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Relative strength of three cohorts (2015-17) of Atlantic Cod, from nearshore surveys of demersal age 0 and 1 juveniles in Newman Sound, Bonavista Bay

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Foreword

This series documents the scientific basis for the evaluation of aquatic resources and ecosystems in Canada. As such, it addresses the issues of the day in the time frames required and the documents it contains are not intended as definitive statements on the subjects addressed but rather as progress reports on ongoing investigations.

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ABSTRACT

We qualitatively assessed the relative strength of three cohorts (2015-17) of Atlantic Cod (*Gadus morhua*) based on abundance of demersal age 0 and 1 juveniles in Newman Sound, Bonavista Bay in summer and autumn of two years (2016-17) at nearshore sites (<10 m deep) using a seine net. Our assessment was based on comparisons with abundance of Atlantic Cod sampled at 6-12 sites, every 2 weeks from July until November, from 1995-2017 in Newman Sound, Bonavista Bay. Analysis of annual length frequency and abundance data indicated that age 0 Atlantic Cod settled in the nearshore in several distinct pulses, the first pulse arriving in early August in 2016 and mid-July in 2017, which was typical for this coastal location. Second and subsequent pulses followed the first by as much as two months later. The 2016 and 2017 cohorts were numerically strong, especially for the first recruitment pulse. The 2015 and 2016 cohorts remained strong as age 1 fish in 2016 and 2017 seasons. Age 0 and 1 abundances in Newman Sound in 2016 and 2017 suggests that all three of these cohorts will be moderate to strong, relative to other cohorts in the time series, but well below that of the large 2013 cohort, which remains the strongest cohort in the time series. Stronger than average abundances and lower than average age 0 mortality rates within season have been observed during each of the past three years (2015-17) compared to other years within our 22 years of monitoring. In addition, preliminary results of a companion study we conducted at eight additional coastal sites in both Trinity Bay and Notre Dame Bay in 2017, supported our long-held view that settlement pulse structure of Atlantic Cod in Newman Sound is typical of broad patterns by age 0 juvenile cod along the northeast Newfoundland coast from all three of these major bays.

INTRODUCTION

Age 0 and 1 Atlantic Cod in NAFO Divisions 3K and 3L (Northeast Newfoundland Shelf) are distributed predominantly in inshore waters (DFO 2006; Dalley and Anderson 1997). During autumn months within these inshore waters, age 0 cod are most common in depths less than 10 m (Methven and Schneider 1998), due to the influence of piscivorous fishes in deeper waters (Linehan et al 2001). The Fleming surveys historically (1959-64, Lear et al. 1980; 1992-97, e.g., Methven et al. 1998), sampled nearshore abundances of juvenile Atlantic Cod in this depth range with the objective of assessing relative year-class strength of adjacent cohorts. The working principle employed was that the relative strength of adjacent cohorts in the first years of life is carried through to subsequent age groups within that cohort over time (Schneider et al. 1997).

In autumn 1995, an investigation of the abundance of age 0 cod and their association with nearshore habitat types and coastal ecology was initiated in Newman Sound, Bonavista Bay by Gotceitas et al. 1996. The 1995 study was followed by similar efforts during the years 1996-2015 (e.g., Gregory et al. 1997, 1999, 2000, 2002, 2004, 2006, 2017, 2018). These studies have collectively shown that the nearshore of Newman Sound is a nursery area for demersal fishes, including age 0 Atlantic Cod. In this study, we have continued to track the strength of temporally adjacent cohorts in Newman Sound, through the first two years of life.

We have qualitatively assessed the relative strength of three cohorts (2015-17) of Atlantic Cod based on abundance of demersal age 0 and 1 juveniles in Newman Sound, Bonavista Bay in summer and autumn of two years (2016-17). We compared the abundances of age 0 and age 1 Atlantic Cod to those in previous years (1995-2015). We have previously shown that interannual trends between the Newman Sound data and the larger geographic scale Fleming survey data are consistent (Methven et al. 1998; Gregory et al. 2002, 2004, 2006). We also suggest that during years of relatively high recruitment, settlement occurs in more than one pulse (Methven and Bajdik 1994; Grant and Brown 1998; Gregory et al. 2006, 2017) several weeks apart. The three cohorts examined in this report represented several of the strongest we have yet observed in Newman Sound during the past 22 years.

METHODS

Newman Sound seine sites (Fig. 1) – described in Gregory et al. 1997 – were selected on the basis of sampling logistics. We used seasonal catch data from all 12 of our primary study sites, sampled every two weeks from July to November, in both 2016 and 2017.

