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Evaluation of the utility of summer trawl surveys (1990 to 1994) in the Shediac Valley (NAFO unit area 4Tl) as an index of pre-recruit abundance for southern Gulf of St. Lawrence cod

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ABSTRACT

Demersal fish surveys were conducted with a bottom trawl ("Rock Hopper" footgear, 14.5 m wing width, 12 mm mesh in cod end) in the Shediac Valley area (NAFO unit area 4Tl) of the southern Gulf of St. Lawrence during July or August, 1990-1994. The goal was to develop an index of abundance, independent from the existing September survey, of pre-recruits (< age 5) of Atlantic cod (*Gadus morhua*). A stratified random survey design was used. Mean numbers per standard tow for ages 1 to 9 were obtained for all five years of the survey. Coefficients of variation varied between 21% and 80% for fish age 1 and 2 but decreased to between 12% and 33% for fish age 3 to 9. There was no evidence of strong incoming recruitment from this survey, the strongest year-class identified to date was that born in 1987. Although the time series is very short, simple correlation analyses suggest that numbers of age 3 fish are a useful index of numbers of fish recruiting to the stock. A multiplicative analysis of age and year-class effects showed peak catches in the juvenile survey occurred at age 3 compared to age 4 in the September survey. There was a strong stratum*age interaction in the analysis. Age 1 and 2 fish were consistently found in shallow strata and were absent from the deeper strata; the converse was true for ages 4 and 5. Age 3 cod occurred in all four strata. The confidence intervals about year-class estimates were wide but the mean catch rates suggest that the juvenile survey tracks the same strong and weak year-classes as the September survey. The 1987 year-class was identified as the strongest and 1992 the weakest year-class in the period 1983 to 1993. As more years are added to the time series, the juvenile cod survey should become an increasingly useful index of pre-recruit cod abundance in the southern Gulf of St. Lawrence.

RÉSUMÉ

On a réalisé des relevés de recherche sur le poisson démersal au moyen d'un chalut de fond («Rock Hopper», 14,5 m de largeur d'aile, cul-de-chalut à maillage de 12 mm) dans la région de la vallée Shediac (zone 4Tl de l'OPANO), située dans le sud du golfe du Saint-Laurent, en juillet ou en août, de 1990 à 1994. Ces relevés avaient pour but d'établir un indice d'abondance, indépendant de celui du relevé de septembre, des prérecrues (< âge 5) du stock de morue de l'Atlantique (*Gadus morhua).* On a procédé par relevé stratifié aléatoire et obtenu des moyennes par trait standard pour les âges 1 à 9 dans les cinq années considérées. Les coefficients de variation s'échelonnaient entre 21 % et 80 % pour les poissons d'âges 1 et 2, mais ne situaient plus qu'entre 12 % et 33 % pour les poissons des âges 3 à 9. On n'a pas décelé de signe de fort recrutement à venir, la plus forte classe d'âge repérée jusqu'ici étant celle de 1987. Quoique la série chronologique soit très courte, des analyses de corrélation simple indiquent que le nombre de poissons d'âge 3 constitue un indice utile du recrutement dans le stock. Une analyse multiplicative des effets de l'âge et de la classe d'âge révèle que les plus fortes prises capturées lors du relevé sur les juvéniles se produisaient à l'âge 3, comparativement à l'âge 4 dans le relevé de septembre. Une forte interaction âge*strate se dégageait de l'analyse. Les poissons d'âges 1 et 2 étaient uniformément présents dans les strates peu profondes et absents des strates profondes; l'inverse était vrai des âges 4 et 5. Quant aux morues d'âge 3, elles étaient présentes dans les quatre strates. Les intervalles de précision des estimations sur les classes d'âge étaient vastes, mais il ressort des taux de prises moyens que le relevé sur les juvéniles porte sur les mêmes classes d'âge fortes et faibles que celui de septembre. Il a été déterminé que la classe d'âge de 1987 était la plus forte et celle de 1992 la plus faible de la période 1983-1993. Au fur et à mesure que la série chronologique inclura un plus grand nombre d'années, le relevé de recherche sur la morue juvénile devrait devenir de plus en plus utile comme indice de l'abondance des morues prérecrues dans le sud du golfe du Saint-Laurent.

INTRODUCTION

Prediction of the strength of age-classes recruiting to a stock has long been a goal in fisheries science but successes have been very few. The most commonly used method has been to use regression models of numbers of recruits as a function of stock size or some measure of the environment. There are few stocks for which strong stock-recruitment relationships exist and even fewer for which environmental predictors of prerecruit abundance have been identified (e.g., Hutchings & Myers 1994; Tuljapurkar et al. 1994). At best, these relations yield qualitative predictions of year-class strength (e.g., small spawner biomass is less likely than large spawner biomass to yield large year classes) (Koslow 1992). An alternative approach has been to use one or more measures of abundance of larval fish, or occasionally juveniles, as indices of year-class strength. Logically, the closer a life history stage is to the parameter of interest, in this case numbers of fish recruiting to a fishery, the more useful the estimate is likely to be. Research to date has focused on the farthest stages (e.g., eggs and larvae).

Studies of larval stages have yielded much information on the biology of these organisms. Recent studies show, however, that after more than 100 years, there are few (if any) cases where measures of premetamorphic larva abundance can be used to predict incoming recruitment to any stock (Peterman et al. 1988; Campana et al. 1989; Bradford 1992). In contrast to larval fish, the biology of juvenile stages (post-metamorphic but before sexual maturity) is often poorly known and there have been few attempts to use measures of juvenile abundance as indices of year-class strength. Since 1990, a research survey to develop an index of prerecruiting age-groups (< age 5) of Atlantic cod (*Gadus morhua*) has been conducted annually during July or August in the southern Gulf of St. Lawrence. Subsequent to initiation of this survey series, Sinclair and Chouinard (1992) and Sinclair et al. (1994) have shown that a multiplicative model using the September survey yields a good recruitment index for catch projections. Based on the five surveys conducted, this paper evaluates the potential of juvenile cod survey as an independent index of prerecruiting year-class strength of southern Gulf of St. Lawrence cod.

