Aquaculture and Fisheries 2 (2017) 24–33

Contents lists available at ScienceDirect

Aquaculture and Fisheries

journal homepage: www.keaipublishing.com/en/journals/aquaculture-and-fisheries/

Original research article

Can back-calculated lengths based on otoliths measurements provide reliable estimates of Atlantic halibut (*Hippoglossus hippoglossus*) growth in the Gulf of Maine (U.S.A.)?

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ARTICLE INFO

Article history:
Available online 23 February 2017

Keywords:
Otolith
Back-calculation
Growth
Gulf of Maine
Hippoglossus hippoglossus

ABSTRACT

Atlantic halibut (*Hippoglossus hippoglossus*, Linnaeus, 1758) are a data-poor stock within the waters of the United States. This study evaluated the use of otolith measurements to back-calculate lengths of Atlantic halibut at previous ages. Back-calculations have proven useful for estimating length at age and growth rates of other species. To the best knowledge of the authors, this study is the first to document the use of this method for Atlantic halibut. Otolith back-calculations rely on a few key assumptions, such as proportionality of fish length and otolith length, which are not always met. This study shows that back-calculations using the Fraser-Lee method can provide reasonable estimates of Atlantic halibut length at previous ages, especially when samples from young halibut are included to improve estimates of the intercept of the linear regressions. Based on back-calculated estimates, female and male halibut in the Gulf of Maine showed different growth rates after age five. There was no evidence of changes in growth rates over an approximately 15 year time period. Halibut caught in the Gulf of Maine and on the neighboring Scotian Shelf showed some differences in growth rates; however, the results did not support strong conclusions about differences between the two regions as the direction of the differences was not consistent between the sexes and previous tagging studies have shown extensive movement between the two areas. The finding of reasonably accurate back-calculated lengths at previous ages is important for this data-poor species, as back-calculations increase the amount of information that can be obtained from otoliths.

1. Introduction

In the early 1800s Atlantic halibut (*Hippoglossus hippoglossus*, Linnaeus, 1758) were so abundant in the Gulf of Maine (GOM) as to be considered a nuisance to fishermen targeting Atlantic cod (*Gadus morhua*, Linnaeus, 1758) and other groundfish. Halibut were an abundant, low-value species in New England until the mid-nineteenth century when the expansion of railroads, changing social tastes, and declining abundances of other commercial species led to the development of a brief but intense targeted commercial halibut fishery in the GOM. In some areas, fishermen noticed declines in halibut abundances after little more than a decade of targeted commercial fishing. Halibut abundances throughout the GOM collapsed by the turn of the century (Goode & Collins, 1887; Grasso, 2008). The stock remains overfished (Northeast Fisheries Science Center, 2015). The National Marine Fisheries Service considers Atlantic halibut a “species of concern”, a designation for species the agency thinks may warrant listing as endangered or threatened under the Endangered Species Act, but for which insufficient data exist to make such a listing determination.

Both fisheries-independent and fisheries-dependent data on halibut in the GOM are quite limited. Semi-annual fishery-independent bottom trawl surveys that take place in the region catch few halibut each year, in most years catching fewer than ten halibut and in some years catching no halibut (Blaylock & Legault, 2012; Sherman, Stepanek, King, Tetrault, & Eckert, 2012). This is likely the result of low abundances and survey gear selectivity. Fisheries for Atlantic halibut in the GOM are relatively small. Landings throughout the northeast U.S., including state and federal waters,

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http://dx.doi.org/10.1016/j.aaf.2017.01.002

averaged 32.5 mt per year from 2007 through 2014 (Northeast Fisheries Science Center, 2015). Maine is the only state which allows a directed fishery in state waters. From 2007 through 2014, the Maine Atlantic halibut commercial fishery averaged 23.00 mt landed per year (DMR, 2016).

The Scotian Shelf and Grand Banks (both in Canadian waters) are generally considered the center of halibut distribution in the Northwestern Atlantic. The GOM is in the southern extent of the species' range (Collette & Klein-MacPhee, 2002, pp. 569–572; Trumble, Neilson, Bowering, & Mccaughran, 1993). Past studies have shown evidence of regional variation in Atlantic halibut growth rates (Armsworthy & Campana, 2010; Haug, 1990; Sigourney, Ross, Brodziak, & Burnett, 2006). A tagging study found extensive movement of Atlantic halibut between the GOM and nearby Canadian waters (Kanwit, 2007). One objective of this study was to compare growth rates of halibut in the GOM to halibut in neighboring Canadian waters to determine if there are differences in growth between these regions.

This study examined halibut growth rates in the GOM using a collection of otoliths obtained from a variety of sources. Most otoliths were obtained from cooperative research efforts carried about by the Maine Department of Marine Resources (DMR) with commercial halibut fishermen and seafood dealers (DeGraaf & Bennett, 2010; Kanwit, 2007). These samples were used to characterize length at age and growth of halibut off the coast of Maine and to evaluate the use of back-calculated size at previous ages based on otolith measurements. Back-calculations based on otolith measurements have proven useful for estimating individual growth for others species, including the closely-related Pacific halibut (*Hippoglossus stenolepis*, Southward, 1962, 1967; Campana, 1990). The authors found no examples of back-calculations of size at previous ages for Atlantic halibut in the peer-reviewed literature.