Fish samples were collected using a 25 m beach seine – wings, belly and codend consisted of 9 mm stretch mesh; 24.4 m headrope, 26.2 m footrope. Aluminum poles -75 cm long and 25 mm diameter -one on the end of each wing served to maintain the spread between the headrope and footrope. The net was deployed from a 6 m boat at a distance of 55 m from the shore, and then retrieved by two individuals standing 16 m apart on the shore. The seine was pulled along the bottom and sampled the lowest 2 m of the water column. Deployed in the manner described, the net sampled approximately 880 m^2 of the bottom.

All fish collected were identified and counted. Juvenile Atlantic Cod were loosely assigned to age groups in the field based on previously established age-length relationships in Newfoundland waters in late autumn (age 0: ≤10 cm SL [standard length], age 1: 10 to 20 cm SL, and age 2: 20 to 30 cm SL - Dalley and Anderson 1997). Ages were confirmed for age 0 and age 1 fish by examination of otolith microstructure in 1996 and 1997 (Gregory et al.

unpublished data) and 2016 and 2017 (Geissinger and Gregory et al. in prep.) and refined by visual examination of length frequency trajectories throughout each season.

Our analysis consisted of a qualitative comparison of these 2016 and 2017 data to the results of similarly collected data from the entire Newman Sound juvenile cod time series (1995-2017 see above). Comparison of abundance by age within cohort were made using non-parametric sign test and simple unparameterized regression of rank order, across the full time series.

RESULTS AND DISCUSSION

The period 2015-17 produced above average strength cohorts when compared among the 23 -year Newman Sound time series (Fig. 2). The 2013 year-class was the single strongest cohort sampled since the implementation of the 1992 moratorium, and the 2006 cohort remains the lowest. During the past decade, seven cohorts (2007, 2012-17) were relatively strong compared to adjacent cohorts, as age 0 individuals (Fig. 2). Survival rates between years were variable within individual cohorts in the nearshore. High densities as age 0 were consistently followed by higher than average densities at age 1 the following year, for most year classes, with the notable exception of 2014 (Fig. 2). Similarly, low density years as age 0 were succeeded by low densities of age 1 individuals the following year in most instances (e.g., 2003-06 cohorts), with the conspicuous exception of the 2010 cohort (Fig. 2).

Age 0 cod abundance is a qualitative indicator of cohort strength among years. Directional change in age 0 density between adjacent years matches similar changes in age 1 in over 75% of cohorts (Fig. 2). Although qualitatively consistent (i.e., age 1 abundance corresponds loosely with age 0 abundance the previous year, within most cohorts), high interannual variability in age 0 to age 1 mortality appears to make age 0 abundance a poor quantitative predictor of age 1 abundance, in the Newman Sound dataset. However, Newman Sound age 1 abundance and age 3 abundance from Inshore Sequential Population Analysis (SPA) have been positively and highly correlated (>80%) in the past (1995 to 2003 cohorts - DFO 2006; Gregory et al. 2018). Although mortality rates between age 0 and 1 have proven difficult to predict, an annual settlement pattern represented by early settlement followed by a complex pulse structure (e.g., two or more strong modes) has appeared consistently favourable to the production of a strong cohort.

Age 0 pelagic Atlantic Cod settle into nearshore habitats in several settlement pulses each year caused by unique combinations of offshore and onshore wind events (Ings et al. 2008) and remain demersal throughout the remainder of their lives. The implications of multiple settlement pulses on the cohort strength of Atlantic Cod and other gadid species was explored by Ings et al. (2008). Our 2015-17 data (Figs. 3 and 4) indicate a complex and temporally extended pulse structure may signal relatively good recruitment years, compared to years with a simple or weak pulse structure (e.g., only one mode or multiple weak modes). The three cohorts described in this report, showed evidence of moderate to strong settlement pulses about four to six weeks apart, a positive indication of relatively strong cohorts during our 22-year time series. Weak recruitment years (e.g., 1996, 2001, 2003-04; Gregory et al. 2006), in which settlement to the nearshore was often late (i.e., late-August and even early September) and accompanied by few strong pulses, typically do not produce strong cohorts. The 2014 cohort appears to have been such a case (Fig. 2) among recent years (Gregory et al. 2018). The 2014 cohort was entirely absent as age 2 fish during 2016 sampling (Fig. 3). Directional changes in abundance of age 0 individuals between consecutive years have been consistently similar to directional changes in age 1 abundance among cohorts across the data set in 72% of years (13 of 18 comparisons, plus three ties; sign test, $p=0.007$; Fig. 2). Changes among years between adjacent cohorts were in opposite directions less than 12% of the time (sign test; 2 of 18 comparisons, p=0.0013). Similarly, the ranked densities of age 0 and age 1 cod by cohort were correlated across years (ANOVA: F=13.719; d.f. = 1,17; N=19; r= 0.668, p=0.0018).