STUDY AREA

A research survey covering nearly all of the southern Gulf of St. Lawrence has been conducted annually since 1971. Tremblay and Sinclair (1985) showed that the west end of Prince Edward Island (PEI) was an area of consistently high abundance of juvenile (ages 1 to 4) cod during September between 1971 and 1981 and subsequent work has confirmed these findings (Chouinard et al. 1991; Hanson and Chouinard 1992; Sinclair et al. 1994). Using the most recent survey (September 1994) as an example (Fig. 1), the largest sets of ages 1 and 2 cod were caught at the western end of PEI, and large sets were caught by near the Magdalen Islands and the east end of PEI. The ages 3 and 4 cod were more widely dispersed; the largest catches were at the west end and along the north shore of P.E.I. and near the Magdalen Islands. Comparatively few ages 3 and 4 cod were caught near the east end of P.E.I.

To confirm that summer distributions were similar to those observed in September, numbers per tow at age were plotted for the following surveys conducted: in the western Gulf during early July 1990; in the eastern Gulf during late June 1987; and in a comparative survey between two research vessels during late July-early August 1992. The summer distributions of all ages were similar to those observed during September except that ages 3 and 4 fish were distributed somewhat closer to shore during summer (Fig. 2). The results of the July 1994 survey suggests that ages 1 and 2 cod can be found much closer to shore in some years than the depths covered during the July 1990 survey (Fig. 3).

Because the west end of PEI consistently had the highest catches of young cod during summer and early autumn, and is logistically simpler to survey than the area near the Magdalen Islands, NAFO unit area 4Tl (Fig. 4) was chosen as the survey area for this study.

METHODS

Research surveys with the goal of capturing juvenile cod were conducted in NAFO unit area 4Tl during July or August, 1990-1994. All five research surveys followed the standard stratified random sampling design used by the Gulf Region of the Canadian Department of Fisheries and Oceans (Hurlbut & Clay, 1990). Four depth strata were selected and partitioned into sample units of about 3 X 3 nm. Possible sample sites were identified based on the centre point of each square. There are 90 potential sampling sites in stratum 1 (8 fm to 16 fm), 80 in stratum 2 (16.1 fm to 24 fm), 37 in stratum 3 (24.1 fm to 32 fm) and 17 in stratum 4 (32.1 fm to 40 fm). For each survey, the number of sets selected in each stratum was proportional to stratum area.

For a variety of reasons, the timing of the survey and the vessels used have not remained constant. The survey vessels were: the research trawler *CSS J. L. Hart* (20 m stern trawler) during late July-early August 1990 (34 successful sets); the commercial trawler *r/v Anita-Bernard* (26 m shrimp trawler) during early August 1991 (47 successful sets); the research trawler *CSS E. E. Prince* (40 m stern trawler) during early July 1992 (39 successful sets) and 1993 (54 successful sets); and the research trawler *CSS Calanus II* (20 m stern trawler) during early July 1994 (45 successful sets). All five surveys used the same Number 286 bottom trawl (wing width 14.5 m; 12 mm mesh liner in extension piece and cod end) fitted with "Rock-Hopper" foot gear, the same bridles, and similar trawl doors and ground warps. No attempt was made to correct numbers per tow for differences in catchability of cod to the various research vessels because these conversion coefficients are unknown. Differences in research vessel, and even in wing width between trawls, do not necessarily result in significant differences in catch per standard tow when direct comparisons are made (DeAlteris et al. 1989; Nielsen, 1994).

The Atlantic cod ages used in this study represent age at time of capture. Ages were determined from thin sections of otoliths embedded in polyester resin (Bedford, 1983). Otolith sections were examined under a binocular microscope (12.8 X) to count annuli at time of capture. Age determinations were made by two experienced readers. Age reading consistency was maintained by testing age-readers against a reference collection weekly or every 1,000 age-determinations, whichever came first. Age readers were required to maintain an 80% consistency with no directional bias and no ages ± 2 or more years from the reference. If consistency was low, or a bias detected, the reader was required to redo the calibration exercise and the age determinations of the last 1000 otoliths were discarded. The age reading of those otoliths was repeated, not necessarily by the same reader. Failure to maintain age-reading consistency was a rare event. A high level of consistency has been maintained in age-determinations for the southern Gulf stock. For example, the average consistency against the reference collection was 87% (SE = 0.96; $\underline{n}$ = 12) for 1991 and 91% (SE = 1.01; $\underline{n}$ = 12) for 1992 with no detectable bias in either year.

The number of fish at age per standardized tow was calculated using the survey analysis program RVAN (Clay, 1989) written for use with SAS/IML (SAS Institute Inc., 1989a). Age 0 fish were not included in this study because the survey was conducted during early July from 1992 to 1994 and age 0 fish are not available to the net at this time of year. Because age 0 fish settle to the bottom over a lengthy period, demersal trawls likely are not a good gear to sample this age group.

Although there were only five years of data, it was possible to attempt two types of analyses to evaluate the utility of the surveys as an index of year-class strength: correlation analysis and application of two multiplicative models. A first correlation analysis involved correlating the number-per-tow at age in the survey with abundance at the same age from the most recent SPA (e.g., age 3 in survey and age 3 in SPA). A second analysis correlated numbers-at-age in the survey in one year with abundance of the same year-class the following year in the SPA (e.g., age 3 in survey against age 4 in SPA of following year). For comparison, the same correlations were attempted with the mean numbers at age (1990 to 1994) from the September survey (all strata).

