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Strength of Three Cohorts (2016–18) of Atlantic Cod, from Nearshore Surveys of Demersal Age 0 and 1 Juveniles in Newman Sound, Bonavista Bay, Relative to the 2J3KL Stock

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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 (2016–18) 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 (2017–18) 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 two weeks from July until November, from 1995–2018. Analysis of annual length frequency and abundance data indicated that age 0 Atlantic Cod settled in the nearshore in several distinct pulses, a typical pattern along the Newfoundland coast. In 2017, the first pulse of age 0 individuals settled in mid-July; subsequent pulses followed two months later and were numerically weak. In 2018, the first settlement pulse was weak and was detected in early-August; similar to 2017, second and subsequent pulses also arrived two months later and were weak as well. In contrast, the 2016 and 2017 cohorts were above average abundance as age 1 fish in 2017 and 2018, respectively. Abundances at age 0 and 1 in Newman Sound in 2017 and 2018 suggest that 2016 and 2017 cohorts will be moderate to strong, relative to other cohorts in the time series. Due to low abundances of the first and subsequent settlement pulses, the 2018 cohort appears weak in comparison with others in the 23-year Newman Sound time series. Lower than average age 0 mortality rates within season were observed during each of the three cohorts of this study (2016–18) compared to other years within our 23 years of monitoring. In addition, results of a companion study we conducted at eight additional coastal sites in Trinity Bay and Notre Dame Bay in 2017–18, confirmed existing evidence that settlement pulse structure of Atlantic Cod in Newman Sound, Bonavista Bay is typical of broad patterns by age 0 juvenile cod along the northeast Newfoundland coast. The Newman Sound age 0 and age 1 abundances (1999–2015 cohorts) are significantly correlated with the Northern Cod Assessment Model (NCAM) results at age 2 and age 3, especially between age 0 and age 2. The relative interannual change of age 0 across adjacent cohorts was significantly correlated with NCAM results for age 2 and 3 in 80 and 91% of the years of the Newman Sound time series, respectively.

INTRODUCTION

Age 0 and 1 Atlantic Cod in North Atlantic Fisheries Organization (NAFO) Divisions 3K and 3L (Northeast Newfoundland Shelf) are predominantly distributed in inshore waters (Dalley and Anderson 1997; DFO 2006). During autumn months, age 0 cod are most common over substrates shallower than 10 m (Methven and Schneider 1998), due to the influence of piscivorous fishes in deeper waters (Linehan et al. 2001). Historically, the Fleming surveys (1959–64, Lear et al. 1980; 1992–97, e.g., Methven et al. 1998) sampled coastal abundances of juvenile Atlantic Cod with the objective of assessing relative year-class strength among 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). This 1995 study was followed by similar efforts 1996–2018 (e.g., Gregory et al. 1997, 1999, 2006, 2017, 2018, 2019). These studies have collectively shown that the nearshore of Newman Sound is a nursery area for several demersal fishes, including Atlantic Cod. In this study, we have continued to track the strength of temporally adjacent cohorts of age 0 and 1 cod in Newman Sound, through their first two years of life.

We have assessed the relative strength of three cohorts (2016–18) 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 (2017–18). We compared abundances of age 0 and age 1 cod in these two years to those in previous years of monitoring (1995-present). 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 abundance, settlement occurs in more than one pulse (Methven and Bajdik 1994; Grant and Brown 1998; Gregory et al. 2006, 2016) several weeks apart, most likely a by-product of protracted cod spawning activity along the coast (Myers et al. 1993; Hutchings and Myers 1994) and environmental factors – e.g., upwelling and onshore winds (Ings et al. 2008). The three cohorts examined in this report represented a mix of strong and weak annual year-classes, relative to others within our 23-year time series in Newman Sound.

We also report on our findings from two studies expanding the inference of our Newman Sound monitoring effort by broadening the spatial and temporal implications of our results, linking them to NCAM (Cadigan 2016). This model forms the single most substantive data input tool to the 2J3KL cod assessment in the recent decade.

METHODS

Newman Sound seine sites (Figure 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 2017 and 2018.

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. Aluminium 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 this manner, the net sampled approximately 880 m^2 of the seabed at our sites.

All fish collected were identified, counted, and measured (nearest mmSL [standard length]). 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: $\leq$10 cm SL, age 1: 10 to 20 cm SL, and age 2: 20 to 30 cm SL – Dalley and Anderson 1997); biweekly length frequencies were refined at the end of the field season by visual examination of scatterplots for discontinuity. The size gap between age 0 and age 1 fish on each trip, generally makes this process easy to accomplish each year. However, in the process of conducting other research, we have verified these age determinations daily growth increments by examining microstructure of lapillus otoliths in 1996 and 1997 (Gregory et al. unpublished data), and again most recently in 2016 and 2017 (Geissinger et al. 2022). Pulse structure of age 0 and age 1 cod was identified by the application of mixture models for each biweekly sampling trip (Geissinger unpublished data) to distinguish settlement pulses of age 0 juveniles based on the length data from each sampling trip, then resolve discrepancies by visual examination of length frequency trajectories through each season using scatter plots of all fish measurements in each year. Age 1 cod pulse structure was evaluated in the same manner including, early spring data (we have not reported these data here) as a post-winter basis (i.e., overwinter survival) for these assignments.