A similar pulse structure is also generally observed over spatial scales covering multiple embayment's along the northeast Newfoundland coast; it does not appear unique to the vicinity of individual nursery areas such as Newman Sound (Fig. 5). Similar settlement patterns occur annually at widely separated sites along the northeast Newfoundland coast (Methven and Bajdik 1994; Grant and Brown 1998) suggesting that these observations reflect broader geographic phenomena. We investigated this pattern further in 2007 by conducting a protracted juvenile fish beach seining program in Smith Sound, Trinity Bay as well as our annual Newman Sound effort (Gregory and Morris, unpublished data) and again for three monthly occasions in 2017 at a total of eight sites - two sites in each of Bull Arm and Trinity (Trinity Bay), and Fortune Harbour and Woodford Arm (Notre Dame Bay). The seasonal size pattern of age 0 juveniles in Smith Sound was very similar to those in Newman Sound, suggesting that similar settlement dynamics were at play over wider geographic areas and is not restricted to a single embayment. Our preliminary 2017 results (Fig. 5) are similar and more comprehensive. From genetic evidence, we also know that different stock components contributed differentially to each of these settlement pulses in 1999 (Beacham et al. 2000). However, it remains to be determined if individual stock components contribute only to a single pulse (but see Horne et al. 2016). Size-selective mortality factors should affect differential survival between individuals from different recruitment pulses (Sogard 1997) and possibly survival overwinter (Laurel et al. 2017). Our evidence from the Newman Sound cod nursery area suggests that age 0 mortality rates are highly variable – 0.5-11%$\cdot d^{-1}$ – among years and settlement pulses, as calculated from pulse-specific abundance data 1995-2005 (Gregory et al. 2006). The mortality rates of the first settlement pulse (within-season) for the 2015-17 cohorts were among the lowest observed in the 22-year record of the Newman Sound dataset (Fig. 6). The 2017 cohort was dominated by a strong early pulse of age 0 fish settling in early July. Although, followed by only numerically weak subsequent pulses in October-November, this first pulse exhibited low daily mortality (<1.4%$\cdot d^{1}$; Fig. 6) consistent with recent years. Therefore, depending upon mortality during the overwinter period (2017-18), the 2017 cohort could be another strong one among recent years of the 22-year dataset.

Based on the results of this study, we make the following predictions:

- the 2015 and 2016 cohorts will be strong compared to all others we have observed in the 22 years of our research in Newman Sound (1995-2017); and,
- the 2017 cohort will be relatively strong compared to others in the past decade, based on high initial age 0 abundance and low within-season mortality, assuming the 2017-18 winter is not severe.