The multiplicative analyses attempted were similar to those done by Sinclair and Chouinard (1992). The basic model was of the form:

$$\ln (C_{ij} + 0.5) = int + b_1 I + b_2 J + E \qquad (1)$$

where C_{ij} = the survey index at age i in year j,
I = matrix of 1 and 0 to designate ages
J = matrix of 1 and 0 to designate year-classes
int = model intercept
E = error term

The years included in the model were 1990 to 1994; the ages were 1 to 9; and the year-classes were 1983 to 1993. This model was run with mean number-per-tow at age obtained from the five juvenile cod surveys as well as with the mean number-per-tow at age from the 1990 to 1994 September surveys (all strata).

A second multiplicative model was run to test for stratum effect in the juvenile cod survey data. In this case, a stratum term (strata 1 to 4) and stratum*age term were added to the model. The year-class estimates derived from this model were also compared to those for the September survey.

The statistical analysis was performed using the general linear models procedure (GLM) of SAS (SAS Institute Inc. 1989b). Estimates were presented either as least squares means or were back-transformed to the arithmetic scale with the appropriate bias adjustment.

RESULTS AND DISCUSSION

Mean numbers per tow

The numbers at age do not indicate any strong recruitment (Table 1) since the survey began. The coefficients of variation suggest that cod of ages

2 and older are consistently captured by the net; however, few cod older than age 9 were caught. The largest catch of age 3 cod occurred in 1990 and represents the 1987 year-class. Because the survey began in 1990, there is no estimate of numbers of the 1987 year-class at age 1 or age 2. There are two columns for the 1994 survey. One very large tow of 2400 cod was comprised primarily of age 3 (1535 fish) and age 2 (400 fish) fish and its omission greatly reduced the estimate of the size of the 1991 year-class at age 3 in 1994 and decreased the CVs for ages 1-4. To be conservative, estimates excluding the large set have been used in the analyses. In contrast with the 1987 year-class, that for 1992 appears to be weak in all surveys to date (Sinclair et al. 1994, 1995; this study).

The summer series is not as consistent as the September series. All estimates for 1993 appeared to be anomalously low in the juvenile survey. The September survey indicates a higher than average proportion of the juveniles were caught around the Magdalen Islands and lower than average proportion were caught in the Shediac Valley during 1992 and 1993 (Sinclair et al. 1994). It is not known whether the current distributions of juveniles have returned to those typically found during the 1970s and 1980s. It appears that 1994 also was an unusual year because large numbers of adults (especially age 6 and older) were caught near shore in both the juvenile survey (this study) and the September survey (Sinclair et al. 1995). Distribution changes could have a greater affect (in terms of unexplained variation) on the juvenile cod survey series than the September survey because the whole stock area is not covered during the juvenile survey.

Correlations with SPA results

The juvenile cod series showed a significant correlation between number at age 3 in the survey and SPA estimates at age 3 in the same year while the September survey showed a significant correlation at age 4 (Table 2). Neither index showed a significant correlation for age 5. The small number of years severely restricts the analysis because very high correlation coefficients are needed to be considered significant. Secondly, there is very little contrast in the data. There have been no strong year-classes since the juvenile survey began in 1990. The 1992 year-class appears to be particularly weak in the juvenile survey and may provide the necessary contrast once it enters into the SPA.

There was a significant correlation between numbers of cod at age 2 in the juvenile survey and those in the SPA at age 3 one year later. This correlation was negative, however, largely due to the anomalously low 1993 point. A marginally significant correlation was observed between numbers at age 3 in the juvenile survey and numbers at age 4 one year later in the SPA. There were no significant correlations based on data from the September survey. In these analyses, the number of cases was only 4 and the r^2 value had to exceed 0.90 for statistical significance at $P = 0.05$. Nevertheless, these very preliminary analyses suggest that the juvenile survey has promise as an index of recruiting age-groups.

Multiplicative model results

<u>Age and year class model</u>: The multiplicative models based on juvenile cod and September survey data both showed significant age effects but the year-class effect was not significant for the juvenile survey model (Table 3). It is likely that juvenile survey, which covers a limited area, does not track

the older age-groups as well as the main September survey. Furthermore, the only strong year-class occurring in the time series (that of 1987) was not observed at age 1 or 2. The estimated year-class size were significantly different from zero in the juvenile cod survey but the 95% confidence were very wide and none of the estimates were different from each other.

The least significant mean catch per tow at age showed the September survey peak catch was at age 4 compared to age 3 for the juvenile cod survey (Fig. 5). The slope of lower limb of the catch curve (age 6 to 9) for the main September survey (-0.77) was steeper than that for the juvenile survey (-0.63) suggesting that apparent mortality was stronger outside of the Shediac Valley. This is consistent with earlier work showing the Shediac Valley is near the centre of distribution for most age-groups in this stock (Swain and Wade 1993).

Age, year class, stratum, and age*stratum interaction model: The model incorporating the four depth strata showed significant stratum, age, and age*stratum effects (Table 4). Again, the year class effect was not significant. The least squares means estimates of mean catch/tow expressed for each stratum showed the peak catches were for age 2 in the shallowest stratum progressing to age 5 in the deepest stratum (Fig. 6). Cumulative distributions with depth show the same pattern of younger fish consistently being found in shallower and warmer water than older fish (Swain 1993; Swain and Kramer 1995; Hanson ms1995).

Year-class estimates from the model based on the juvenile survey with no stratum effect do not give the same trend as estimates based on the September survey (Fig. 7). The juvenile cod model suggested the 1991 year-class was stronger than indicated by the September survey. In contrast, the model for the juvenile survey that incorporates the age*stratum interaction effect mirrors the analysis based on the September survey quite closely. Given the biological basis for the age*stratum interaction, this model probably best represents the results of the juvenile survey.

Although the length of the time series remains very short, the juvenile cod survey clearly has potential to provide a second, independent, index of pre-recruit year-class strength for the southern Gulf cod stock. Changes in sampling periods and survey vessels, such as those that have already occurred in this time series, must be avoided because they add an unknown amount of imprecision to the data.