Leading to the 2019 assessment, we expanded the inference of our Newman Sound age 0 and age 1 monitoring effort by conducting two additional investigations which both broaden the scope of our Newman Sound juvenile cod findings. First, we increased the spatial scope of the inferences of our information. We did this by using identical techniques, at eight additional sites in Trinity and Notre Dame bays (4 each), on the same dates, on three occasions in both 2017 and 2018, we determined consistency in age 0 settlement patterns across 500 km length of coastline (centred on Newman Sound). Second, we increased the temporal scope of our inferences from juvenile cod abundance in Newman Sound cod nursery habitat by comparing abundances with those of the annual cod assessment produced from NCAM (Cadigan 2016), within the assessment meeting itself. Interannual patterns of our age 0 and age 1 abundance within this coastal cod nursery against model output of age 2 and age 3 abundance estimated using NCAM for 21 relevant cohorts across corresponding years (1995–2016 cohorts for age 2, and 1995–2015 for age 3).

Our analysis consisted of a qualitative comparison of these 2017 and 2018 data to the results of similarly collected data from the entire Newman Sound juvenile cod time series (1995–2018 see above). Comparisons of abundance by age within cohort were made using non-parametric sign tests and simple unparameterized regression of rank order, across the full time series. We also conducted a regression analysis of both age 0 and age 1 abundance against NCAM results (DFO 2019) for age 2 and age 3 age groups, by cohort, for the first time.

RESULTS AND DISCUSSION

The period 2016–18 produced mixed results for abundance of age 1 and post-settled age 0 juvenile cod in this study (Figure 2). For age 0, the 2016 and 2017 cohorts were strongly represented (2016, 61.8 ± 12.1·$haul^{-1}$ [mean ± se {standard error} $haul^{-1}$] and 2017, 56.0 ± 9.1·$haul^{-1}$), both above the long-term mean for age 0 (27.5·$haul^{-1}$), for the time series (Figure 2). In contrast, 2018 cohort at age 0 (10.2 ± 1.5·$haul^{-1}$) was well below the 23-year mean. As age 1 fish, the 2016 (8.6 ± 2.3·$haul^{-1}$) and 2017 (3.9 ± 0.7·$haul^{-1}$) cohorts remained above the time-series mean (2.8·$haul^{-1}$). Across the entire time series, the 2013 cohort (age 0, 110.2 ±

19.4·haul^{-1}; age 1, 13.2 ± 2.4·haul^{-1}) was the single strongest cohort sampled, while the 2006 cohort remained the weakest cohort (age 0, 2.0 ± 0.6·haul^{-1}; age 1, 0.1 ± 0.0·haul^{-1}).

In our assessments of pre-recruits for 2J3KL cod prior to 2018, we used age 0 and 1 cod abundance across years as a qualitative indicator of differential strength among cohorts within the time series (Gregory et al. 2018), and Gregory et al. (2019) reported patterns between years across adjacent cohorts (i.e., if age 0 increased between Year 1 and Year 2, did age 1 then also increase between Year 2 and Year 3?), which would suggest that numerical success or failure of a cohort of cod carries forward from age 0 to age 1, within individual cohorts. We have used a similar approach here. During the decade 2007–17, seven cohorts (2007, 2012–17) have been relatively strong compared to adjacent cohorts (Figure 2). Survival rates between years are highly variable within individual cohorts of juvenile cod in the nearshore. However, high densities of age 0 have been consistently followed by higher-than-average densities of age 1 fish the following year, for most year classes (e.g., 1999, 2002, 2007, and 2013), with the notable exception of 2014 (Figure 2). Similarly, low abundance years as age 0 were typically succeeded by low abundance of age 1 individuals the following year in most instances (e.g., 2003–06 cohorts), with the conspicuous exception of the 2010 cohort (Figure 2).[1]

Age 0 pelagic Atlantic Cod settle into nearshore habitats in several settlement pulses each year caused by unique combinations of coastal upwelling and onshore wind events (Ings et al. 2008). Following settlement into nearshore nurseries, age 0 cod remain demersal throughout the remainder of their lives. 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 numerically stronger cohorts, compared to those cohorts where this pattern is absent (e.g., Gregory et al. 2006). The implications of multiple settlement pulses on the cohort strength of Atlantic Cod and other gadid species were explored by Ings et al. (2008). Complex and temporally extended pulse structure appear to signal relatively good recruitment years, compared to years with a simple or weak pulse structure (e.g., only one mode or multiple numerically weak modes). The three cohorts described in this report (2016–18), showed mixed evidence of numerical strength – 2016 was strong with a complex pulse structure which remained evident in 2017 as age 1 fish (Figure 3). In contrast, as age 0 juveniles, the 2017 cohort exhibited an unusually strong first settlement pulse followed by weak subsequent pulses about two months apart. Typically, such a pattern is an indication of a relatively weak cohort during our time series (four weeks between settlement pulses is more common at our sites). The 2017 cohort may represent an exception to the typical pattern, as it was above average strength as age 1. Years of weak recruitment (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 weak pulses, typically do not produce strong cohorts. The 2018 cohort appears to have been such a case (Figure 2 and Figure 4) among the previous seven years (Gregory et al. 2019).

Among cohorts, patterns in age 0 abundance are reflected in age 1 abundance across cohorts in 80% of years (12 of 15 relevant comparisons, sign test, $p=0.0176$; Figure 2). Abundance of age 0 was correlated to age 1, across cohorts 1995–2017 in Newman Sound (Analysis of Variance [ANOVA]; $F=11.949$, $r^2=0.386$, d.f.=1,19, $n=20$, $p=0.0026$, Figure 2). Similarly, the rank order abundance among cohorts between adjacent years (i.e., age 0 to age 1) was significant across the time series (ANOVA; $F=15.379$, $r^2=0.447$, d.f.=1,19, $n=20$, $p<0.001$, Figure 2).