ACKNOWLEDGEMENTS

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FIGURES

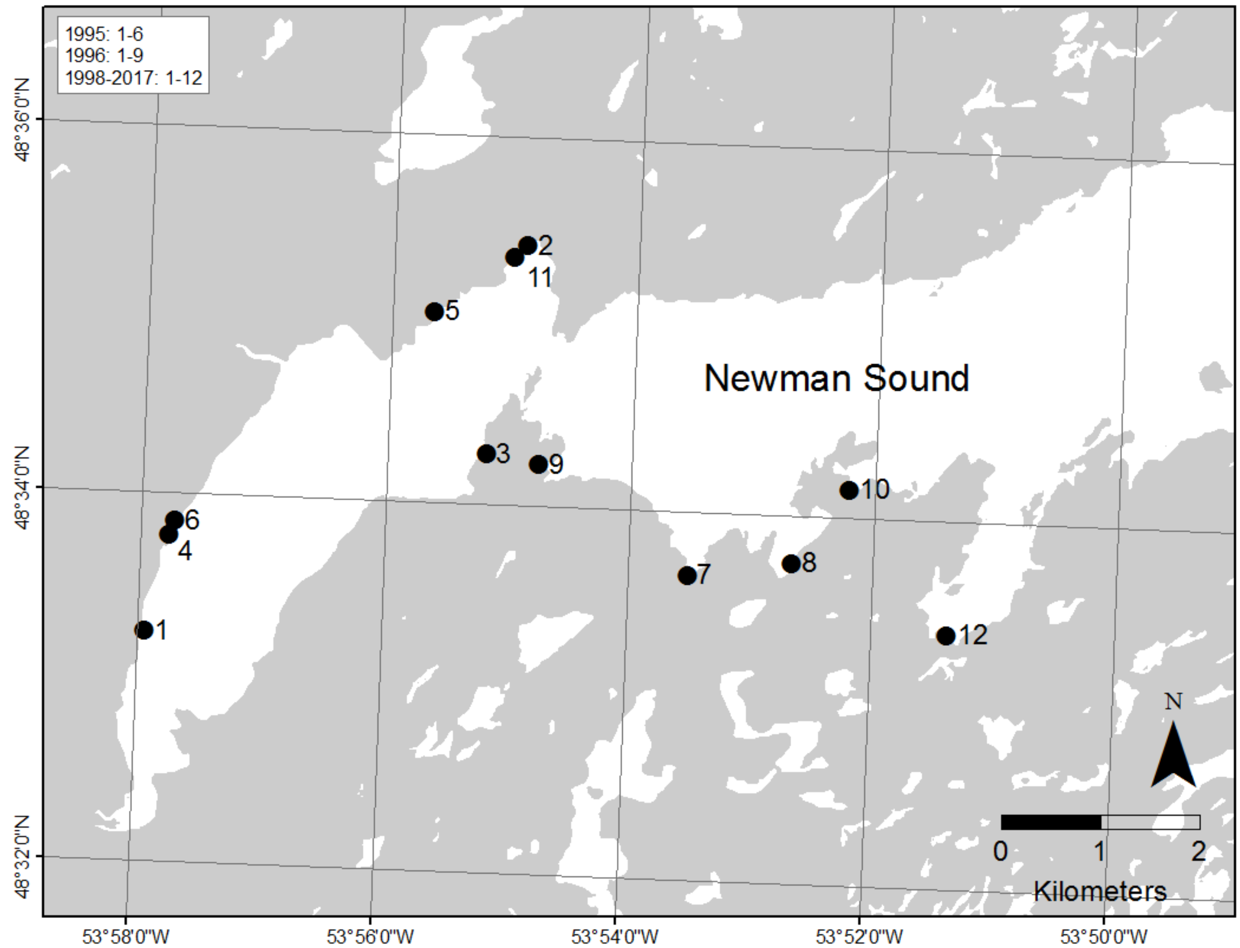

Figure 1. Location of nearshore sampling sites in Newman Sound, Bonavista Bay July to November 1995-2017.

