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Comparison of Research Survey Population Estimates of Cod in 4T, 4Vn, and 4Vs

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Abstract

Research survey estimates of mean numbers per tow at age of cod in 4T, 4Vn, and 4Vs were examined to address two questions relevant to the terms of reference of the Scotia Fundy Region working group on 4Vn cod. The consistency of the year-class estimates among ages was examined to evaluate the utility of the survey results for providing management advice for the separate stocks if indeed these stocks exist. It was found that the information content of the 4Vn July and 4Vs spring surveys is relatively low and would yield highly variable assessment data when compared to the 4T September and 4Vs July surveys. Secondly, the age compositions and relative year-class strengths of cod in each area were examined for evidence of stock separation. Given the weak year-class signals at younger ages from several of the surveys and the similarity in trends at older ages, it is not possible to determine if there is stock separation among the areas from these analyses. However, the lack of juvenile cod in 4Vn during summer questions the local spawning population's ability to support the abundance of adults found in the summer surveys.

Résumé

Les estimations du nombre moyen de morues par trait selon l'âge, dans les divisions 4T, 4Vn et 4Vs, ont été examinées, afin de répondre à deux questions associées au mandat du groupe de travail de la Région Scotia-Fundy sur la morue de 4Vn. La constance des estimations des classes annuelles, parmi les groupes d'âge, a été étudiée afin de déterminer dans quelle mesure les résultats des relevés pourraient être utilisés pour donner des conseils de gestion au sujet des stocks distincts, si effectivement ces stocks existent. On a pu déterminer que l'information fournie par les relevés du printemps dans 4Vs et de juillet dans 4Vn est relativement limitée et que l'information qui en serait tirée pour l'évaluation serait très variable, comparativement à celle des relevés de septembre dans 4T et de juillet dans 4Vs. De plus, la composition selon l'âge et l'effectif relatif des classes annuelles de morue dans chaque zone ont été examinés en vue de trouver des signes permettant d'établir une distinction entre les stocks. Étant donné la faiblesse des classes annuelles chez les jeunes selon plusieurs relevés et la similitude des tendances chez les poissons âgés, il n'est pas possible de déterminer à partir de ces analyses s'il existe des stocks distincts. Cependant, l'absence de jeunes morues dans la sous-division 4Vn pendant l'été permet de se demander si la population locale de géniteurs est en mesure de soutenir l'abondance des adultes observés au cours des relevés de l'été.

Introduction

Subdivision 4Vn is a well known cod stock mixing area. There is a resident population which supports a fishery throughout the summer, with the highest activity directed at spawning fish in May. Cod from the southern Gulf of St. Lawrence overwinter in 4Vn and the northern part of 4Vs. They migrate out of the Gulf in November and return in April-May (Lambert 1993; Sinclair and Currie 1994). Tagging information also suggests mixing with the adjacent 4VsW stock complex. A fishery has traditionally exploited these overwintering schools. The 4Vn assessment unit was originally defined to include catches made during the May to December period. All catches made in other months were associated with the southern Gulf of St. Lawrence stock (4TVn). The definition was recently changed to reflect new information on the timing of the outmigration; the 4Vn assessment unit now includes only catches made during the May to October period (D'Amours et al. 1994; Sinclair et al. 1994). The Scotia Fundy Regional Advisory Process Committee raised questions in 1994 concerning the scientific value of a 4Vn cod management unit highlighted by the difficulty in producing an internally consistent stock assessment. Consequently, the committee recommended the formation of an interzonal working group to study the issue and this paper is one of many background documents.

Research vessel surveys designed to track groundfish population abundance have been conducted in the 4Vn and the adjacent areas (4T and 4Vs) since the early 1970's. Analysis of these time series provides two sorts of information relevant to the terms of reference of the working group. First, using the same analytical methods on an area-by-area basis would allow a comparison of the internal consistency of the separate abundance indices. The results may be used to judge whether the existing data are sufficient to manage the areas as separate stocks if indeed these stocks exist. Secondly, the surveys provide independent estimates of both the age composition and relative year-class strengths of cod in each area, which may be used to judge whether the populations are distinct.

