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Relative Strength of the 2001 and 2002 Year-Classes, From Nearshore Surveys Of Demersal Age 0 and 1 Atlantic Cod (*Gadus morhua*) in NAFO Division 3KL and in Newman Sound, Bonavista Bay

Effectif relatif des classes d'âge de 2001 et de 2002 d'après les relevés côtiers de la morue (*Gadus morhua*) démersale âgée de 0 et 1 an dans la division 3KL de l'OPANO et le bras Newman (baie de Bonavista)

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ABSTRACT

From 1959-64 and 1992-97 (i.e. 1990s), and again in 2001, demersal age 0 Atlantic cod (*Gadus morhua*) in the nearshore (<10 m deep) were surveyed by seine from St. Mary's Bay to Notre Dame Bay, Newfoundland during the Fleming survey, conducted annually in September and October. In the absence of a regular coastwide Fleming survey since 1997, we have conducted a qualitative assessment of the strength of six 1997-2002 year-classes of Atlantic cod. Our assessment was based on abundance of demersal age 0 and age 1 Atlantic cod sampled at 6-13 nearshore sites in Newman Sound, Bonavista Bay in five summer-autumn periods during 1995-2002. Sampling techniques and collection dates for the Fleming survey and Newman Sound study were similar. Therefore, cod abundances in the two studies were comparable, albeit at different geographic scales. Abundance trends of age 0 and 1 cod covaried between the studies in 1995, 1996, and 2001, when both were conducted concurrently, suggesting that abundances of juvenile cod in Newman Sound mirrored those observed in the spatially broader Fleming survey. In 1997, age 0 abundance in the Fleming survey was the highest observed in the 1990s, leading to the prediction that age 1 cod would be high the following year. High age 1 abundance in 1998 compared to 1995 and 1996 in Newman Sound supported this prediction. Compared with the historical low in 1996 observed in both studies, age 0 abundance was 10 times higher in 1998 and 40 times higher in 1999. These results suggest that the 1997, 1998, and 1999 year-classes should be strong compared to those in 1995 and 1996. Analysis of length frequency data collected from July to November in Newman Sound indicated that age 0 Atlantic cod settled in the nearshore in two distinct recruitment pulses in "good years" - i.e. 1998 and 1999 - the first pulse arriving in early August, the second in late September. In "bad years" - i.e. 1995 and 1996 – the first pulse has been weak and late to recruit to the nearshore. The length frequency data also suggest that the pulse structure may remain intact through the first winter and appears to be detectable in age 1 cod the subsequent year. In 2001, Gregory et al. 2002 predicted that the 2000 year-class of Atlantic cod will prove to be weak relative to the strong 1998 and 1999 year-classes which preceeded it. Catches of the 2000 year-class throughout 2001 as age 1 fish, and in 2002 as age 2 fish support this prediction. In contrast to 1997-99, densities of age 0 Atlantic cod have been consistently low throughout much of the season in the past three years (2000-02), and were comparable to 1996, the poorest year-class on record in three independent surveys of age 0 abundance off northeastern Newfoundland.

RÉSUMÉ

De 1959 à 1964 et de 1992 à 1997 (c.-à-d. les années 1990), et de nouveau en 2001, on a effectué un relevé à la senne pour étudier la morue (*Gadus morhua*) démersale de 0 an présente dans les eaux côtières (< 10 m de profondeur) du secteur allant de la baie St. Mary's jusqu'à la baie Notre Dame, à Terre-Neuve – cette initiative a été menée pendant le relevé Fleming, qui est réalisé chaque année en septembre et en octobre. Comme le relevé Fleming n'a pas été effectué régulièrement à la grandeur de la côte depuis 1997, nous avons procédé à une évaluation qualitative de l'effectif de six classes d'âge (1997-2002) de morues. Notre évaluation est fondée sur l'abondance de la morue démersale âgée de 0 et 1 an qui a été prélevée dans 6 à 13 sites côtiers du bras Newman (baie de Bonavista) au cours de cinq périodes, à l'été et à l'automne, de 1995 à 2002. Les techniques et les dates d'échantillonnage du relevé du bras Newman et du relevé Fleming étaient semblables. Les données sur l'abondance de la morue des deux relevés sont donc comparables, bien qu'elles renvoient à des échelles géographiques différentes. La tendance relative à l'abondance des morues âgées de 0 an et de 1 an a affiché une covariance entre les relevés de 1995, de 1996 et de 2001, alors que les deux relevés ont été effectués simultanément, ce qui porte à croire que l'abondance des juvéniles notée dans le bras Newman correspondrait à celle observée au cours du relevé Fleming, qui affiche une plus grande couverture spatiale. En 1997, l'abondance de la morue âgée de 0 an notée lors du relevé Fleming était la plus élevée des années 1990, ce qui nous a permis d'avancer que l'abondance de la morue âgée de 1 an serait élevée l'année suivante. Aussi, l'abondance élevée de la morue âgée de 1 an en 1998 observée dans le bras Newman, comparativement à celle des années 1995 et 1996, a confirmé cette prévision. Comparativement aux faibles valeurs historiques enregistrées en 1996 lors des deux relevés, l'abondance de la morue âgée de 0 an était respectivement 10 et 40 fois plus élevée en 1998 et en 1999. Ces résultats laissent entendre que les classes d'âge de 1997, de 1998 et de 1999 devraient être abondantes par rapport à celles de 1995 et de 1996. L'analyse des données sur les fréquences de longueurs obtenues de juillet à novembre dans le bras Newman indique que la morue âgée de 0 an s'est établie dans la zone côtière en deux vagues de recrutement distinctes au cours des « bonnes années » (1998 et 1999), la première au début d'août et la seconde, à la fin de septembre. Au cours des « mauvaises années » (1995 et 1996), la première vague était faible, et le recrutement dans les zones côtières a tardé. Les données sur les fréquences de longueurs indiquent également que la structure des vagues de recrutement peut demeurer intacte après le premier hiver et semble être décelable chez la morue âgée de 1 an l'année suivante. En 2001, Gregory *et al*. (2002) ont prédit que la classe d'âge de 2000 serait moins abondante par rapport aux fortes classes d'âge de 1998 et de 1999. Le nombre de morues de la classe d'âge de 2000 capturées à l'âge de 1 an tout au long de 2001 et à l'âge de 2 ans tout au long de 2002 confirme cette prévision. Contrairement à 1997-1999, les densités de la morue âgée de 0 an sont demeurées constamment faibles pendant la majeure partie des trois dernières années (2000-2002) et étaient comparables aux valeurs de 1996, année où l'on a observé la classe d'âge la plus faible jamais enregistrée dans le cadre de trois relevés indépendants visant la morue âgée de 0 an que l'on a effectués au nord-est de Terre-Neuve.

