et al., 2007; Genovesi et al., 2011). This DO decrease was accompanied by a warming of bottom waters by about 2 °C (Gilbert et al., 2005; Genovesi et al., 2011). Since the mid-1980s, oxygen levels in the bottom waters have remained stable (Gilbert et al., 2005).

Ait Youcef et al. (2013) examined the potential effects of hypoxia on the spatial distribution and abundance of Greenland Halibut *Reinhardtius hippoglossoides*, which has been one of the most important commercial demersal flatfish species in this region over the last 20 years. Juvenile and adult Greenland Halibut are concentrated in the estuarine portion of the Gulf of St. Lawrence (habitats characterized by low oxygen levels, ~21% saturation) at both high and low levels of stock abundance. These authors highlighted a strong association between high fish densities and low oxygen concentrations, indicating a high tolerance of Greenland Halibut to hypoxia. Although low levels of oxygen did not directly affect fish distribution, they could have marked effects on growth when adequate food is available. Indeed, under laboratory conditions, Dupont-Prinet et al. (2013) showed that severe hypoxia (19% saturation; levels presently encountered in the St. Lawrence estuary) reduced the aerobic scope by 72% compared to normoxia and increased the duration of digestive processes in Greenland Halibut juveniles. However, whether this reduction of aerobic scope would impact the growth of wild fish has not been assessed.

A reduction in growth rate would be of major concern because 16% of the Greenland Halibut biomass, including a high concentration of juveniles (1 and 2 years old), is found in the St. Lawrence estuary (MPO, 2010), which is characterized by low DO levels. Indeed, the estuary has been identified as the main nursery area in this system (Ait Youcef et al., 2013). Moreover, juvenile Greenland Halibut that settle in the St. Lawrence estuary are sedentary for at least their first 2 years of life (Ait Youcef et al., 2013). The aim of this study is to determine the relative importance of dissolved oxygen on the growth of juvenile Greenland Halibut. To do this, we examined the environmental characteristics of different areas occupied by juveniles. More specifically, growth rate and mean size at age 1 and 2 in juveniles in the different areas were examined in relation to DO, depth, temperature, and juvenile density. The mean size-at-age of juveniles in early spring and fall in the St. Lawrence estuary was used to determine the seasonal growth pattern. Finally, the relative importance of low DO levels was examined by comparing juvenile sizes-at-age observed in other populations.

## 2. Materials and methods

### 2.1. Data collection

Biological data for Greenland Halibut were obtained from the multidisciplinary research bottom-trawl survey conducted in the estuary and Gulf of St. Lawrence (EGSL; NAFO Division 4RST) each summer since 1990 by the Department of Fisheries and Oceans, Canada (DFO). Surveys used a stratified random sampling strategy with predetermined strata based on geographic region and depth (Gagnon, 1991). A detailed description of the survey design is provided in Ait Youcef et al. (2013). Additional data were also obtained from smaller scale bottom-trawl surveys conducted in the spring (April–May) and fall (October) from 2006 to 2010 in the St. Lawrence estuary. These surveys also used a stratified random sampling design, with tows made in depths ranging from 150 m to 350 m.

For each survey, total catch weight and individual fish length (fork length, cm) and weight (g) of Greenland Halibut were recorded for each set; sex and maturity stage were also noted. For sets with large catches, a random sample of a maximum of 175 individuals was analyzed. In the summer surveys, CTD casts were done at each trawl station to obtain temperature and salinity profiles. Starting in 2004, CTD profilers were equipped with Sea-Bird SBE43 oxygen sensors to measure dissolved oxygen levels at each trawl station. Beginning in 2006, an Aanderaa 3930 oxygen optode/temperature sensor was also attached to the trawl. Some CTD profiles were also done during the spring and fall surveys. A data logger (Vemco minilog-TD) was installed on the trawl to record trawl depth and bottom temperature for each set.

### 2.2. Depth, temperature, dissolved oxygen, and fish density

Average yearly depths, temperatures, and dissolved oxygen concentrations in strata from the EGSL occupied by Greenland Halibut juveniles were calculated from data collected during the DFO summer multidisciplinary surveys. The abundance of juveniles in each tow was used as the weighting factor in calculations. Average depth, temperature, and dissolved oxygen concentrations were estimated for each stratum each year. Depth, temperature, and juvenile density were analyzed for the 1990 to 2012 period while dissolved oxygen concentrations were analyzed for the 2004 to 2012 period.

Fish density per area, determined as the mean number of Greenland Halibut juveniles per standard tow in each area $\bar{Y}_t$, was calculated as:

$$\bar{Y}_t = \sum_{h=1}^{K} \frac{A_h}{A_T} \bar{y}_h \quad (1)$$

where $A_h$ is the surface of stratum $h$, $A_T$ the total surface of the area, $K$ the number of strata in the area, and $\bar{y}_h$ the mean number of juveniles per standard tow in stratum $h$. Fish with lengths smaller than or equal to 30 cm were considered as juveniles, and most of these fish are considered to be of ages 1 and 2 (DFO, 2011).

### 2.3. Length–frequency distribution

Mean lengths-at-age and growth of Greenland Halibut juveniles were estimated from length–frequency distributions of the different surveys. For each survey, length–frequency distributions were analyzed for three distinct areas to take into account spatial variations in environmental conditions and fish densities in the EGSL (Ait Youcef et al., 2013). The three areas identified were (1) the St. Lawrence estuary (SLE), (2) the area northeast of Anticosti Island (NEA), and (3) the Laurentian Channel (LC) (Fig. 1). In the delineation of these areas, the homogeneity of the physical conditions for the different strata included in each area was tested.

In the absence of age determination, an analysis of the length–frequency distribution was used to determine the mean lengths at age of Greenland Halibut juveniles. This analysis was restricted to the juvenile stage, since juveniles are considered to be sedentary for at least their first 2 years of life in the EGSL (Ait Youcef et al., 2013). Length–frequency distributions were analyzed separately for each area and year between 1990 and 2012. Only fish measuring less than 40 cm were considered for the analysis. Mean lengths-at-age and juvenile growth obtained were related to environmental factors (depth, temperature, and oxygen) and fish density.

Fish length–frequency distributions typically show distinct modes representing different age groups (Macdonald, 1987). Mixed probability density functions (mixture models) were fit to each distribution to determine the mean length for each mode (i.e., age group) (Ricker, 1975). The mixed probability density function is a weighted sum of $k$ probability density functions:

$$g(x|\pi, \mu, \sigma) = \pi_1 f(x|\mu_1, \sigma_1) + \cdots + \pi_k f(x|\mu_k, \sigma_k) \quad (2)$$