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Table 1. Mean number per tow and coefficients of variation at age from the annual juvenile cod survey, 1990 to 1994. 1994b represents estimates with the 500 kg set included.

Age	1990	1991	1992	1993	1994	1994b
			Mean number per tow			
0	0.38	1.50	0.00	0.00	0.00	0.00
1	0.71	3.28	10.70	0.61	1.13	2.56
2	7.24	7.45	31.50	3.07	3.80	13.64
3	45.94	16.22	26.91	7.58	26.65	61.81
4	31.13	26.00	16.24	8.61	19.79	26.93
5	15.58	13.53	11.22	13.35	23.37	24.32
6	10.06	5.42	2.37	8.46	20.95	21.04
7	6.94	2.39	1.51	3.47	9.34	9.19
8	2.38	1.52	0.70	1.60	3.31	3.26
9	1.38	0.25	0.47	0.38	1.30	1.28
10	1.05	0.15	0.21	0.30	0.59	0.59
11	0.88	0.13	0.19	0.06	0.45	0.44
12	0.00	0.18	0.04	0.17	0.14	0.14
13	0.00	0.02	0.07	0.04	0.15	0.14
14	0.12	0.09	0.04	0.02	0.04	0.04
15	0.00	0.00	0.00	0.00	0.03	0.03
16+	0.36	0.05	0.05	0.09	0.00	0.00
0+	123.87	78.11	102.33	47.74	111.25	164.74
3+	115.54	65.88	60.14	44.07	106.33	148.52
5+	38.47	23.67	16.99	27.88	59.88	59.77
			Coefficient of Variation			
0	41.20	44.49	0.00	0.00	0.00	0.00
1	37.37	32.94	84.34	70.78	28.80	57.81
2	27.62	33.48	44.24	76.99	28.77	72.54
3	22.81	21.32	33.42	22.82	33.24	58.42
4	21.62	21.93	28.39	17.04	22.94	30.85
5	14.74	16.85	24.66	14.91	16.94	15.98
6	12.68	16.94	22.73	12.27	15.40	14.82
7	12.19	18.37	20.69	11.74	13.92	13.78
8	11.75	15.12	20.70	12.32	14.62	14.28
9	14.48	21.82	49.04	18.66	13.74	13.52
10	10.44	36.27	21.50	11.26	14.09	13.22
11	15.31	25.10	53.48	0.00	17.10	16.18
12	0.00	24.57	0.00	26.94	22.43	23.08
13	0.00	0.00	48.65	0.00	30.84	32.17
14	44.17	37.20	0.00	0.00	0.00	0.00
15	0.00	0.00	0.00	0.00	0.00	0.00
16+	52.40	105.33	91.26	49.69	0.00	0.00
0+	18.06	15.80	27.76	14.70	18.02	34.42

Table 2. Correlation coefficients and significance levels of correlations of mean number per tow (at age) in the juvenile cod survey in 4Tl or the September survey (all strata) on number per tow (at age) from the SPA.

	SPA for same year			Same year class in SPA at year + 1		
Age	r	P	n	r	P	n
			Juvenile cod survey			
2	-	-	-	-0.950	0.0501	4
3	0.945	0.0154	5	0.953	0.0471	4
4	0.751	0.1440	5	0.893	0.1074	4
5	0.381	0.5274	5	0.887	0.1136	4
			September survey all strata			
2	-	-	-	0.665	0.3353	4
3	0.758	0.1373	5	0.945	0.0552	4
4	0.901	0.0367	5	0.762	0.2371	4
5	0.701	0.1868	5	0.826	0.1738	4

Table 3. Summary of analysis of variance for multiplicative model of mean catch at age with age and year class effects for surveys conducted from 1990 to 1994.

Source	Overall model				Type I SS			Type III SS		
	df	F	P	R^2	df	F	P	df	F	P
					Juvenile cod survey in 4Tl					
Model	20	4.81	0.0002	0.80						
Error	24									
Year class					12	4.97	0.0004	12	0.61	0.8137
Age					8	4.56	0.0018	8	4.56	0.0018
					September survey all strata					
Model	20	20.73	0.0001	0.95						
Error	24									
Year class					12	16.95	0.0001	12	5.12	0.0003
Age					8	26.39	0.0001	8	26.39	0.0001

Table 4. Summary of analysis of variance for multiplicative model of mean catch at age with age, year class, stratum, and age*stratum effects for juvenile cod surveys (in 4T1) conducted from 1990 to 1994.

Source	Overall model				Type I SS			Type III SS		
	df	F	P	R^2	df	F	P	df	F	P
Model	47	10.33	0.0001	0.79						
Error	132									
Year class					12	12.93	0.0001	12	1.28	0.2367
Stratum					3	14.57	0.0001	3	14.57	0.0001
Age					8	18.24	0.0001	8	18.24	0.0001
Stratum*Age					24	5.86	0.0001	24	5.86	0.0001

Figure 1. Distribution of juvenile cod in the southern Gulf of St. Lawrence during September 1994.