INTRODUCTION

It has been shown, at least for the 1990s, that age 0 and age 1 Atlantic cod in Div. 3KL (northeast Newfoundland Shelf) are distributed predominantly in inshore waters (Dalley and Anderson 1997). Within these inshore waters during autumn, age 0 cod are most common in shallow water in the nearshore (<10 m deep - Methven and Schneider 1998). The Fleming surveys (1959-64, Lear et al. 1980; 1992-2001, Methven et al. 1998, 2003) have historically sampled nearshore abundances of age 0-2 Atlantic cod, with the objective of assessing relative year-class strength. These surveys have generally been successful at predicting the relative strength of adjacent cohorts through the first years of life (Schneider et al. 1997).

The 1997 Fleming survey (Methven et al. 1998) reported the highest abundance of age 0 cod in the nearshore during the 1992-97 period. However, the success (or failure) of the 1997 year-class could not be assessed directly as the survey was not conducted for the next three years.

Fortunately, we have access to nearshore abundance data similar to the Fleming time series in a small area within the region sampled annually by that survey. In fall 1995, an investigation of the abundance of age 0 cod and their association with nearshore habitat types was initiated in Newman Sound, Bonavista Bay (Gotceitas et al. 1996). The 1995 study was followed by similar efforts in 1996-2000 (Gregory et al. 1997, 1999, 2002). These studies showed that the nearshore of Newman Sound represents a significant nursery area for demersal age 0 Atlantic cod. The Newman Sound studies were conducted using the same sampling techniques as the Fleming surveys; collection dates also overlapped. Therefore, the abundance data of the two surveys during the period of study were comparable, albeit at different spatial scales.

In this study, we qualitatively assessed the relative strength of the 2000, 2001 and 2002 year-classes based on abundance of demersal age 0 and age 1 Atlantic cod in the nearshore in Newman Sound, Bonavista Bay in summer and fall 2001-02. We compared abundances of age 0 and age 1 Atlantic cod in Newman Sound in 2001-02 to previous years (1995-96 and 1998-2000), linking interannual abundance trends to those demonstrated in the Fleming surveys (1992-97 and 2001). We showed that interannual trends between the Newman Sound data and the larger scale Fleming survey were consistent. This consistency allowed us to conclude two things: 1) the 1998 and 1999 year-classes were relatively stronger than the 1995 and 1996 year-classes; and 2) the strong 1997 year-class predicted as a result of the 1997 Fleming survey (Methven et al. 1998) was supported. We also present evidence that links age 0 abundance to temporal recruitment patterns within years. We suggest that in years of relatively higher recruitment, settlement occurs in more than one recruitment pulse (Methven and Bajdik 1994; Grant and Brown 1998) several weeks apart; in years of relatively poor recruitment, recruitment is often limited to a single pulse. We also show that despite a

detectable multiple pulse structure, the first three year-classes of this millenia appear destined to be weak relative to those of the late 90's.

METHODS

Sites sampled during the 1992-97 and 2001 Fleming surveys have been described in previous reports (Methven et al. 1998, 2003). In the 1990's, the Fleming survey was conducted at between 37-45 nearshore sites extending from St. Mary's Bay in the south to Notre Dame Bay in the north from 19 September to 27 October. In Bonavista Bay, sampling during the Fleming survey was generally 5-9 October (18 October in 1997).

Newman Sound seine sites (Fig. 1) – described in Gregory et al. (1997) – were selected on the basis of sampling logistics, and were similar to those of the Fleming survey (Lear et al. 1980). To maintain consistency among years, we have presented age 0 and age 1 abundance data from four of these sites (#1, 2, 3, and 6, Fig. 1), which were in common among our field programs in all years, 1995-2002 in Newman Sound. For comparison with the Fleming survey data, we analyzed data from Newman Sound which had been collected only during the first two weeks of October during these years. In order to investigate seasonal growth and timing of recruitment pulses, we examined sizes of Atlantic cod captured and measured from all sites sampled in Newman Sound - September to November, 1995 (6 sites) and July to November in 1996 (9 sites), 1998-2002 (13 sites).

Both the Fleming survey and Newman Sound studies used the same sampling techniques. Fish samples were collected using a 25 m beach seine - wings and belly 19 mm stretch mesh, codend 9 mm stretch mesh bag; 24.4 m headrope, 26.2 m footrope; 75 cm long and 25 mm diameter aluminum poles on 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 samples approximately 880 m^2 of the bottom. Less than 5% of all fish enclosed by the net are missed or escape (D. Ings, Memorial University of Newfoundland, unpublished data).

All fish collected were identified and counted. Juvenile cod were assigned to tentative age groups based on previously established age-length relationships in Newfoundland waters in late autumn (age 0: $\leq$ 10 cm SL [standard length], age 1: 10-20 cm SL, and age 2: 20-30 cm SL - Dalley and Anderson 1997). We then refined these estimates by visual inspection of length frequency trajectories through time.