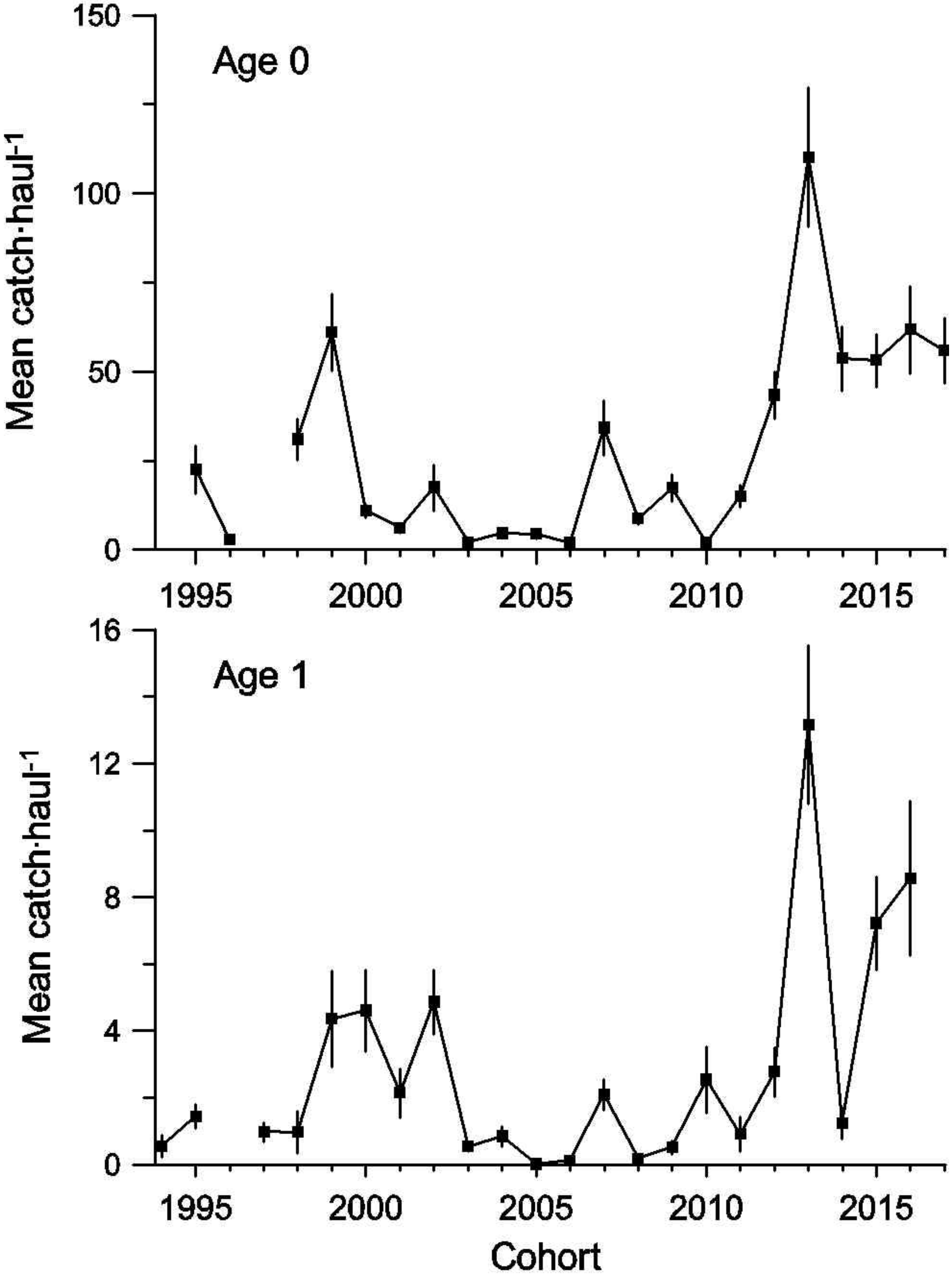

Figure 2. Mean age 0 (top panel) & age 1 (bottom panel) Atlantic cod caught by cohort by beach seine in Newman Sound, Bonavista Bay, 1995-2017 (bars are +/-1 SE; n=102-130 seine sets/year, 48 in 1995).