[1] Data from the 2010 and 2014 cohorts form part of an ongoing investigation of abiotic and biotic influences on juvenile cod survival by our group, as of the date of this Res Doc.

In our assessment of the Newman Sound pre-recruit index here, we compared age 0 and age 1 densities with those calculated for age 2 and age 3 (DFO 2019) by the NCAM model (Figure 5). Similar patterns were evident in age 0 to NCAM results (DFO 2019) – age 2 (ANOVA; $F=10.039$, $r^2=0.346$, d.f.=1,19, $n=20$, $p=0.346$) and age 3 (ANOVA; $F=3.734$, $r^2=0.172$, d.f.=1,19, $n=20$, $p=0.172$). However, directional changes in the age 0 abundance between adjacent cohorts were significantly similar across years – age 2 was 80% similar (sign test; 12 of 15 comparisons, $p=0.0176$) and age 3 was 91% similar (sign test; 10 of 11 comparisons, $p=0.0059$). Evidence of similarity among cohorts between Newman Sound age 1 and NCAM age 2 and 3 were generally not significant ($p>>0.05$) or inconclusive ($0.05<p<0.10$). Similar results have been positively and highly correlated in the past (e.g., 1995 to 2003 cohorts; DFO 2006; Gregory et al. 2018). The results (Figure 5) show common years (i.e., 1998–2015) but not all years in our time series (1995–2020), but demonstrate statistical links between Atlantic Cod abundances in nursery habitats and immature Atlantic Cod (age 2 and age 3 abundances in the research vessel survey, before they enter the fishery. These results are supported by similar findings by Cooke (2019) and Lunzmann-Cooke et al. (2021), who described stronger significant links between age 0 and age 1 cod abundance in Newman Sound, with age 3 cod in the RV data in the past decade compared to the decade following the moratorium when stocks were substantially depleted. Cooke (2019) linked the strength of these relationships to improving environmental conditions in the coastal zone over the past decade.

We observed a similar age 0 settlement pulse structure to that which we report in the Newman Sound nursery over spatial scales covering multiple embayments along the northeast Newfoundland coast. Such pulse structure does not appear unique to the vicinity of individual nursery areas such as Newman Sound (Figure 6). Similar settlement patterns have also occurred in other studies at other sites from ours 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). We expanded this approach again in 2017 and 2018 to cover three monthly occasions each year at a total of eight sites – including two sites in each of Bull Arm and Trinity (Trinity Bay), and two sites in each of Fortune Harbour and Woodford Arm (Notre Dame Bay), totalling 48 samples (2 years x 3 months x 8 sites), in addition to their comparison with 72 samples from Newman Sound (2 years x 3 months x 12 sites), on the same dates. 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 were not restricted to a single embayment. Our 2017 and 2018 results (Figure 6) are similar and far more comprehensive than these earlier efforts. From genetic evidence, we 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 settlement pulse (Beacham et al. 2000, Horne et al. 2016). Size-selective mortality factors should affect differential survival between individuals from different recruitment pulses (Sogard 1997) and possibly to survival overwinter (Laurel et al. 2017; Geissinger et al. 2022).

Age 0 mortality rates across the time series in the Newman Sound cod nursery are highly variable ($0.5\text{-}11\%\cdot d^{-1}$) 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 2016–18 cohorts were among the lowest observed in our dataset (Figure 7). The 2018 cohort was dominated by a weak and late-settling first pulse of age 0 fish (mid-August). Although, followed by only numerically weak subsequent pulses in October-November, this first pulse exhibited low daily mortality ($<1\%\cdot d^{-1}$; Figure 7) consistent with those observed throughout the past decade.

Based on our data, we make the following predictions:

- the 2016 cohort will be strong compared to others we have observed in Newman Sound (1995–2018);
- the 2017 cohort will be moderate to strong, compared to others in the past decade, based on its high initial age 0 abundance and low within-season mortality and good overwinter survival to age 1; and
- the 2018 cohort will be weak relative to others across the past two decades.