RESULTS AND DISCUSSION

We observed good correspondence of age 0 and age 1 Atlantic cod density trends in 1995, 1996, and again in 2001 between the Fleming Survey and the Newman Sound studies. In both study datasets, 1996 showed the lowest age 0 cod mean density among years, during the 1990's (Fig. 2). Lowest densities were seen in 2001, in both studies. In the case of Newman Sound, the 2001 and 2002 age 0 densities were both lower than in 1996 (the benchmark low); although densities in 2002 were higher than 2001. Newman Sound abundance in 2001 was less than half of 1996, and 2002 was around 75% of that in 1996. The Fleming survey result for 2001, on the other hand, was similar to 1996. Similarly, age 1 abundance was higher in 1996 than it had been in 1995 in both the Fleming survey (2.0 times higher) and in Newman Sound (2.4 times higher) data sets (Fig. 3). The results of the 1997 Fleming survey led Methven (1998) to predict that age 1 abundance in 1998 would be higher than in previous years of the Fleming survey in the 1990s. Age 1 abundance observed in Newman Sound in 1998 was higher than in 1995 and 1996 qualitatively supporting this prediction (Fig. 3). This observation further strengthens our confidence that Newman Sound emulates larger scale, possibly coast-wide recruitment processes. Age 0 Atlantic cod abundance in Newman Sound was over an order of magnitude higher in 1998 and 40-times higher in 1999 than in 1996. Abundance of age 0 Atlantic cod in 1996 was the lowest recorded in three independant prerecruit studies in the 1990s (1992-97 Fleming - Methven 1998, 1992-99 NE Newfoundland Shelf - Dalley et al. 2000, 1995-2000 Newman Sound - this study). We suggest that the 2000, 2001, and 2002 year-classes will be weak compared to the final two years of the 1990's, and will be similar or worse than 1996, with the 1999 year-class remaining the strongest cohort since the implementation of the 1992 moratorium.

Age 0 Atlantic cod appear to recruit (=settle) into nearshore habitats in a recruitment pattern consisting of a number of settlement pulses each year. Analysis of size distribution of age 0 Atlantic cod collected July-November in Newman Sound indicated that age 0 cod settled in only a single recruitment pulse in 1996 (Fig. 4). Similarly, we identified only a single Atlantic cod recruitment pulse in 1995 (Gotceitas et al. 1996), although sampling in Newman Sound only started in late September that year, making definitive statements regarding pulse structure somewhat tenuous. In contrast, both 1998 (Fig. 5) and 1999 (Fig. 6) age 0 Atlantic cod recruited to the nearshore in two or more strong recruitment pulses - the first arriving in late-July to early-August, the second in September. In 1998, the first pulse was the strongest, whereas the two pulses were equally weighted in 1999 (Fig. 6). In 2000, recruitment to the nearshore was late (late-August and early September) compared to previous years; although there was evidence of multiple modes in the length frequency (Fig. 7). Overall densities in 2000 were low - only slightly higher than 1996. The pattern of recruitment for both the 2001 and 2002 year-classes was similar to 2000, with the first pulse recruiting to the nearshore late in the summer (Fig. 8 and Fig. 9). These years show a similar recruitment pattern to that in 1996, a poor year (Fig 4). In 2000, there was evidence of multiple

recruitment pulses in as many as three or four separate “events” in these years (Fig. 7, 8 and 9), but no strong pulses were evident.

The pulse structure established for age 0 cod in any given year appears to be maintained in the size structure of age 1 cod in the subsequent year. Evidence of a multiple pulse recruitment pattern was present in both 1996 (Fig. 4) and 1998 (Fig. 5). However, the evidence was especially compelling in 1999 (Fig. 6) when we examined data on the same year-class (1998) in two consecutive years - as age 0 in 1998 (Fig. 5) and as age 1 in 1999 (Fig. 6). The two pulses of the 1999 year-class although readily apparent, were only weakly separated in time and size frequency (Fig. 6), possibly explaining why the pulse structure among age 1 Atlantic cod in 2000 was poorly defined (Fig. 7). In comparison, there was no pulse structure apparent for the 2000 and 2001 year-classes when they were 1-year-old (2000 cohort – Fig. 8, 2001 cohort – Fig. 9).

We have not explored fully the ecological implications of multiple recruitment pulses on year-class strength. The data in this study suggest that a complex pulse structure (e.g. two or more modes) may signal a relatively good recruitment year compared to a simple or weak pulse structure (e.g. one mode). From genetic evidence, we do know that different stock components contributed differentially to each of these pulses in 1999 (Beacham et al. 2000). We do not yet know if the multiple recruitment patterns we observed in Newman Sound are restricted to individual sites. However, we do know that similar recruitment patterns occur annually at other sites along the northeast Newfoundland coast (Methven and Bajdik 1994; Grant and Brown 1998) suggesting that these observations reflect broader geographic phenomena. Although the ecological implications of complex recruitment pulse structure remain to be worked out, these implications could be substantive. Size-selective mortality factors should effect differential survival between individuals from different recruitment pulses (Sogard 1997; Linehan et al. 2001).

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

- we reinforce our prediction from 2001 (Gregory et al. 2002) that the 1999 year-class will be strong relative to other year-classes before or after it in our time series, now including the 2000-02 year-classes;
- the Newman Sound data set has shown itself a reasonable barometer of wider recruitment processes. Agreement between the Newman Sound and Fleming data sets is qualitatively high;
- we predict that the 2001 and 2002 year-class will be very weak, possibly even worse than the 1996 year-class.

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Figure 1. Location of sampling sites and nearshore habitat in Newman Sound, Bonavista Bay July to November 1995-2002.