Methods

Surveys in 4T

Data were available from a late summer (September) survey conducted in Div. 4T during 1971-94. Three vessels have been used, the *E.E. Prince* from 1971-85, the *Lady Hammond* from 1985-91, and the *Alfred Needler* from 1992-94. The *E.E. Prince* fished 12-hour days and used a Yankee-36 bottom trawl while the other 2 vessels fished 24-hour days with a Western II-A bottom trawl. Comparative fishing experiments were conducted between the *E.E. Prince* and *Lady Hammond* during the 1985 survey and the *Lady Hammond* and *Alfred Needler* just prior to the 1992 survey (Nielsen 1994). The results indicated a depth dependent difference in fishing power between both *E.E. Prince* and *Lady Hammond*, and *Lady Hammond* and *Alfred Needler*. A combination of results indicated a depth-independent difference in fishing power between *E.E. Prince* and *Alfred Needler*. These corrections were applied to make all the data equivalent to the *Alfred Needler*.

Previous to 1995, the 4T RV index used only stations from the stratified random survey design. However, several additional stations were fished including a set of 13 fixed stations from 1971-88, another set of fixed stations from 1984-87, comparative fishing stations fished by *Lady Hammond* in 1985, and repeat stations fished from 1984-88. An analysis was conducted to investigate the effect on the abundance index of including these additional stations. It was concluded that their inclusion resulted in a improved abundance index and it was decided to treat the fixed stations as random stations and average the repeat stations before including them in the index (Nielsen 1995).

The 4T survey was divided into eastern (strata 428, 430-439) and western (strata 415-427, 429) areas which correspond to possible stock components as indicated by juvenile distribution (Tremblay and Sinclair 1986; Chouinard et al. 1991; Sinclair et al. 1994).

Surveys in 4Vn and 4Vs

Annual survey results from 4Vn, July were available for 1970-93 and for a fall survey (October-November) for 1978-83. In 4Vs there was a spring survey (March) in 1979-84 and 1986-94; a summer survey in 1970-93, and a fall survey (October-November) in 1978-84. However, the fall surveys were not used in this analysis because of the short time series. Three research vessels were used for these surveys, the *A.T. Cameron* (July surveys 1970-81), the *Lady Hammond* (summer 1982, spring 1979-83), and *Alfred Needler* (spring 1984-94, summer 1983-94). Comparative fishing experiments were conducted between *A.T. Cameron* and *Lady Hammond*, and between *Lady Hammond* and *Alfred Needler*. The analysis suggested that the results of surveys conducted by both *A.T. Cameron* and *Lady Hammond* should be multiplied by 0.8 to make them comparable with *Alfred Needler* and this was done

Statistical Analysis

Stratified mean numbers per tow at age were calculated for each area and survey according to the experimental design (Cochran 1977; Halliday and Koeller 1981). Separate age-length keys were used for each area and survey. Comparisons were restricted to ages 1-10. Outside this age range sample sizes were low and mean numbers at age estimates were less reliable.

One of the principle objectives of research vessel surveys is to track variations in year-class abundance. It is important to know at what age the surveys provide reliable estimates of relative year-class abundance, and to what degree the relative estimates are consistent from age to age. Cod from these stocks become available to the commercial fishery at age 3, but are not fully recruited until age 5-6. Correlation coefficients between the estimated mean numbers per tow of a specific year-class but at different ages were calculated as a check on the internal consistency of the different RV series. The statistical significance of these correlations were plotted using shaded boxes.