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FIGURES

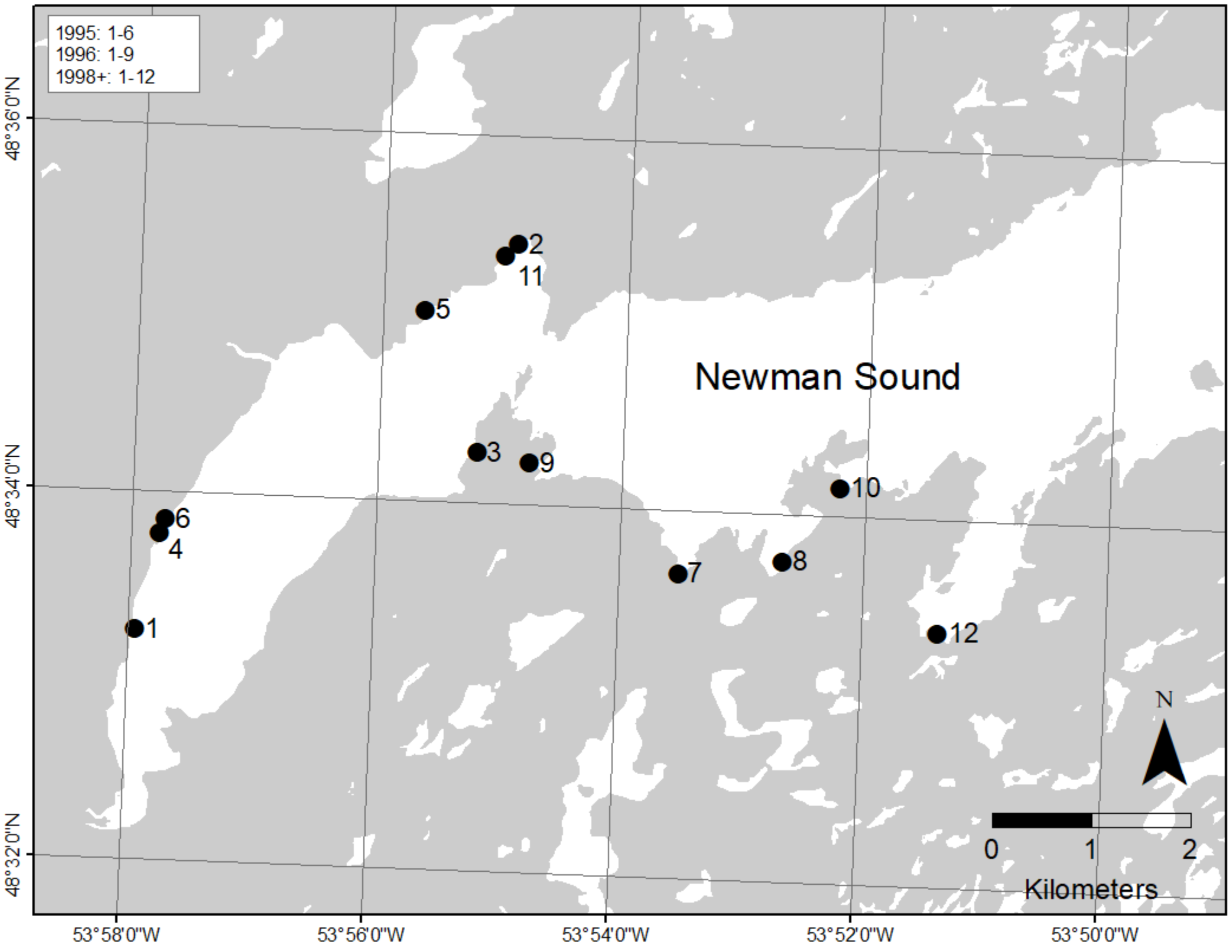

Figure 1. Location of nearshore sampling sites in Newman Sound, Bonavista Bay, July-November 1995–2018.