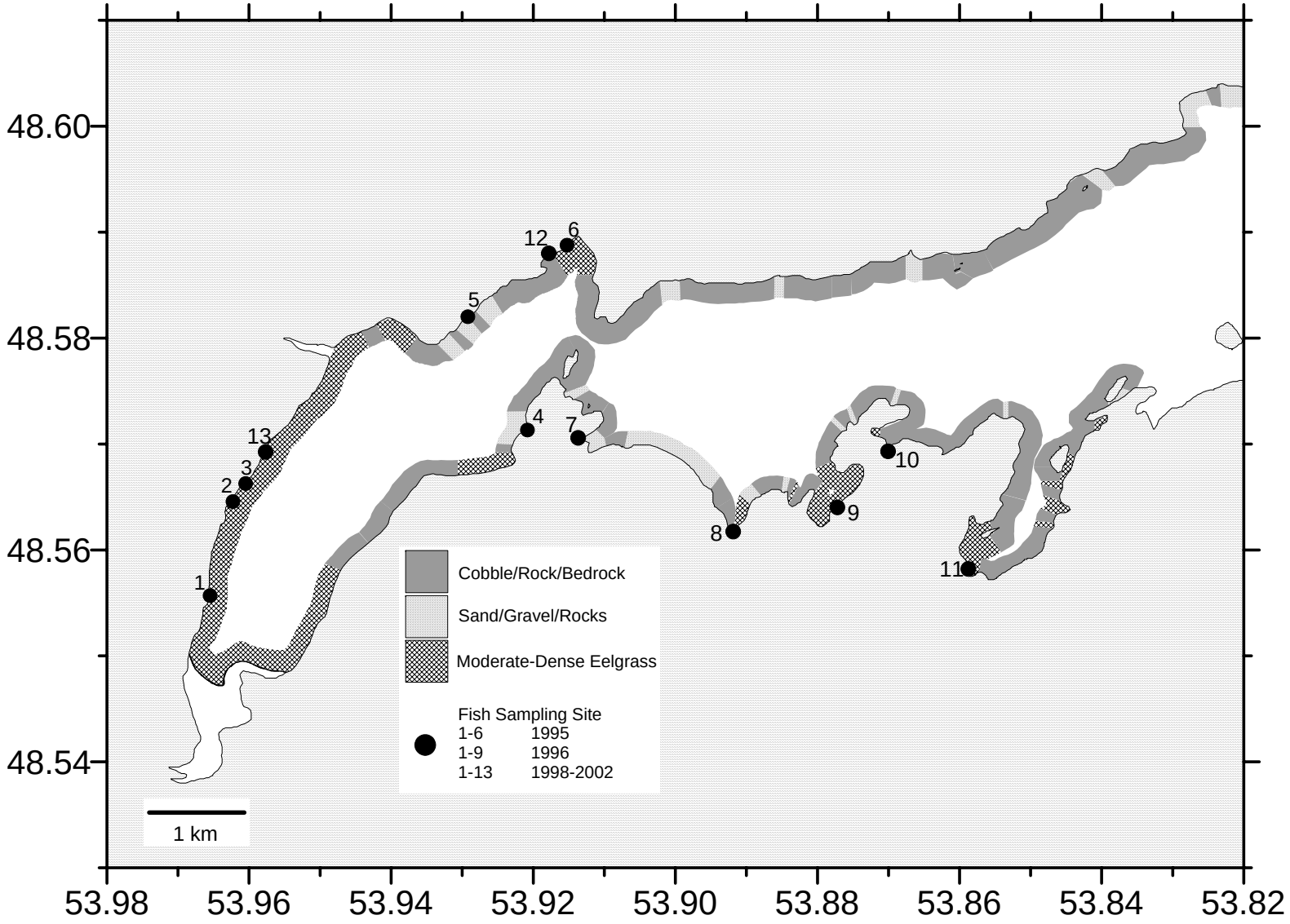

Figure 2. Mean age 0 Atlantic cod abundance (mean/set) caught by beach seine in the Fleming survey 1959-64 and 1992-2001, St. Mary's Bay to Notre Dame Bay (upper panel) and in Newman Sound Bonavista Bay, 1995-2002 (lower panel). Vertical bars are 95% confidence intervals estimated by randomized data resampling.

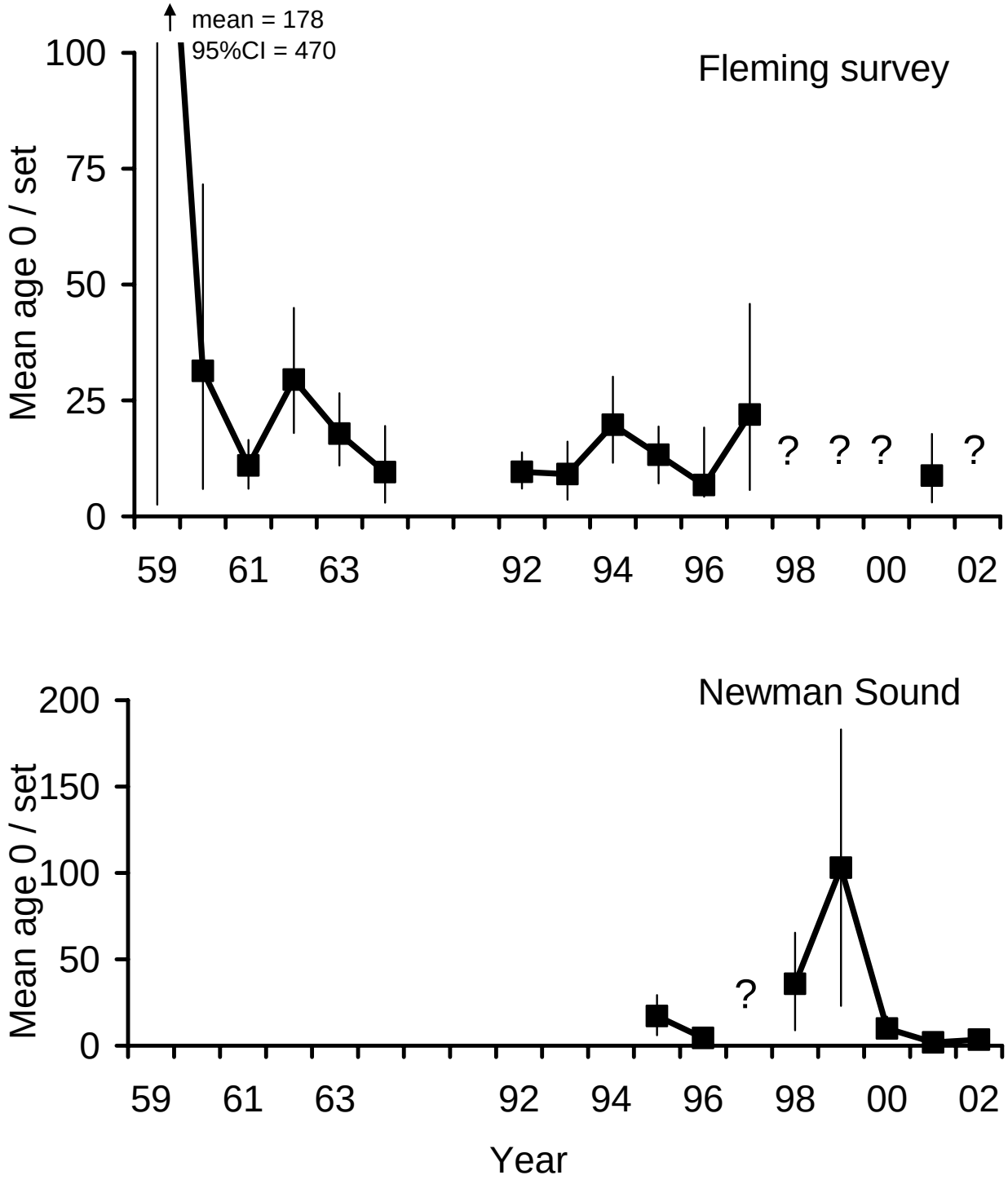

Figure 3. Mean age 1 Atlantic cod abundance (mean/set) caught by beach seine in the Fleming survey 1992-2001, St. Mary's Bay to Notre Dame Bay (upper panel) and in Newman Sound Bonavista Bay, 1995-2002 (lower panel). Vertical bars are 95% confidence intervals estimated by randomized data resampling.