Multiplicative models have been used to extract information on relative year-class strength and relative abundance at age from fishery catch at age data (Shepherd and Nicholson 1991; Sinclair and Chouinard 1991; Sinclair et al. 1994). The multiplicative framework is used for two reasons. The abundance of a year-class at a given age is often considered to be a multiplicative function of it's relative abundance and it's cumulative mortality to that age. Secondly, lognormal error distributions are often considered to be appropriate for research vessel estimates of population abundance. In the case of an annual research vessel survey index, the mean numbers per tow at age may be expressed as a multiplicative function of age and year-class. The following model was used to estimate the average age and year-class effects of the five survey time series.

$$\ln A_{ij} = \beta_0 + \beta_1 \mathbf{I} + \beta_2 \mathbf{J} + \varepsilon$$

where A_{ij} = the RV index at age i and year j
$\mathbf{I}$ = a matrix of 1 and 0 to designate ages
$\mathbf{J}$ = a matrix of 1 and 0 to designate year-classes

An important structural assumption of this analysis is that the two main effects are independent. However, this is most likely not the case as variations in total mortality (either natural or fishing) and the fishery exploitation pattern will affect the cumulative mortality of a year-class.

Three sets of multiplicative analyses were used in an attempt to account for the possible effect of variations in total mortality during the time series. In the first, ages 1 to 10 were used for all years. The objective was to obtain the average age distribution in the various populations during the time periods and a rough estimate of relative year-class size. The latter should not be used in a stock assessment context since there have been important variations in both fishing mortality and the exploitation pattern over the time period of the study. However, the year-class estimates were compared between areas using correlation analysis. In the second analysis only ages 1 to 3 were used. This was done to minimize the effects of variations in the respective fisheries on the year-class estimates and to obtain an objective measure of the strength of the year-class signal from the different surveys. The latter may be useful to judge the information content of the surveys. Only ages 4-6 were used in the third set of analyses. These were done to obtain year-class estimates during the period when they are recruiting to the commercial fisheries.

Results

The estimated mean numbers per tow from the five research vessel surveys are given in Tables 1-5.

The internal consistency of the 4T east and west indices was the highest of the 5 surveys (Figure 1). For the western area there were significant ($p<0.05$) correlations for most ages except age 1. For the eastern area, age 1 abundance was significantly correlated with ages 2-4, and there were high correlations among the older ages. There were significant correlations between ages 5-9 in the 4Vs July survey index. Age 2 , 4, and 5 estimates were also significant. The internal consistency of the 4Vn July and 4Vs spring index was low. When the correlations were significant, they were generally between adjacent ages.

The main effects in the age 1-10 multiplicative analyses were all highly significant (Table 6). Residual distributions were normal.

The estimated age effects differed among the areas (Table 7). Once retransformed and scaled to proportions at age, the patterns for 4T east and west were very similar with a modal age of 4 (Figure 2). The average age in the 4Vs summer and spring surveys was less than in the other areas, with the modal age in the spring survey at 2 and in the July survey at 3. There were relatively few young fish (ages 1-3) in the 4Vn July survey. The modal age was 5.

The least square means estimates of relative year-class strengths from the five surveys are presented in Table 8, and inter-survey correlations are presented in Table 9. The correlations were all significantly ($p < 0.05$). The highest correlations were between 4Vs July and 4Vs spring estimates, the 4Vs spring and 4T west, and the 4T east and 4T west estimates. The lowest were between 4Vs July and 4T east, and 4Vs spring and 4T east.

The age effects of the multiplicative analyses using ages 1-3 were all highly significant (Table 10). However, the year-class effects were not significant for the 4Vn and 4Vs July surveys ($p = 0.7$ and 0.13 respectively). The year-class effects were significant at $p <0.01$ for the 4T east and west surveys and at $p<0.05$ for the 4Vs spring survey.

The 4T west year-class estimates increased from 1970 to 1975, were relatively stable through the late 1970's to mid-1980's and declined from 1987 to 1991 (Figure 3). The 4T east estimates were more variable, with peaks in 1973, 1980, and 1987. The 4Vs spring estimates had a declining trend from 1978 to 1991 with the exception of a peak in 1986-87. The 4T east and west estimates were significantly correlated ($p<0.05$) while the correlations were weak between the 4Vs spring series and the other two (Table 12).

The age effects for the multiplicative analyses using ages 4-6 were highly significant for the 4T west, 4T east, and 4Vs July surveys (Table 11). The relatively weak effects in 4Vn is because these are the ages of maximum catch in the survey. The year-class effects were all highly significant. There were significant correlations among all the year-class time series except for the 4Vs spring - 4Vn July ($p = 0.17$) (Table 12).