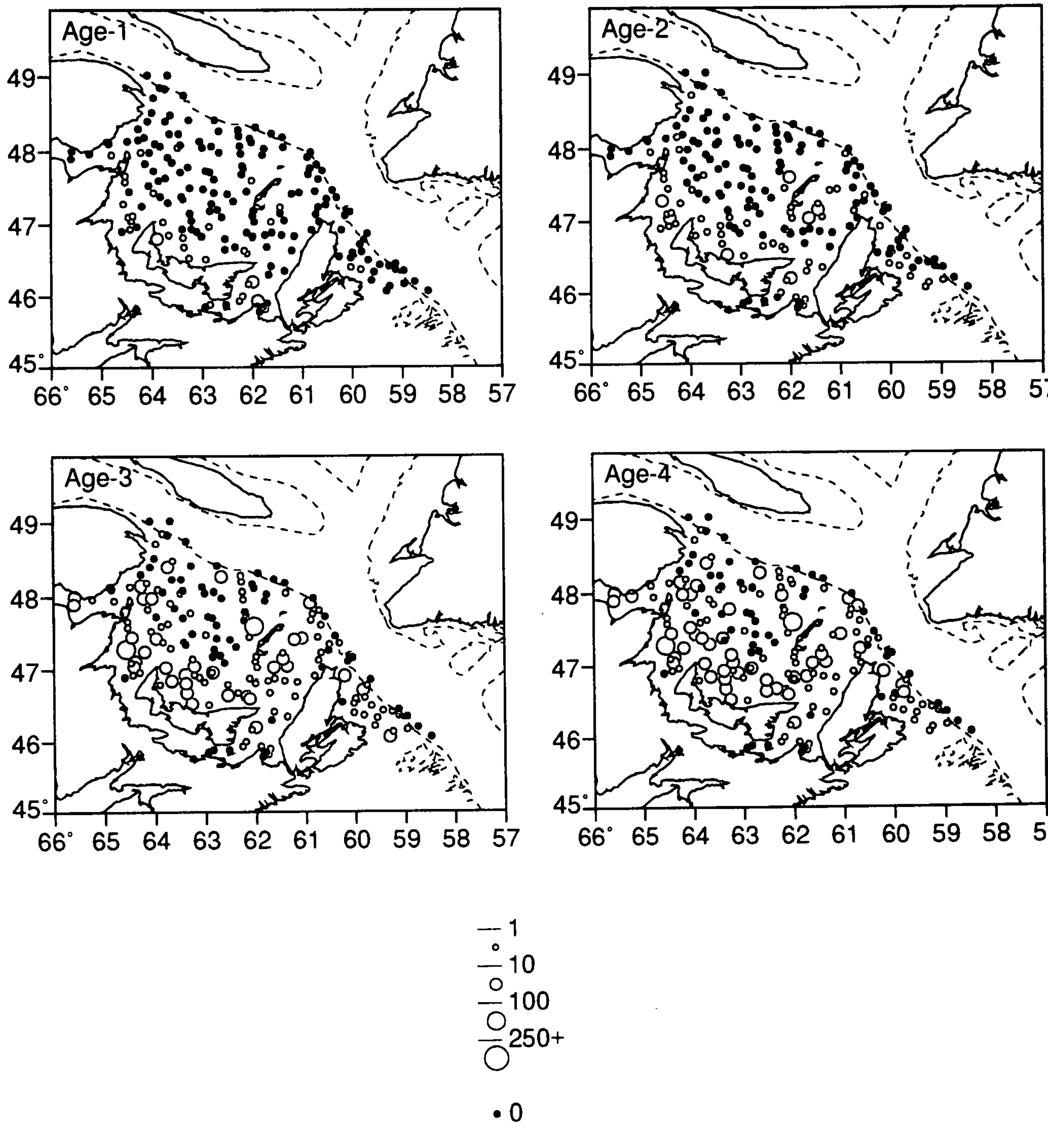

Figure 2. Distribution of juvenile cod in the southern Gulf of St. Lawrence during summer (based on research surveys conducted during late June 1987, July 1990, and August 1992).