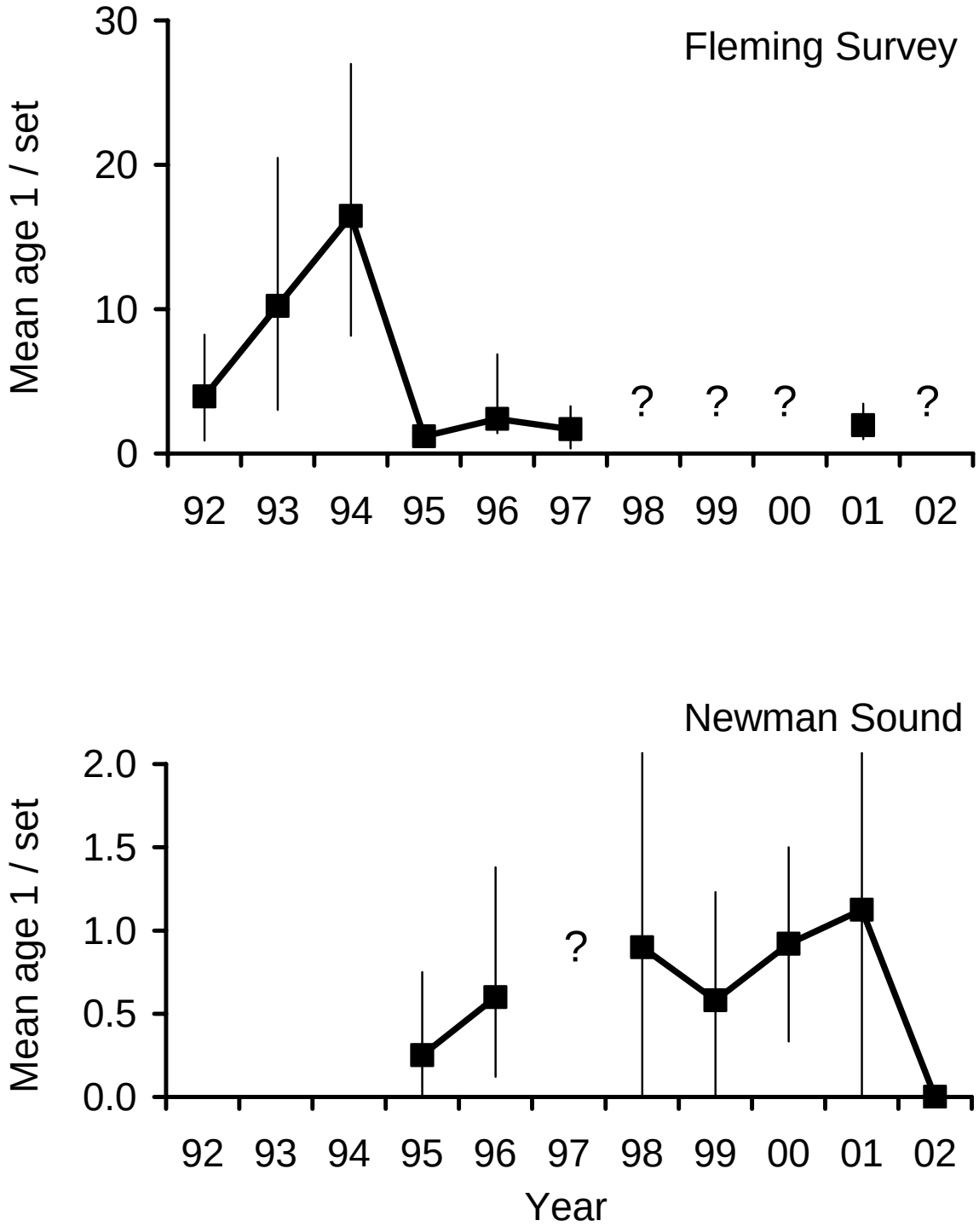

Figure 4. Sizes of Atlantic cod captured by beach seine in Newman Sound, Bonavista Bay, July - November, 1996 and their potential age and recruitment pulse structure.