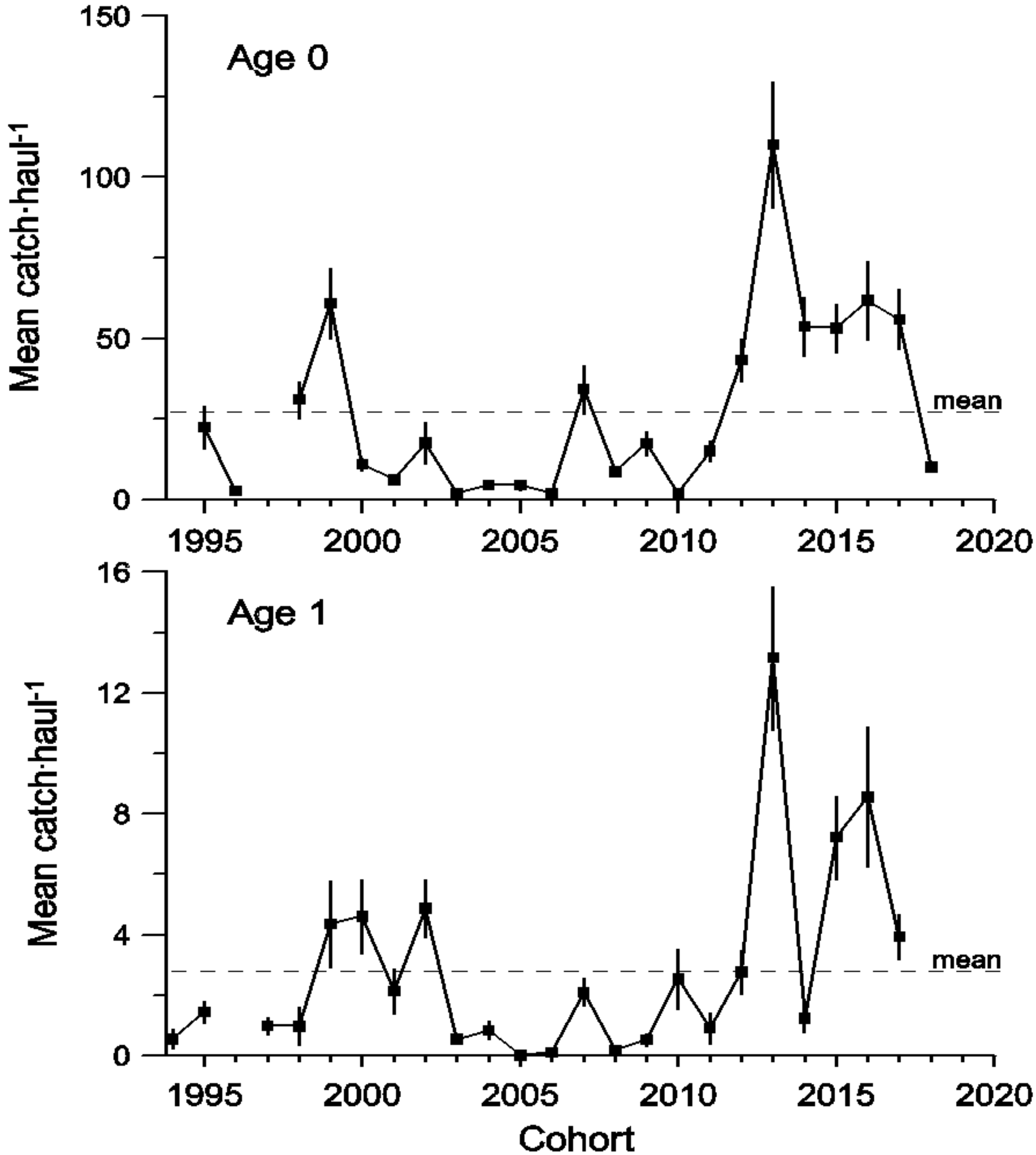

Figure 2. Mean age 0 (top panel) and age 1 (bottom panel) Atlantic Cod caught by cohort using beach seines in Newman Sound, Bonavista Bay, 1995–2018 (bars are ± 1 SE; n=102–130 seine sets/year, 48 in 1995).

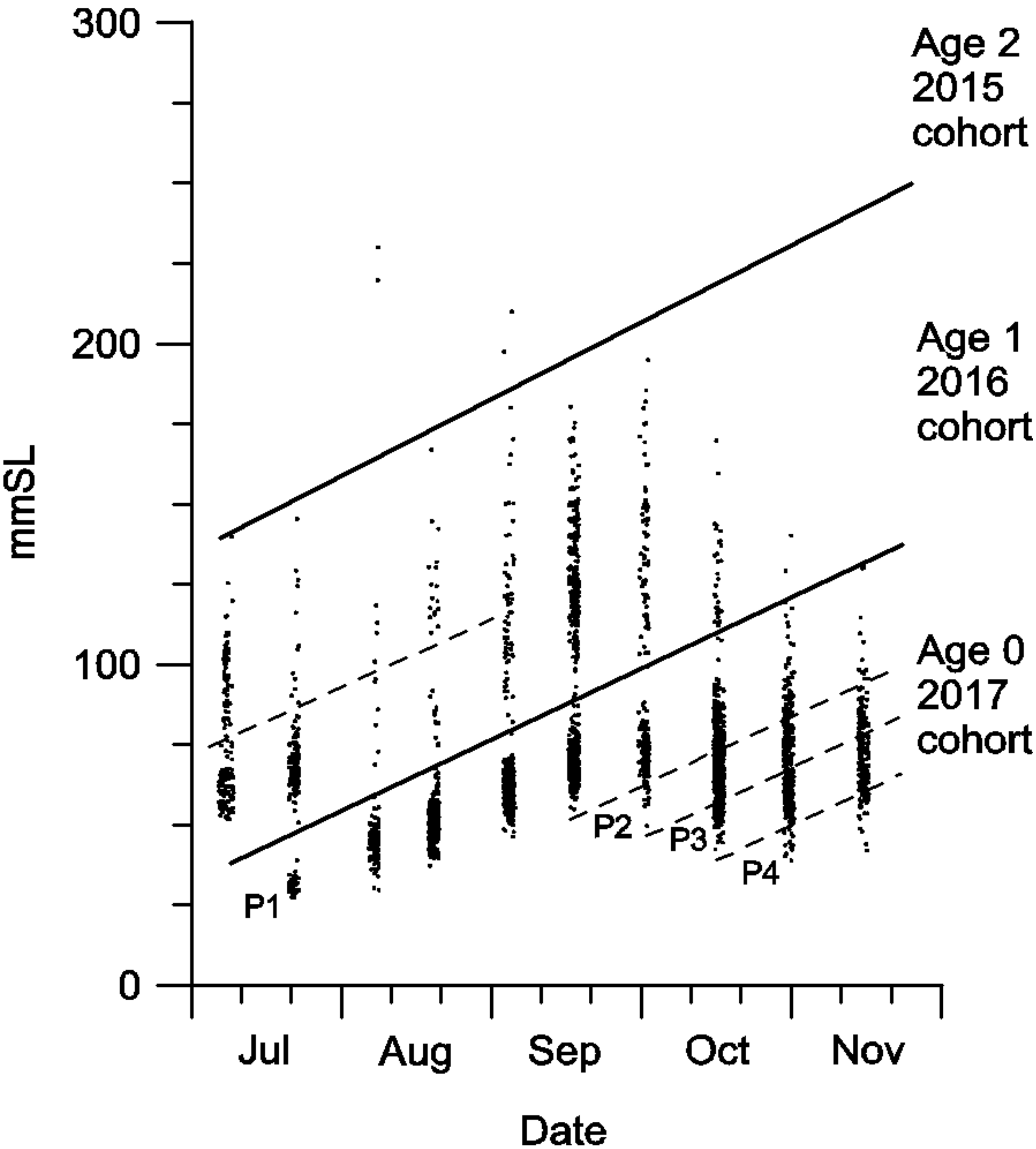

Figure 3. Sizes of Atlantic Cod captured by beach seine in Newman Sound, Bonavista Bay, July-November, 2017 and their potential age and settlement pulse structure (solid lines and dashed lines separate ages and settlement pulses (within age), respectively; P=1,2,3,4 are pulses).

