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Lack of life history change in two over-exploited haddock (*Melanogrammus aeglefinus*) stocks

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ABSTRACT

Concomitant with declines in abundance, many commercially exploited marine fishes have undergone significant life history changes that are critically important as they impact population growth rate and, thus, recovery rate of depleted stocks. By examining data collected as part of offshore surveys conducted during 1971–2012, we evaluated whether there have been changes in growth rate and size at maturity for haddock on Grand Bank and St. Pierre Bank, two over-exploited stocks at the northern extremity of the species range in the western Atlantic Ocean. Contrary to expectation, we found no evidence for change in either growth or maturity since 1971. However, there were differences in life history characteristics between the two stocks, as well as between males and females. Although no difference in growth was observed between sexes, differences in maturation were evident with 50% of males maturing at ~40 cm and 50% of females maturing at ~48 cm. Haddock from Grand Bank were larger than haddock from St. Pierre Bank at ages 8 and 10 by 4.4% and 7.6%, respectively. We also found that haddock on Grand Bank matured at smaller sizes (length at which the probability of maturity was 50% was 38.2 cm for males and 46.3 cm for females) than those from St. Pierre Bank (42.1 cm for males and 49.9 cm for females). The haddock fishery off Newfoundland developed rapidly from 1945 but collapsed within less than two decades. Available information suggests that while fishery exploitation rates were undoubtedly high, haddock on Grand Bank and St. Pierre Bank may not have been exposed to sufficient multigenerational fishing pressure to generate decreases in growth and maturity timing as seen in other over-exploited stocks and appear to have maintained historic life history characteristics.

1. Introduction

Concomitant with declines in abundance, many commercially exploited marine fishes have undergone significant life history changes in recent decades (Ricker, 1981; Rijnsdorp, 1993; Trippel et al., 1997; Olsen et al., 2004; Swain et al., 2007). These changes have been particularly well documented for Atlantic cod (*Gadus morhua*) stocks in the northwest Atlantic. For example, the age at which the probability of maturity is 50% declined 2–3 years over the last 5–6 decades for at least five Canadian Atlantic cod populations (Morgan and Brattey, 2005; Hutchings and Rangeley, 2011; Mohn and Rowe, 2012). Substantial reductions in size at maturity have also been evident. Amongst eastern Scotian Shelf cod, for instance, female length at maturity declined from approximately 50 cm for cohorts in the late 1950s to 35 cm in the 1990s (Mohn and Rowe, 2012). Although not as well studied as Atlantic cod, haddock in some areas have demonstrated similar life history changes. Neuheimer and Taggart (2010) reported marked declines in age at maturity and mature fish length at age since 1970 for haddock on the Scotian Shelf. Changes to life history characteristics often coincide with prolonged periods of exploitation and may be the product of phenotypic or genetic responses to fishing (Heino and Dieckmann, 2001; de Roos et al., 2006; Ghalambor et al., 2007; Conover et al., 2009). Perhaps the most common phenotypic response occurs when reductions in population density from fishing reduce competition for limited resources and thus accelerate growth amongst individuals that remain (Engelhard and Heino, 2004; Georg and Heino, 2004). Faster growing fish typically mature at earlier ages than slower growing fish thus affecting a phenotypic response in age at maturity (Policansky, 1993; de

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Roos et al., 2006). Such phenotypic responses are often short-lived and quick to reverse when there is a reduction in exploitation (Georg and Heino, 2004). In contrast, exploitation of fish stocks can also generate genetic changes which tend to be slow to reverse (Ghalambor et al., 2007; Conover et al., 2009). The probability of genetic responses to exploitation is increased with both the level of fishing mortality and the number of generations exploited (Law, 2000; Hard, 2004; Hutchings, 2005). While it can be challenging to distinguish between phenotypic and genetic responses, analyses that have controlled for potential confounding effects suggest that fisheries-induced evolution may be the most parsimonious explanation for recent life history changes in some over-exploited fish stocks (Olsen et al., 2004; Swain et al., 2007; Neuheimer and Taggart, 2010). Such life history changes are critically important as they impact population growth rate and, thus, recovery rate of depleted stocks (Cole, 1954; Roff, 1984). Reduced age and size at maturity, as well as truncated length distributions can be anticipated to negatively influence population growth rate as a result of factors such as increased post-spawning mortality, shortened life span, and decreased fecundity (Hutchings, 1999, 2005; Beverton et al., 2004; Venturelli et al., 2009; Jørgensen and Fiksen, 2010; but see Kuparinen and Hutchings, 2012).

Haddock is a marine demersal gadoid broadly distributed over continental shelves on both sides of the north Atlantic Ocean ranging from Cape Cod to the southern part of the Grand Banks off Newfoundland in the west and in the Irish Sea, Barents Sea, North Sea, northern Baltic Sea, and the Faroe Islands in the east, as well as around Iceland (Blacker, 1971). They can achieve lengths in excess of 1 m and typically mature at 23–73 cm or 2–7 years of age, depending on the location, with males maturing at smaller sizes and younger ages than females (Blacker, 1971). Adult haddock are broadcast spawners, releasing eggs directly into oceanic waters and providing them with no parental care. They are thought to breed annually for several years with individual females potentially producing hundreds of thousands to millions of small (<2 mm in diameter) pelagic eggs each year (Hodder, 1963; Hawkins et al., 1967; Markle and Frost, 1985). Amongst such broadcast spawners, larger, older individuals typically spawn over longer periods in the season and exhibit higher fecundity (Hodder, 1963; May, 1967; Hutchings and Myers, 1993; Wright and Trippel, 2009).