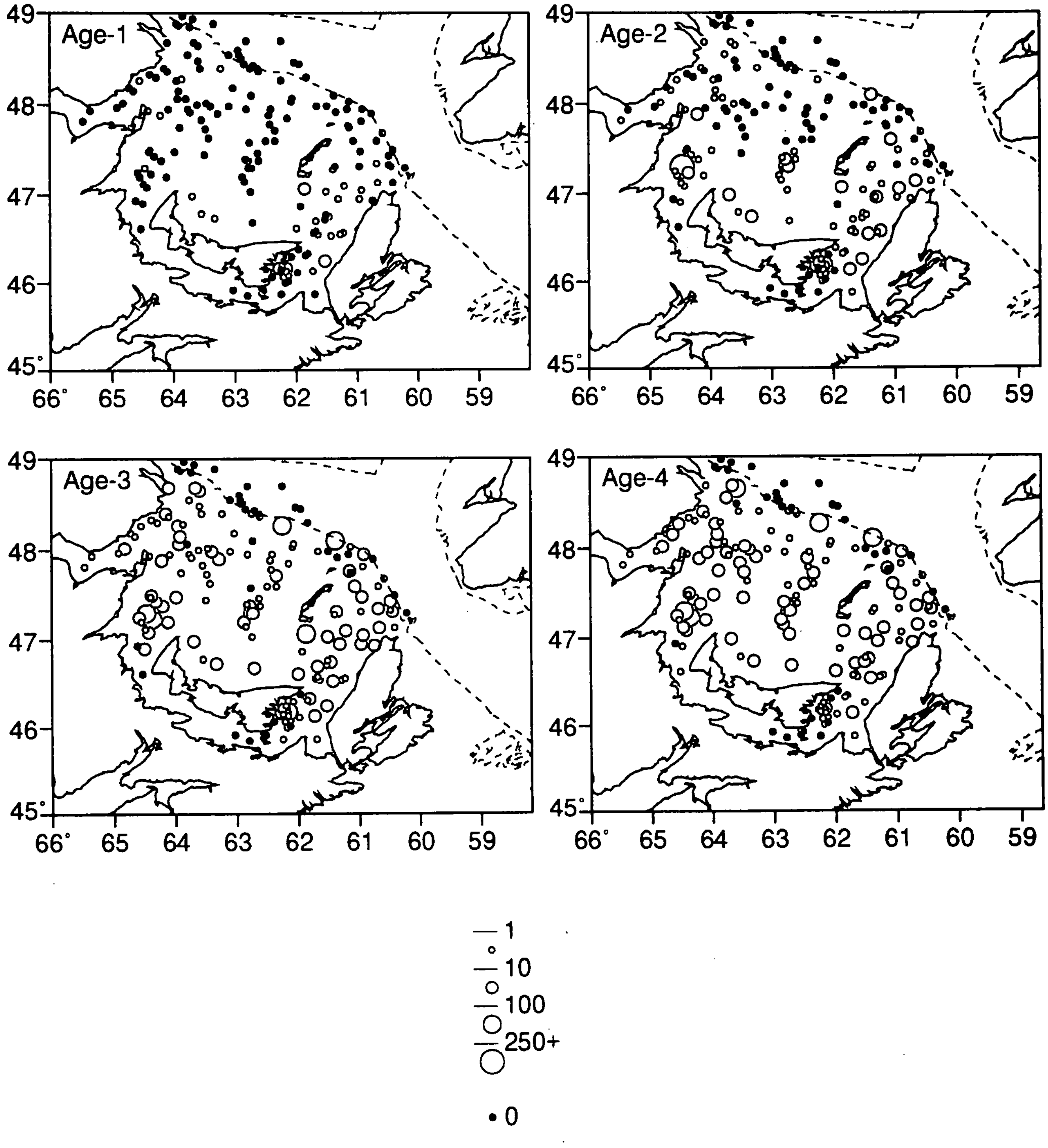

Figure 3. Distribution of juvenile cod during the July 1994 juvenile cod survey in the southern Gulf of St. Lawrence.

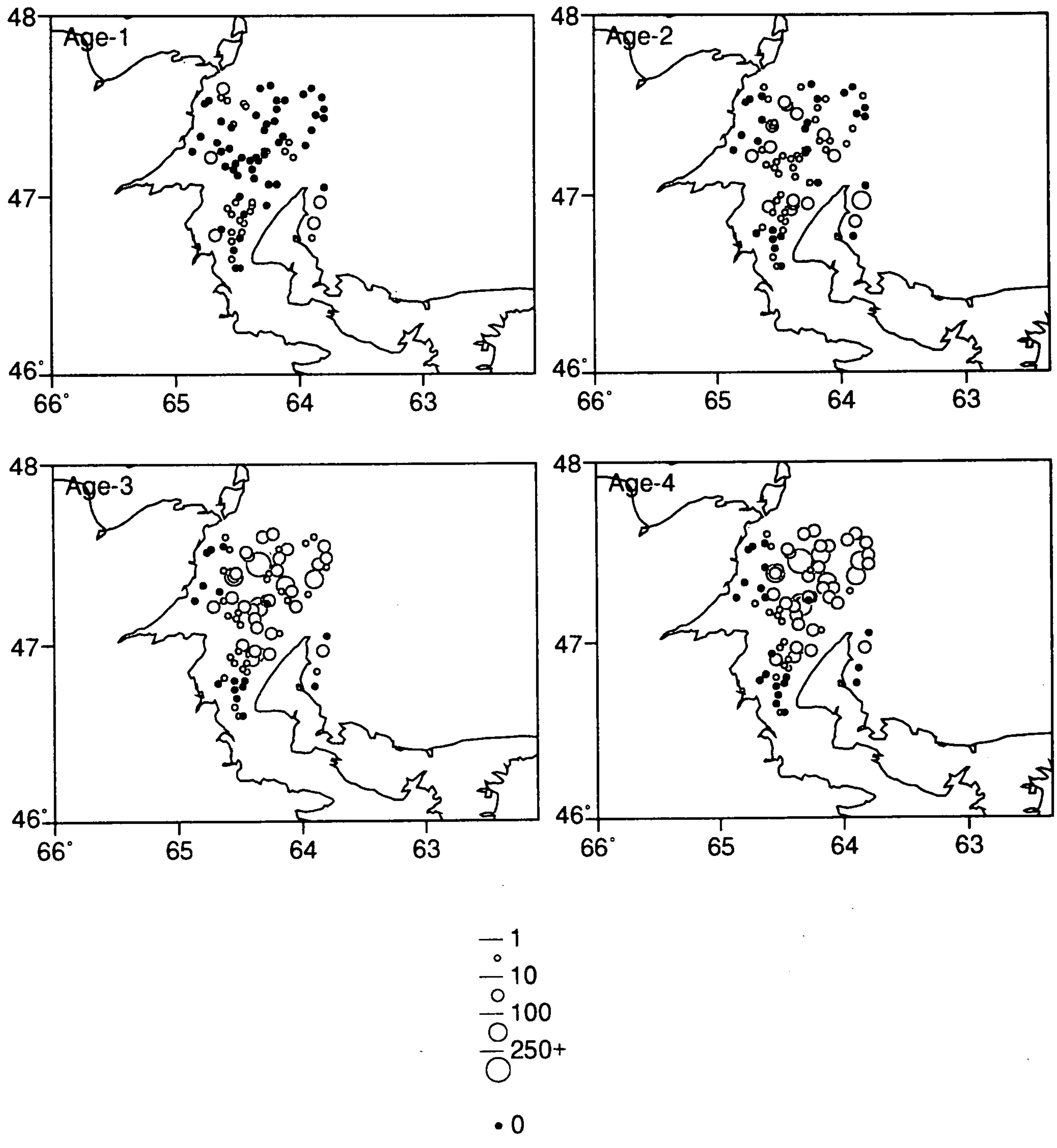

Figure 4. The southern Gulf of St. Lawrence showing the locations mentioned in the text: Prince Edward Island (PEI), Magdalen Islands (M.I.), Chaleur Bay (B.C.), Cape Breton Island (C.B.), and the juvenile cod survey area (4Tl)..