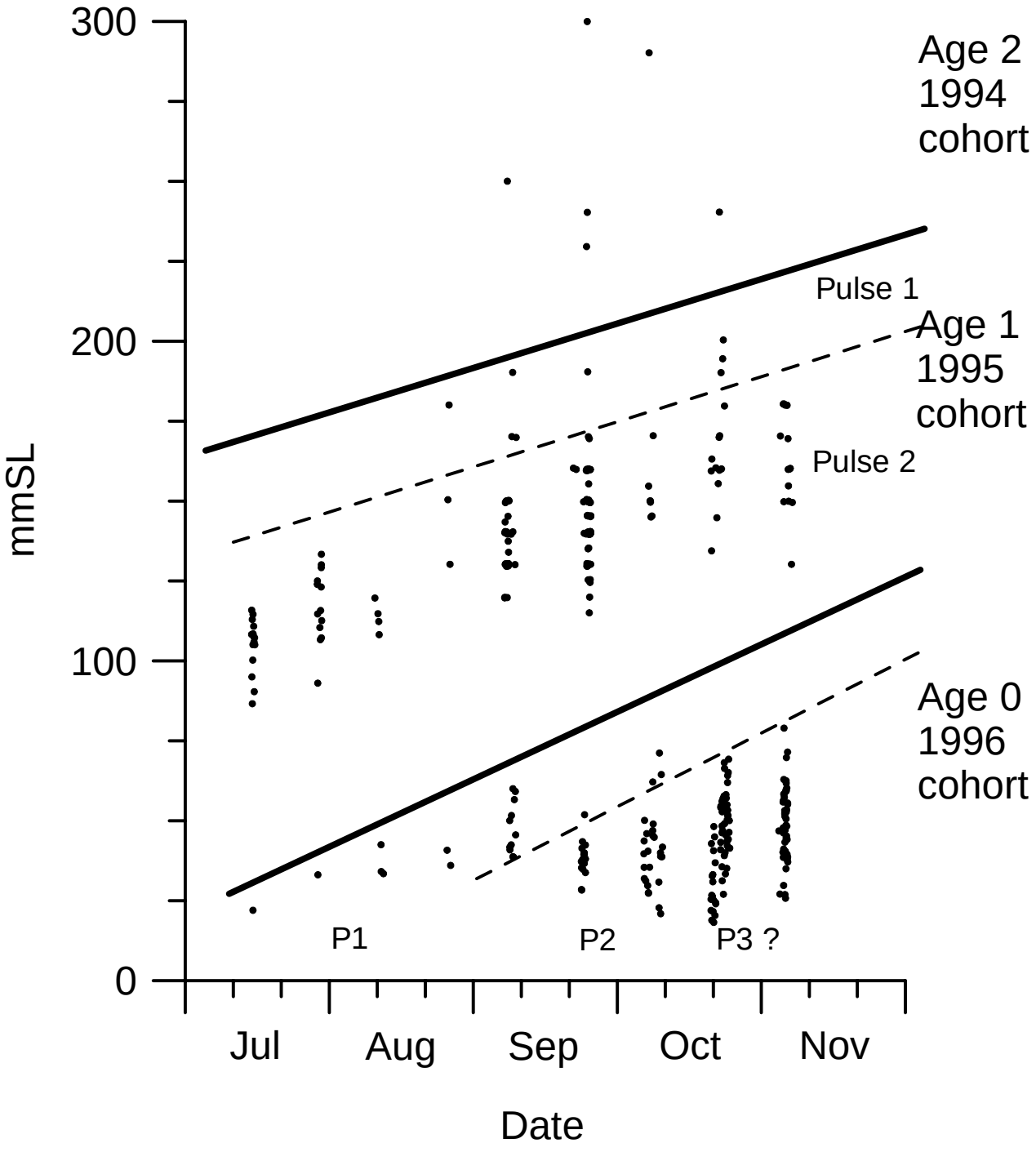

Figure 5. Sizes of Atlantic cod captured by beach seine in Newman Sound, Bonavista Bay, July - November, 1998 and their potential age and recruitment pulse structure.

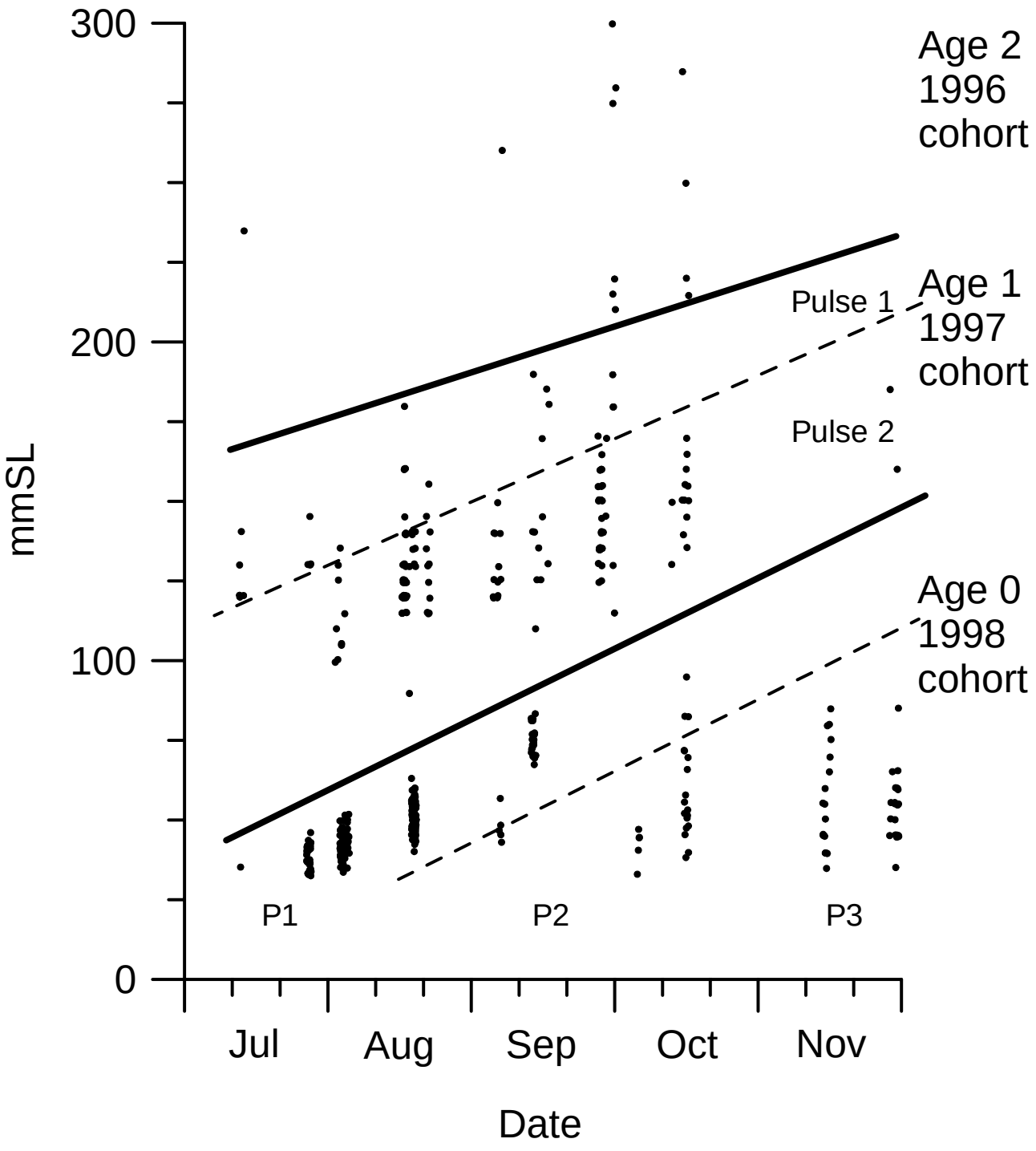

Figure 6. Sizes of Atlantic cod captured by beach seine in Newman Sound, Bonavista Bay, July - November, 1999 and their potential age and recruitment pulse structure.