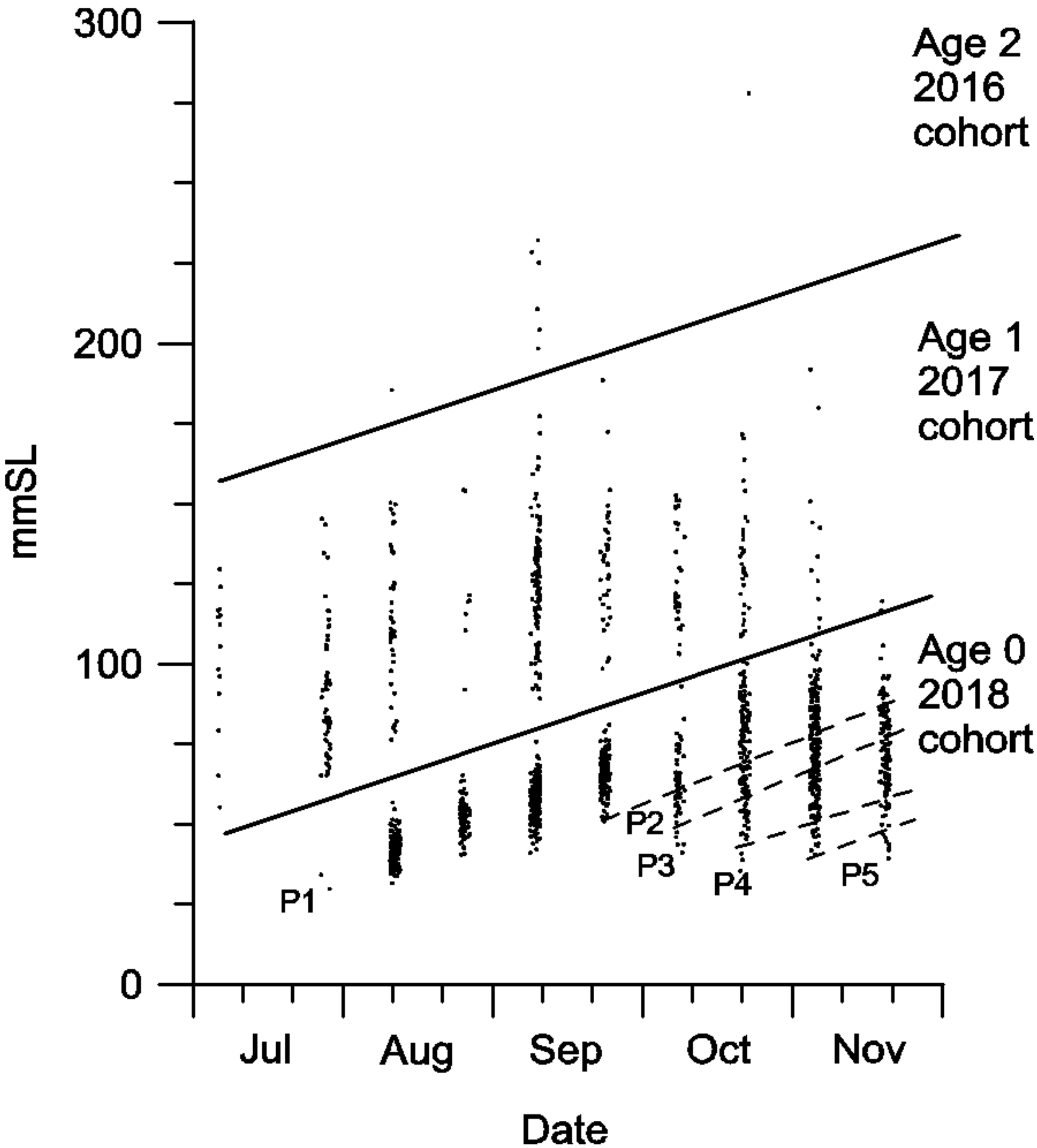

Figure 4. Sizes of Atlantic Cod captured by beach seine in Newman Sound, Bonavista Bay, July-November, 2018 and their potential age and settlement pulse structure (solid lines and dashed lines separate ages and settlement pulses (within age), respectively; P=1,2,3,4,5 are pulses).