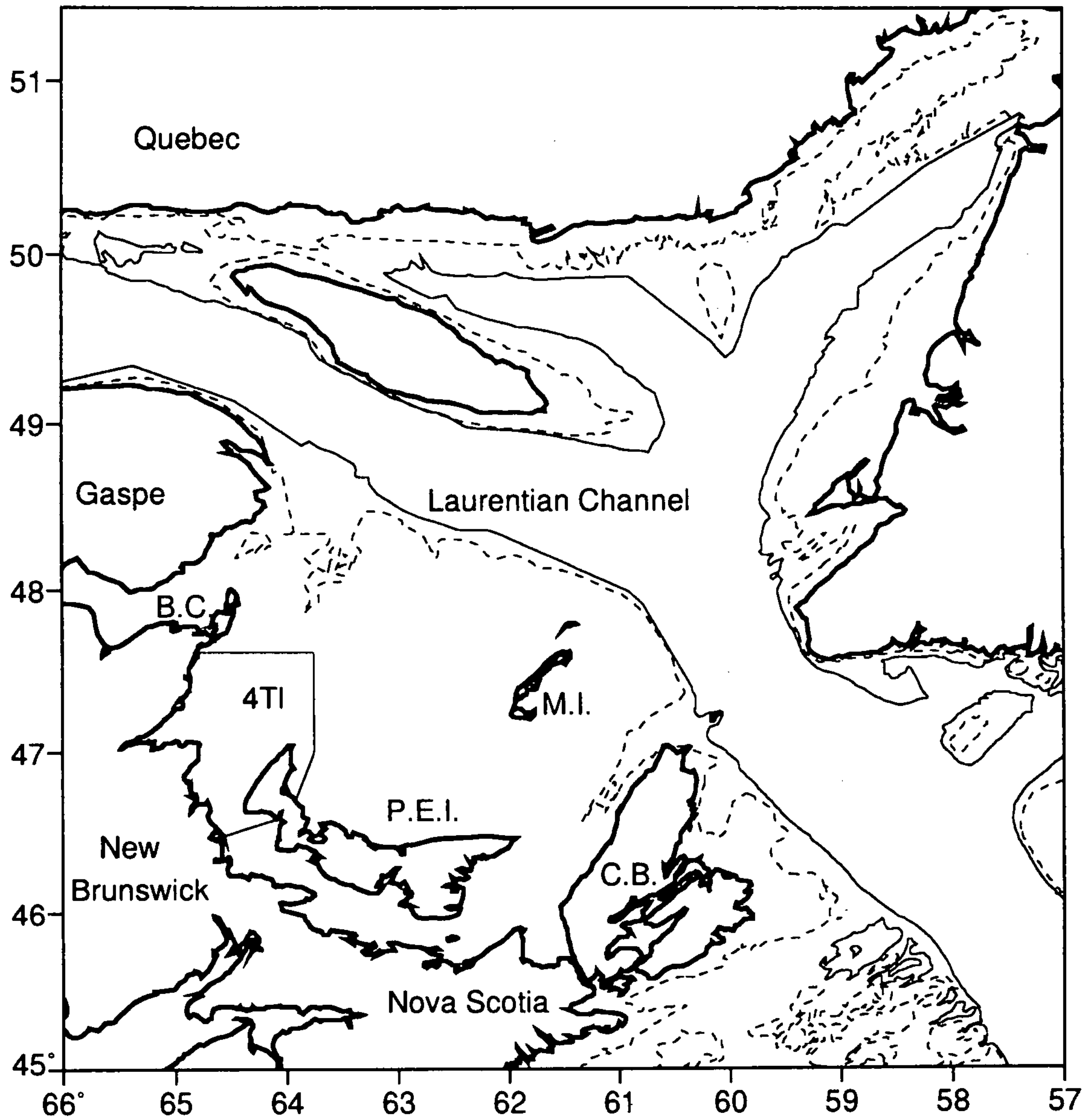

Figure 5. Least squares estimates (age and year-class effects models for 1990-1994) of catches of age 1 to 9 cod in the southern Gulf of St. Lawrence.