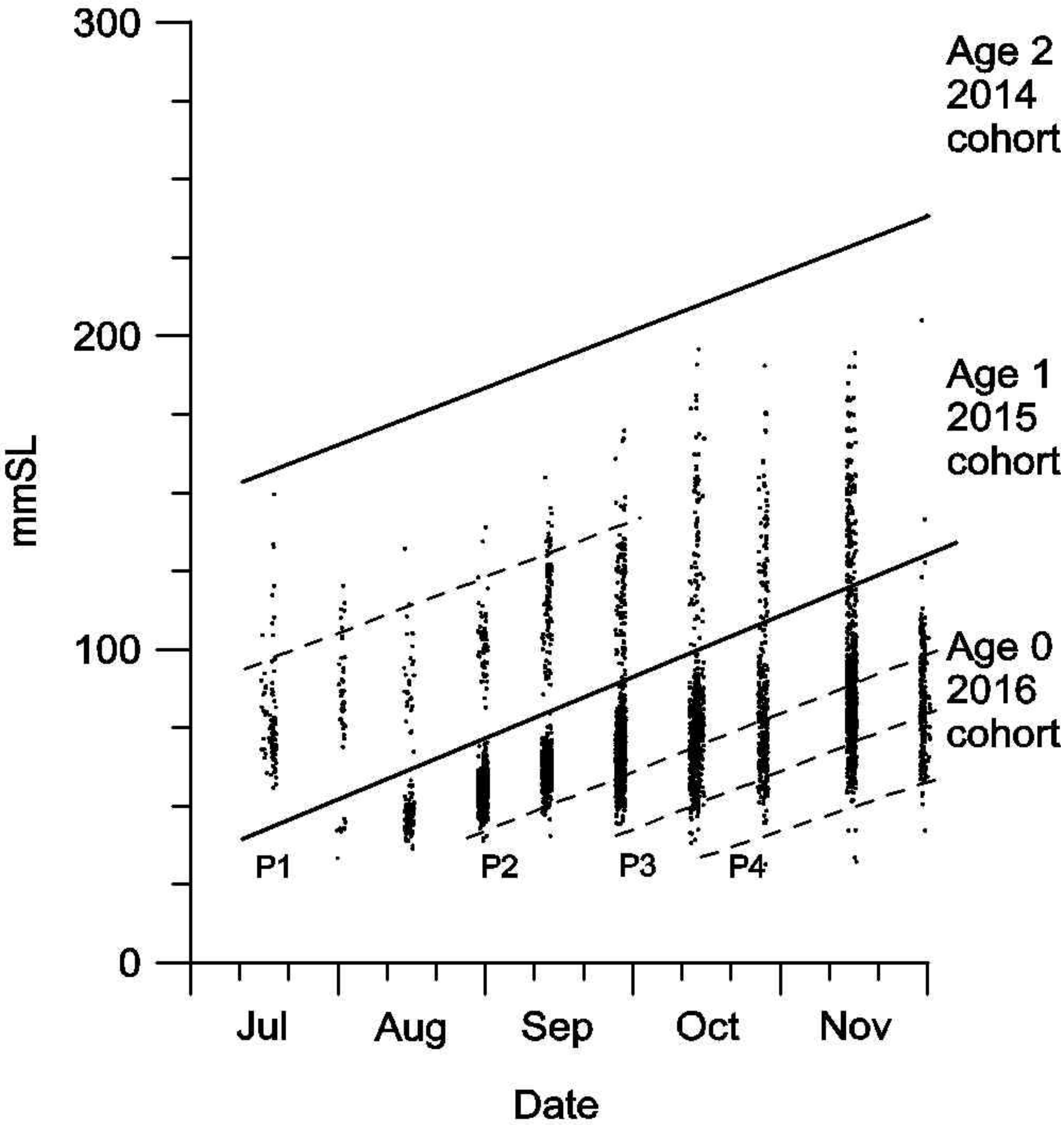

Figure 3. Sizes of Atlantic cod captured by beach seine in Newman Sound, Bonavista Bay, July-November, 2016 and their potential age and settlement pulse structure.