The waters off southern Newfoundland represent the northern extremity of haddock distribution in the western Atlantic Ocean. Haddock in this area comprise two distinct management units or stocks occupying Grand Bank and St. Pierre Bank in Northwest Atlantic Fishery Organization (NAFO) Divisions 3LNO and Subdivision 3Ps, respectively (Fig. 1). Although haddock were abundant (Thompson, 1939), a significant fishery did not begin off Newfoundland until the mid-1940s (May, 1964). The fishery developed quickly with landings of approximately 105,000 t in 1955 but with only sporadic recruitment and having harvested many of the old and large fish of the virgin population, catch levels rapidly declined to reach low levels (<10,000 t per year) by the mid-1960s (May, 1964; DFO, 2014a, 2014b). There was a small increase in catch during the 1980s, primarily as a result of a relatively strong 1981 year class, but this was not sustained and local stocks have been under moratorium to directed fishing since 1993 although haddock continue to be taken as bycatch in other fisheries (DFO, 2014a, 2014b). Bycatch levels since 1993 have averaged 136 t and 277 t annually in NAFO Divisions 3LNO and Subdivision 3Ps, respectively (DFO, 2014a, 2014b).

Given the large changes in haddock life history that have occurred in nearby areas (Neuheimer and Taggart, 2010) and the absence of studies on haddock in Newfoundland waters since the 1970s (Templeman et al., 1978a, 1978b; Templeman and Bishop, 1979a, 1979b), we set out to examine current life history patterns and their implications for management of a potential haddock fishery in the future. Specifically, by examining data collected as part of offshore research surveys conducted during 1971–2012, we evaluated growth rate and size at maturity for both the Grand Bank and St. Pierre Bank haddock stocks including potential sexual and interstock differences, as well as whether there have been any shifts in these traits over time.

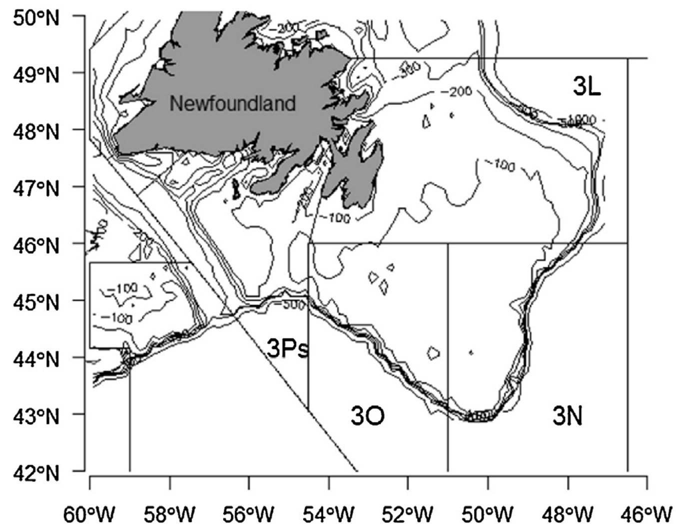

Fig. 1. Waters off Newfoundland showing NAFO Divisions 3LNO and Subdivision 3Ps as well as 100–500 m and 1000 m depth contours.

2. Materials and methods

Haddock life history characteristics in NAFO Divisions 3LNO and Subdivision 3Ps were assessed using data collected from offshore research depth-stratified random bottom trawl surveys conducted during 1971–2012 by Department of Fisheries and Oceans (DFO) Canada. NAFO Divisions 3LNO were surveyed in spring from 1971 to 2012 although there was no survey in 1983. NAFO Subdivision 3Ps was surveyed mainly in February and March from 1972 to 1992 but in April-May since 1993. Although differences in survey timing could impact perceived growth rates, we made no attempt to adjust measurements as 80% of growth takes place between August and November, outside of the winter-spring survey period (Needler, 1931). During 1971–1982, surveys were conducted using the Yankee trawl which was replaced by the Engels trawl during 1983–1995, and the Campelen trawl during 1996–2012. Upon capture at sea, fork length (from the tip of the snout to the medial aspect of the caudal fin) of each individual haddock was measured to the nearest centimetre. Sex and maturity status of each individual were determined by observation of gross morphology of the gonad (Templeman et al., 1978b). For a length stratified subset of captured individuals, scales were extracted for age estimation using standard procedures (Penttila, 1988).

2.1. Growth

Haddock growth was described using the organic growth equation developed by von Bertalanffy (1938)

$$L_t = L_\infty (1 - e^{-k[t-a_0]}) + \varepsilon \quad (1)$$

whereby length at age (L_t) is a function of maximum body length (L_∞), a growth rate coefficient that determines how fast maximum size is attained (k), and the hypothetical age that individuals