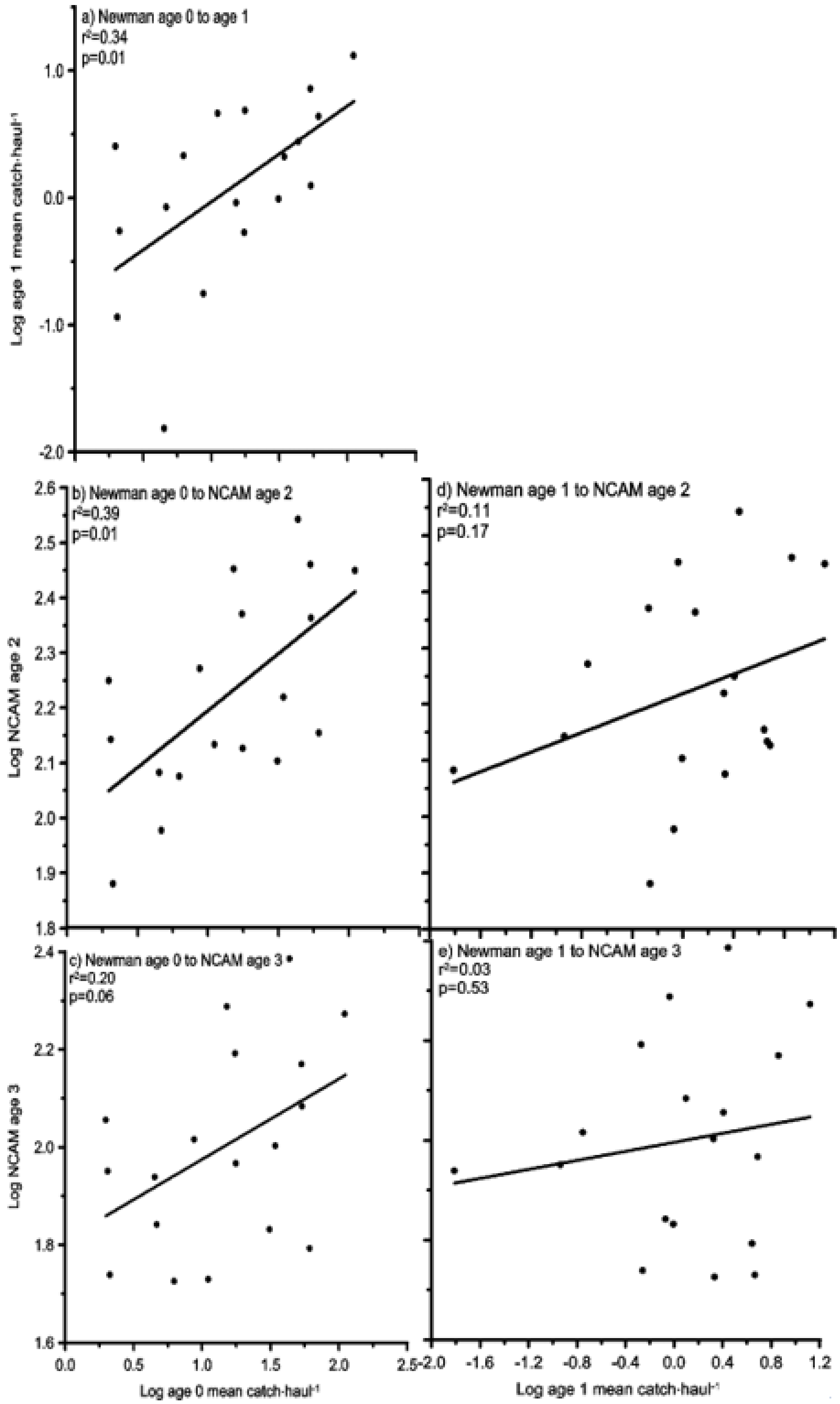

Figure 5. Regression plots (with r^2 and probability) of Newman Sound age 1 (a), NCAM age 2 (b, d) and NCAM age 3 (c, e) Atlantic Cod abundances (DFO 2019) versus Newman Sound age 0 (a, b, c) and age 1 (d, e) Atlantic Cod mean beach seine catches in Newman Sound, for the 1999–2015 cohorts (NCAM estimates are reported in millions of fish – DFO 2019; and here in log of millions).