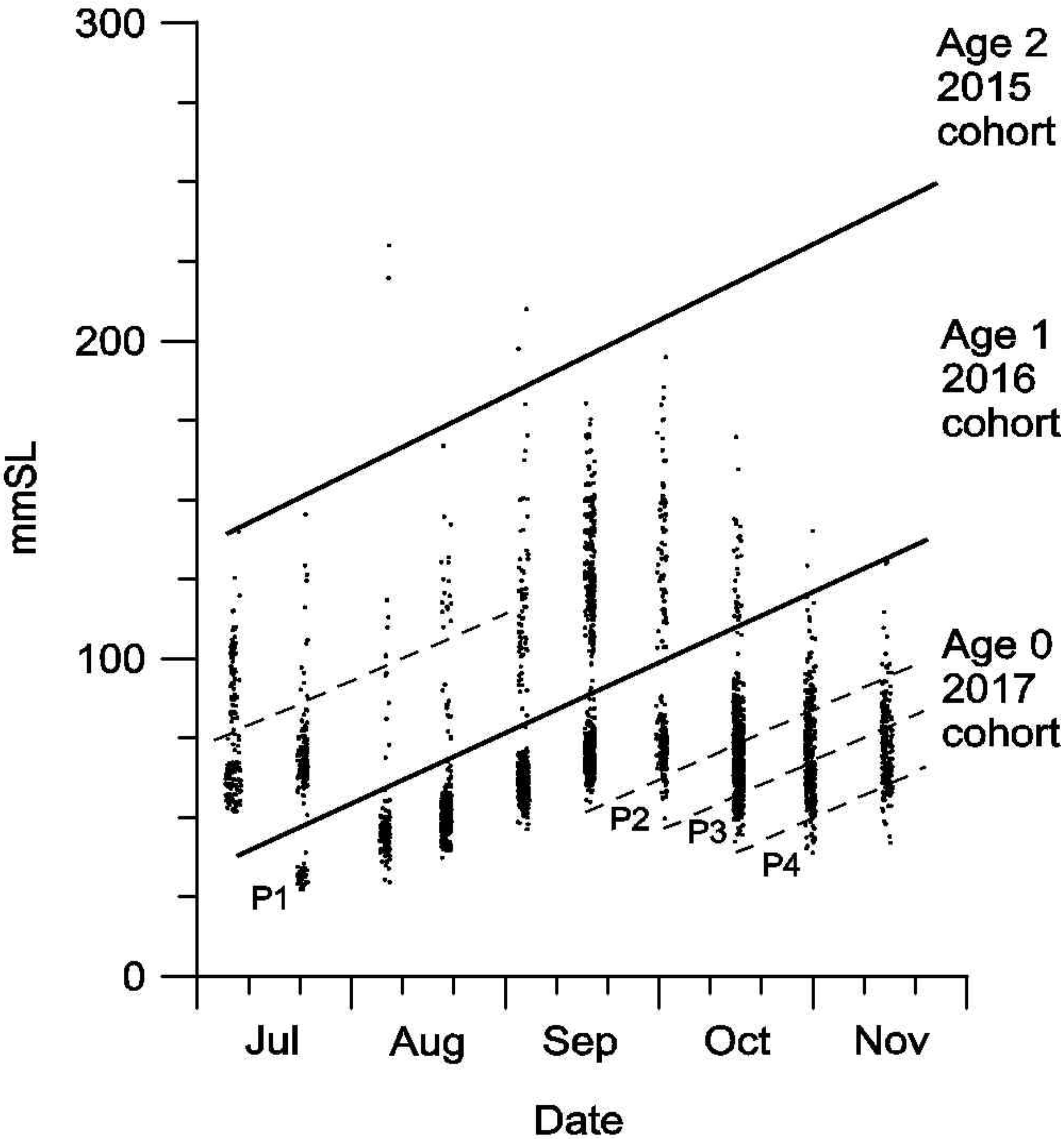

Figure 4. Sizes of Atlantic cod captured by beach seine in Newman Sound, Bonavista Bay, July-November, 2017 and their potential age and settlement pulse structure.

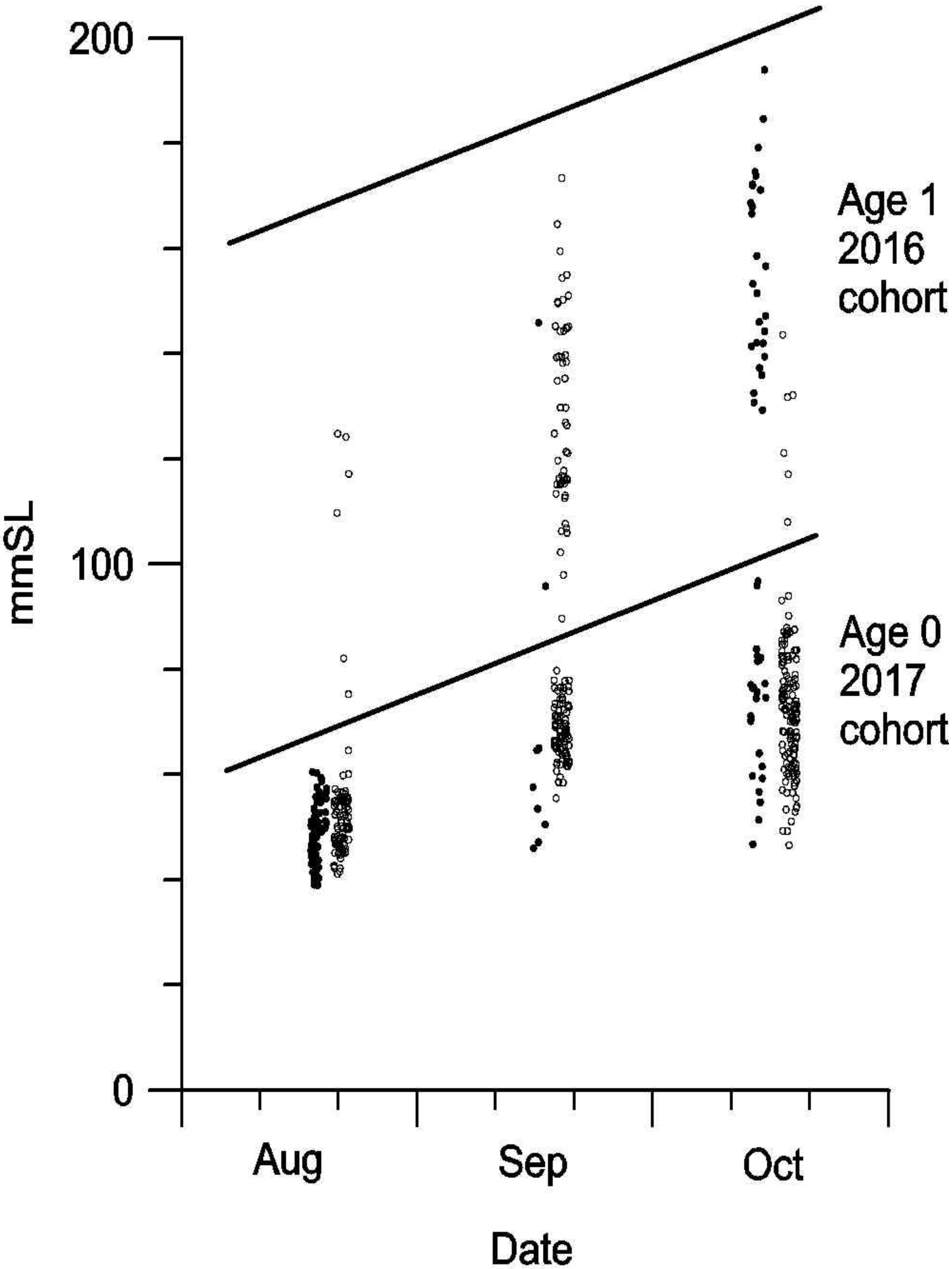

Figure 5. Sizes of Atlantic cod captured by beach seine in 12 Newman Sound, Bonavista Bay (solid) and 8 Trinity Bay and Notre Dame Bay (open) sites, sampled on the same dates (±1 d), Aug-Oct 2017 (20% of points displayed and 3 d offset applied for clarity).