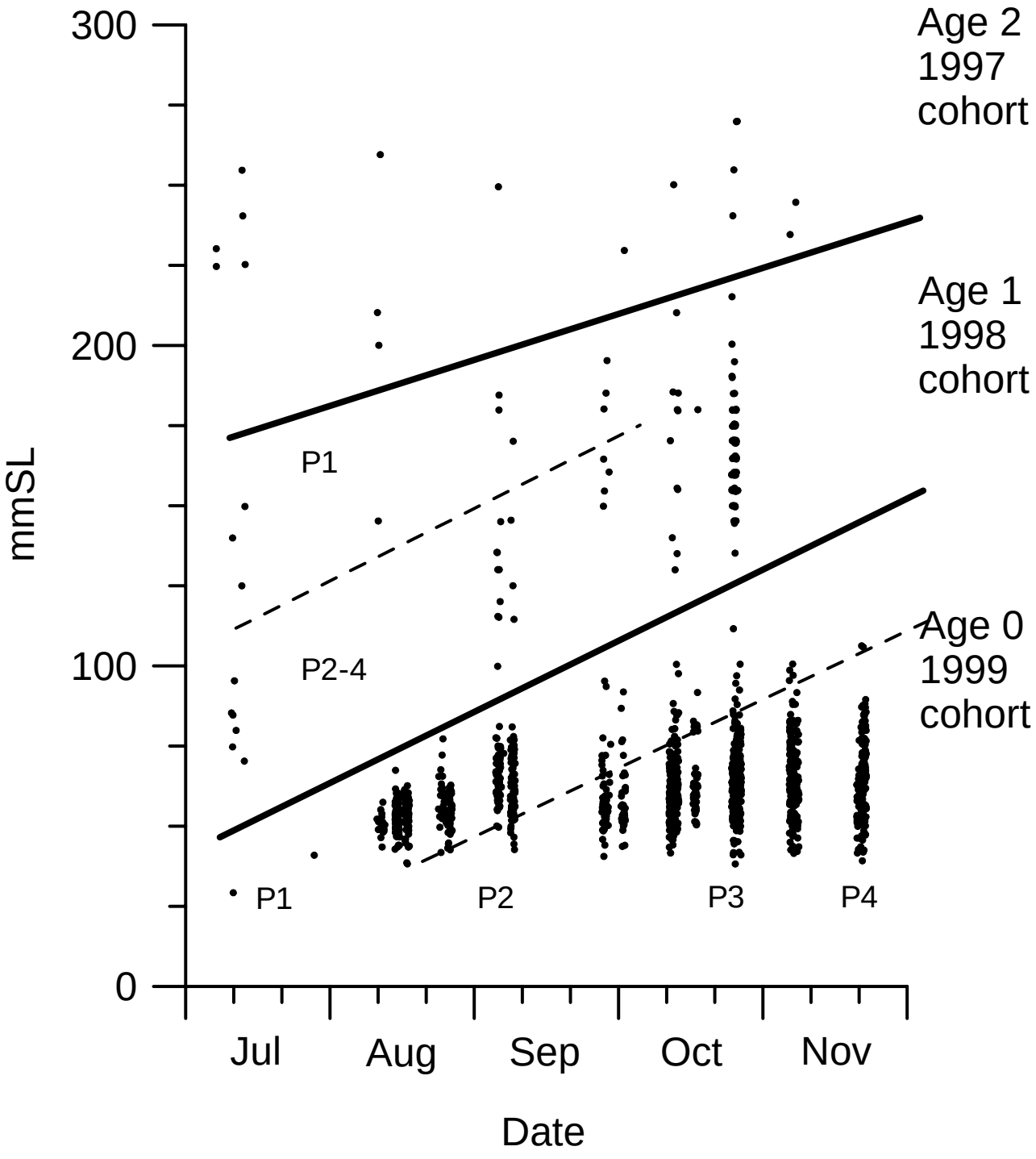

Figure 7. Sizes of Atlantic cod captured by beach seine in Newman Sound, Bonavista Bay, July - November, 2000 and their potential age and recruitment pulse structure.