Back-calculations rely on a number of assumptions, the most important of which is the assumption of a proportional relationship between otolith size and fish size. This assumption is not always met on an individual level and it is often not met when growth rates vary within a population. For example, slow-growing fish can have relatively large otoliths compared to faster growing fish. This can result in underestimation of lengths at previous ages, especially for older fish, and is known as Lea's phenomenon (Campana, 1990; Campana & Jones, 1992). If issues of bias in back-calculated estimates are minimal for Atlantic halibut, this method could provide new information based on existing data. Atlantic halibut are not a research priority in the GOM and are likely to continue to be data-poor, at least for the near future, thus any new information gleaned from existing data may prove useful.

2. Methods

2.1. Origin of otolith samples

A total of 416 left sagittal Atlantic halibut otoliths were examined. Most (i.e. 393) of these otoliths were collected during a cooperative research survey organized by the DMR. Fifteen of the otoliths were collected by the DMR through a sampling program focused on commercial fishermen and fish dealers (Table 1). The DMR collected hundreds of additional otoliths which were not examined because the sex of the halibut from which they were obtained was not known.

All DMR samples (i.e. samples from the cooperative research survey and the commercial fishery) came from halibut caught with circle hooks on demersal longlines (called tub trawls by Maine fishermen). The cooperative survey employed commercial halibut fishermen and their vessels and operated under the same gear, season, and minimum fish size restrictions as the Maine commercial halibut fishery. The survey took place from Penobscot Bay, Maine to the Canadian border, from 3 to about 30 nautical miles from shore (Kanwit, 2007). The Maine commercial halibut fishery is limited to state waters (0–3 miles from shore). All DMR samples were collected during the months of May and June.

Six additional left sagittal otoliths were obtained from halibut caught in Cobscook Bay, Maine as part of a University of Maine bottom trawl survey (Vieser, 2014, p. 133). Two additional left sagittal otoliths were obtained from the GOM Northern Shrimp trawl survey carried out by the Northeast Fisheries Science Center (NEFSC) (Table 1). These eight additional samples from bottom trawl surveys were included in the sample to provide information on small halibut. All samples collected with longline gear were from halibut greater than 86 cm, due to minimum fish size restrictions in the cooperative research survey and the commercial fishery. Longline gear tends to capture larger halibut than bottom trawls gear (Armsworthy & Campana, 2010; Neilson, Waiwood, & Smith, 1989; Scott & Scott, 1988; Sigourney et al., 2006). Additionally, Sigourney et al. (2006) found that longlines capture halibut with larger sizes at age than bottom trawls. The impacts of gear effects on the results of this study are assumed to be minimal because the sample of otoliths from halibut caught with bottom trawls was much smaller than longline sample (Table 1).

One of each pair of otoliths was embedded in resin, cross sectioned, and photographed according to DMR protocols (DeGraaf & Bennett, 2010).

2.2. Growth data for comparison with Canadian waters

The Bedford Institute of Oceanography provided age and length data for 1655 4–15 year old Atlantic halibut caught between 1999 and 2005 in the Canadian commercial halibut fishery on the Scotian Shelf ($n_{female} = 553$, $n_{male} = 304$) and southern Grand Banks ($n_{female} = 497$, $n_{male} = 301$). These otoliths were from halibut caught with longline gear and circle hooks (Armsworthy & Campana, 2010). These data were only used to compare growth of halibut in the GOM with growth in neighboring regions.

2.3. Evaluating the relationship between halibut length and otolith length

Back-calculations rely on the assumption of a proportional relationship between otolith size and fish size (Campana, 1990). This assumption was tested by performing linear regressions of the length of 100 randomly selected otoliths against the length of the halibut from which they came. These 100 otoliths were selected using stratified random sampling to evenly represent both sexes and the full range of sizes in the DMR sample. The 8 otoliths from halibut caught with bottom trawls were not included in this selection. Linear regressions were calculated using six different ways of measuring the otolith to determine which measurement best predicted halibut length. These six measurements were made using dial-readout calipers and the naked eye and included: the posterior radius, the anterior radius, the dorsal radius, the ventral radius, the dorso-ventral diameter, and the antero-posterior diameter (Table 2).

Measurements of right sagittal otoliths were used for the linear regressions of fish length against otolith length; however, annuli measurements from the left sagittal otoliths were used for back-calculations. The position of the nucleus tends to differ between left and right sagittal otoliths (Forsberg, 2001; Welleman & Storbeck, 1995), thus it would have been preferable to evaluate the relationship between otolith length and halibut length using the same "sided" otolith that was used to measure annuli; however, this was not possible because most left sagittal otoliths in the