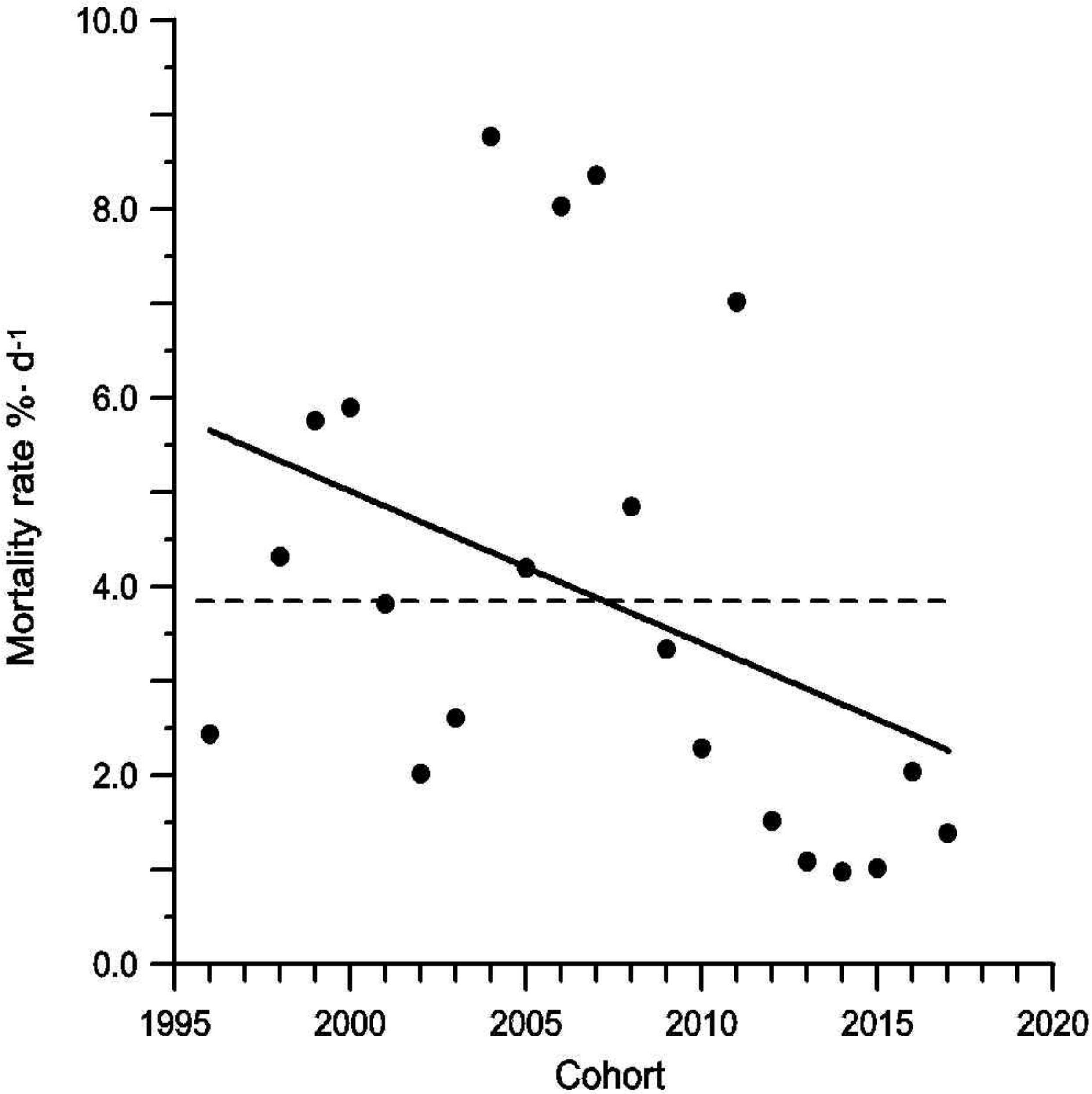

Figure 6. Daily mortality rates of the first settlement pulse of Atlantic cod captured by beach seine in 12 sites in Newman Sound, Bonavista Bay, July-November, 1996-2017 (solid line is the interannual trend; dashed line is the mean mortality rate among all years).