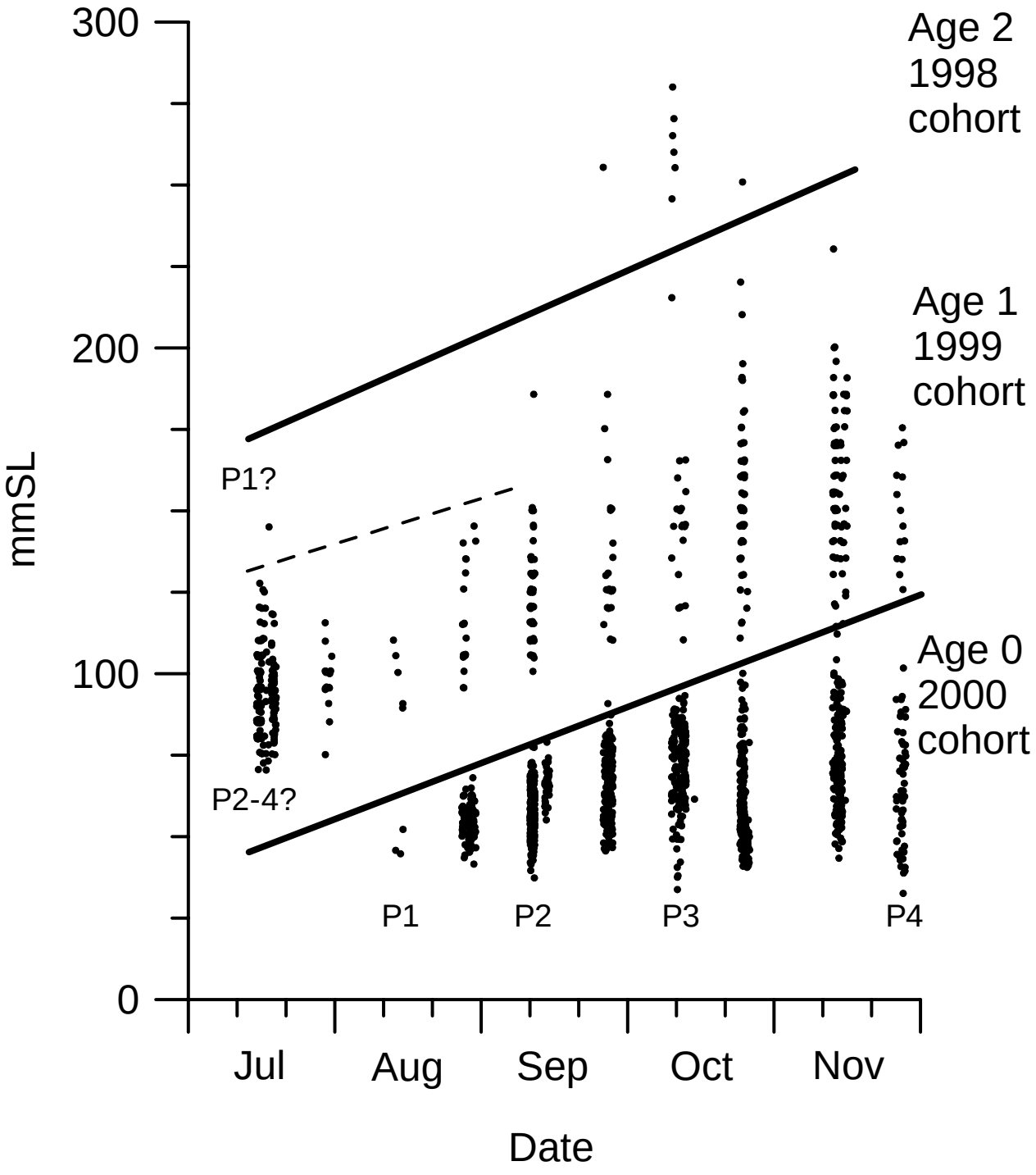

Figure 8. Sizes of Atlantic cod captured by beach seine in Newman Sound, Bonavista Bay, July - November, 2001 and their potential age and recruitment pulse structure.

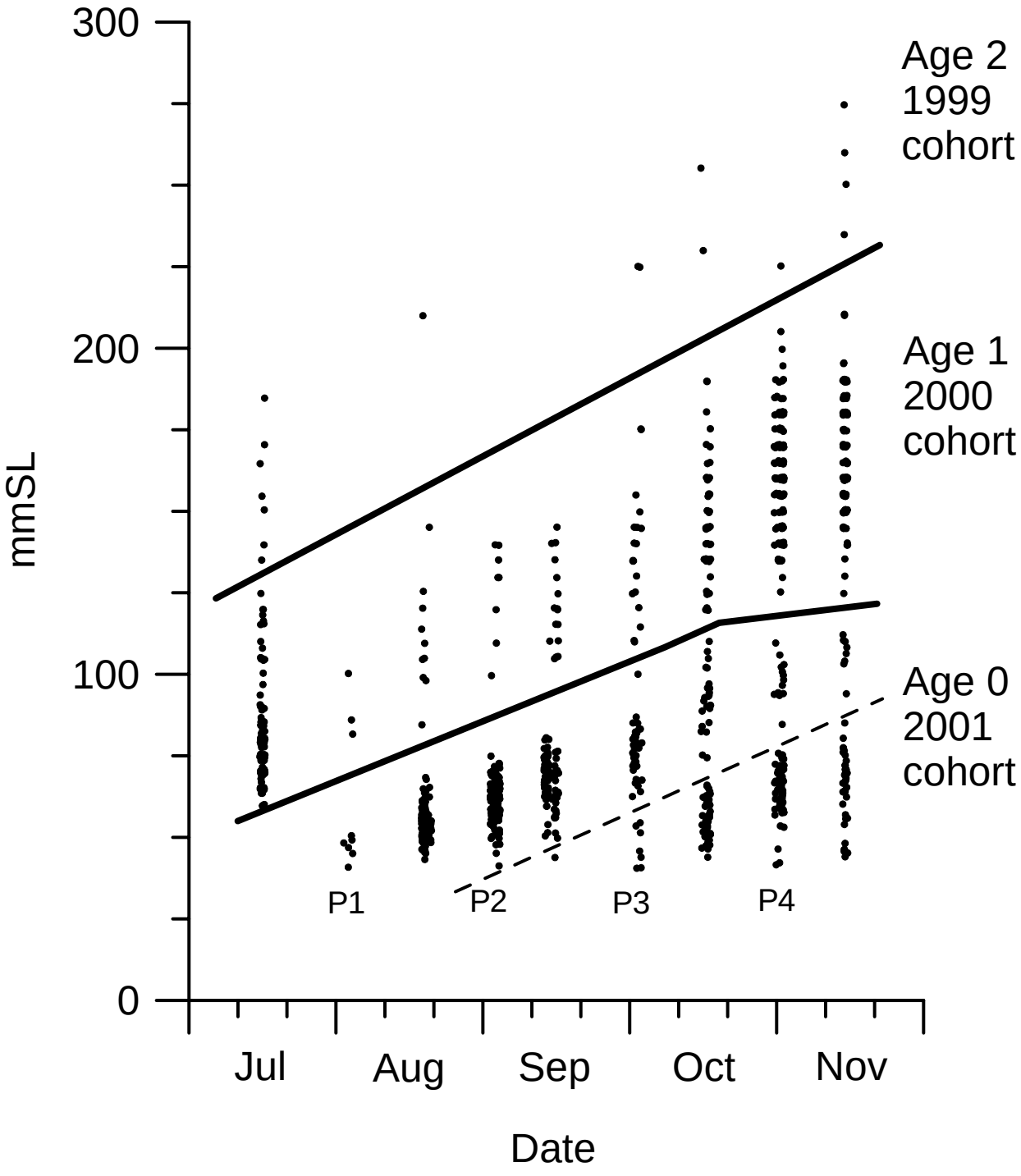

Figure 9. Sizes of Atlantic cod captured by beach seine in Newman Sound, Bonavista Bay, July - November, 2002 and their potential age and recruitment pulse structure.