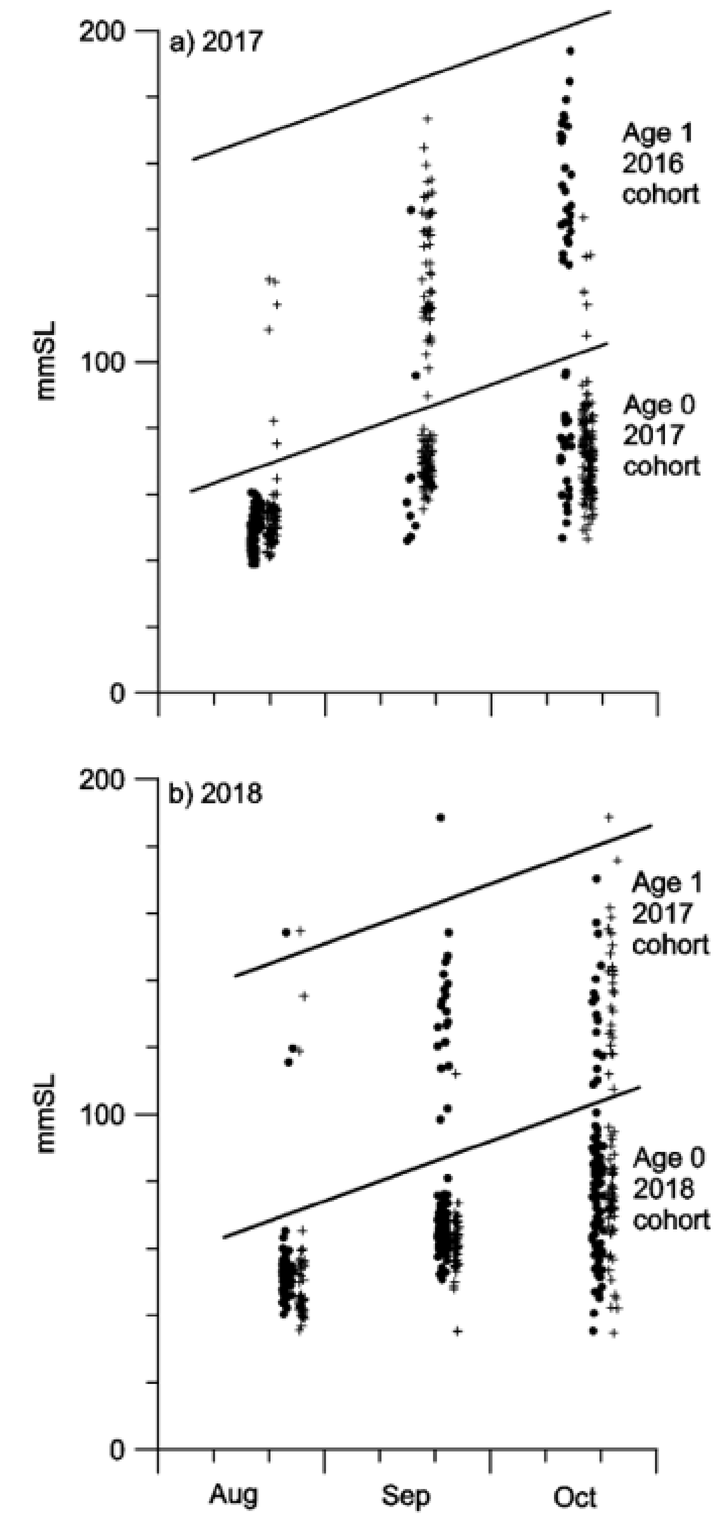

Figure 6. Sizes of Atlantic Cod captured by beach seine in 12 Newman Sound, Bonavista Bay (dots) and 8 Trinity Bay and Notre Dame Bay (plus signs) sites, sampled on the same dates (±1 d), August-October in both 2017(a) and 2018 (b); for display clarity, 20% random points in 2017 and 50% in 2018 have been plotted and Newman Sound data are offset 3 d to the left; Gregory and Dalley, unpublished data).

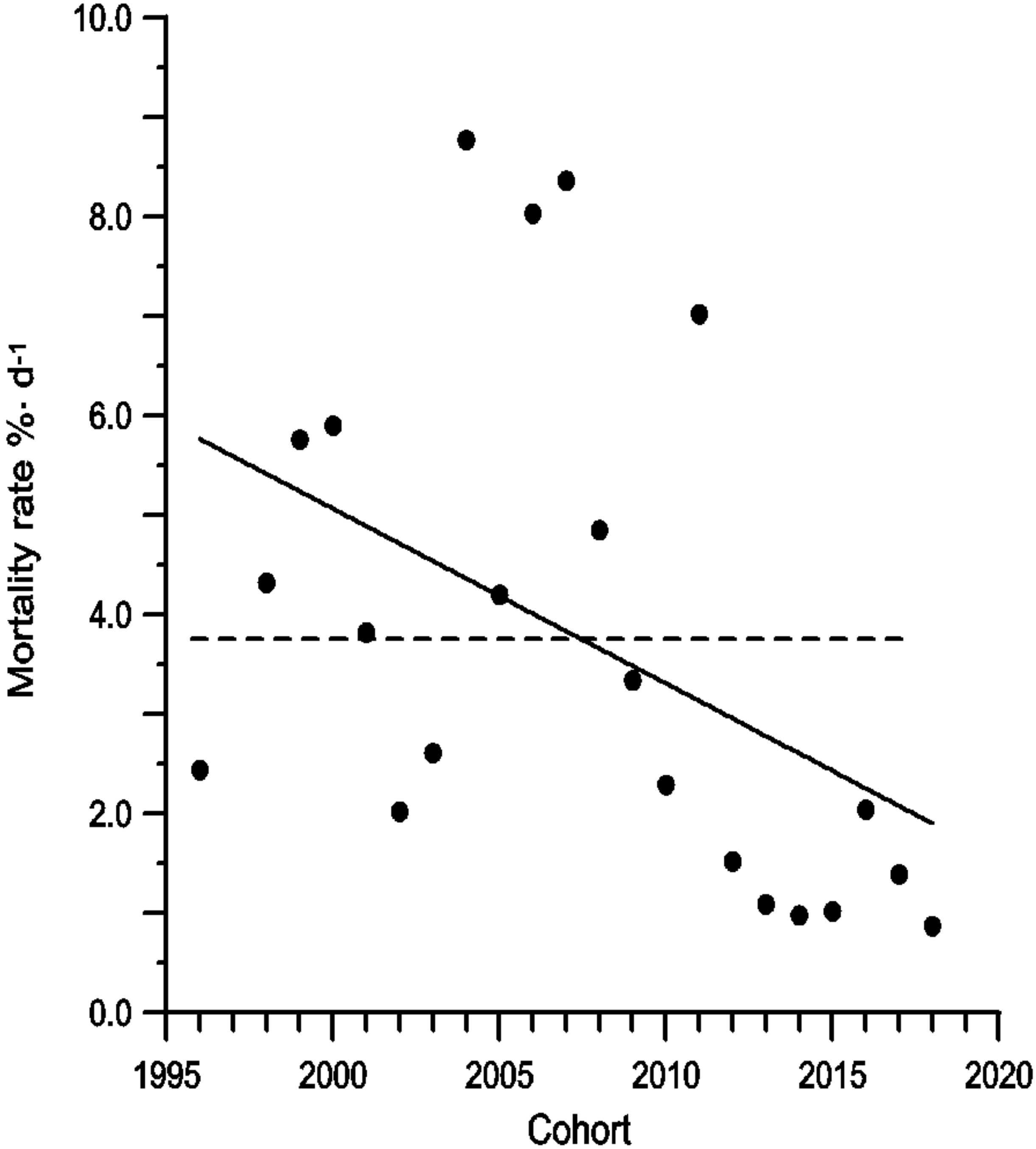

Figure 7. Daily mortality rates of the first settlement pulse of Atlantic Cod captured by beach seine in 12 sites in Newman Sound, Bonavista Bay, July-November, 1996–2018 (solid line is the interannual trend; dashed line is the mean mortality rate among all years).