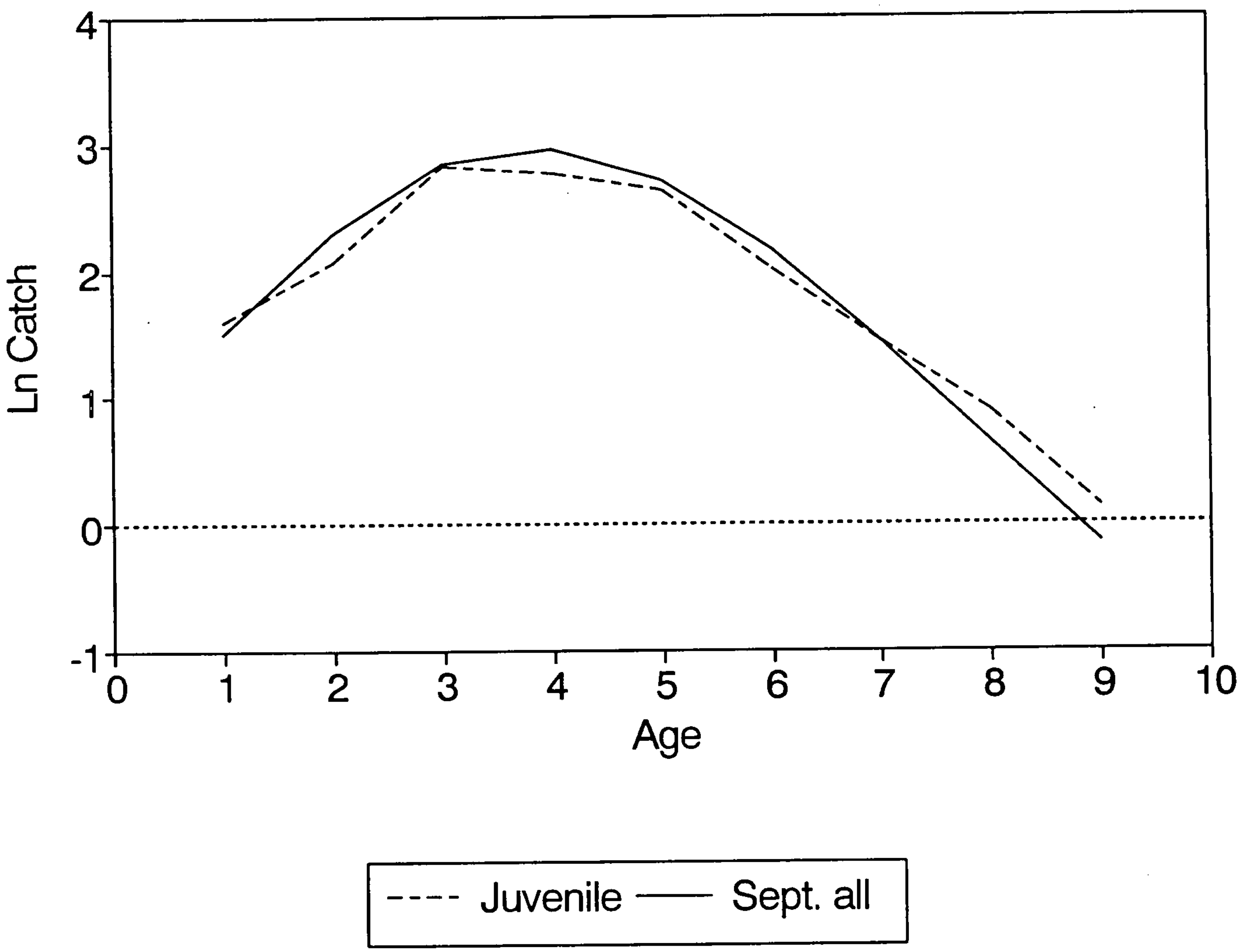

Figure 6. Least squares estimates (age, year-class, stratum, and age*stratum effects model for 1990-1994) of catches of age 1 to 9 cod from juvenile cod surveys in the southern Gulf of St. Lawrence.

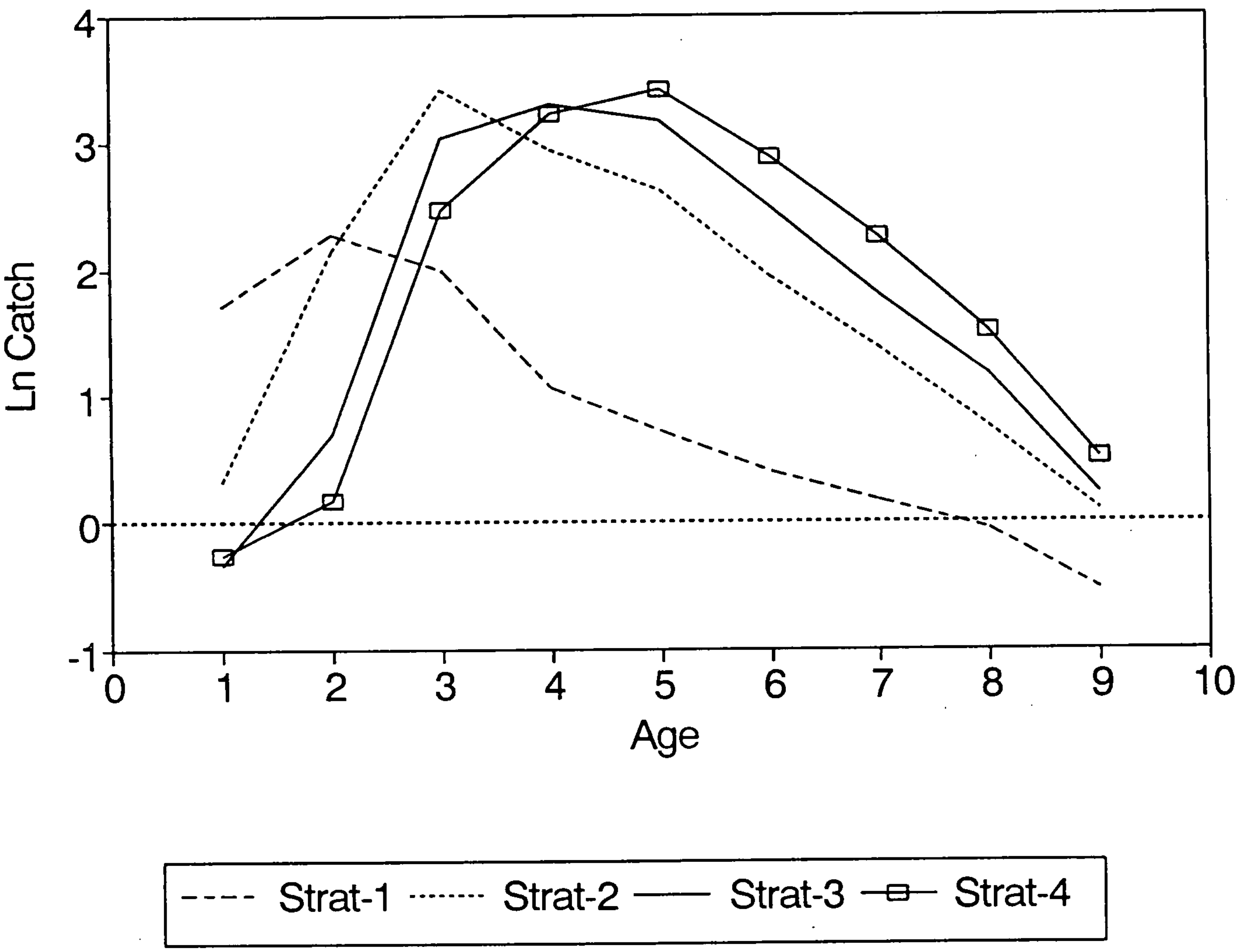

Figure 7. Comparison of year-class estimates (relative to 1987 estimate) for southern Gulf of St. Lawrence cod as derived from the two multiplicative models for the years 1990 to 1994: age and year-class effect model (juvenile cod survey and September survey [all strata]) and age, year-class, stratum, and age*stratum model (juvenile cod survey).