There were several statistically significant correlations among age 1-3 and 4-6 year-class estimates from multiplicative analyses (Figure 5). The 4T west age 1-3 series was significantly correlated with the 4T west ($p<0.01$), 4T east ($p<0.01$), 4Vn ($p<0.01$), and 4Vs July ($p<0.05$) age 4-6 series. The 4T east age 1-3 series was significantly correlated with the 4T east ($p<0.01$) and 4Vn ($p<0.01$) age 4-6 series. The 4Vs spring age 1-3 series was significantly correlated with the 4Vn age 4-6 series ($p<0.01$).

Discussion

The information content of the 4Vn July and 4Vs spring surveys is relatively low and would yield highly variable assessment data when compared to the 4T and 4Vs July surveys. The correlations of year-class estimates of the same cohorts at different ages were strongest for the September surveys in the eastern and western parts of 4T. The correlations were statistically significant ($p<0.05$) for ages 2-5 and ages 4-10 inclusive. The correlations were significant for ages 3-4 and 4-9 inclusive in the 4Vs summer surveys. The correlations for the 4Vn July surveys were relatively low, being significant only between ages 2 and 3, and between adjacent ages from 6-9. For the 4Vs spring surveys the correlations were significant between ages 4 and 5 and between adjacent ages from 6 to 8.

It was hoped that some information on stock structure could be drawn from comparisons of year-class signals at young and older ages in these areas. Unfortunately, this was not possible because of the weak year-class signals at younger ages from several of the surveys. The year-class effects in analyses based on age 1-3 data were only significant for the 4T east, 4T west, and 4Vs spring data. The trends were similar for the two 4T series, but these differed from the 4Vs spring series. The year-class effects from analyses of age 4-6 data were statistically significant in all areas and were correlated among the areas with the exception of between the 4Vs spring and 4Vn summer series. There were significant correlations between the age 1-3 series from 4T east and west and the age 4-6 series from 4T and 4Vn. However, there was not a significant correlation between the age 1-3 and 4-6 analyses in 4Vs. This may be an artifact of the weak year-class signals at ages 1-3.

The lack of juvenile cod in 4Vn during summer questions the local spawning population's ability to support the abundance of adults found in the summer surveys. The 4Vn and 4Vs surveys were conducted with the same vessels and using the same gears. Thus, one would expect the same age-specific selectivity in these surveys. Similar gear and vessels were also used for the 4T surveys. The surveys also covered a large portion of the stock areas in the respective zones. Yet, there were very few young fish (age 1-3) caught in the 4Vn summer surveys (Figure 2). Where the modal age of the catch was 2 in 4Vs spring, 3 in 4Vs July and 4 in 4T east and west, it was age 5 in the 4Vn July survey. While it is possible that the locally spawned juvenile cod are not available to the summer survey, it is also possible that a significant proportion of adult cod found in 4Vn in summer were born and spent their juvenile lives in the adjacent areas.

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Table 1: Mean numbers per tow at age for cod in the eastern part of 4T taken during September groundfish surveys 1971-94.

	Age										
Year	0	1	2	3	4	5	6	7	8	9	10
71	0.00	0.14	1.01	7.24	2.40	2.67	2.37	0.97	0.35	0.04	0.28
72	0.00	0.04	1.33	4.46	12.93	2.83	2.75	2.43	0.97	0.47	0.21
73	0.00	0.10	2.77	4.24	1.12	1.84	0.32	0.44	0.17	0.12	0.11
74	0.00	0.00	2.55	9.72	5.83	2.97	1.71	0.24	0.27	0.35	0.03
75	0.00	1.14	12.20	2.72	6.09	5.29	2.34	0.86	0.47	0.00	0.41
76	0.00	0.46	9.07	31.68	6.15	2.59	1.83	0.41	0.25	0.08	0.00
77	0.04	0.15	11.79	14.05	11.29	5.99	1.24	1.29	1.25	0.44	0.72
78	0.00	0.26	3.48	9.16	9.82	5.35	2.53	1.34	0.70	0.15	0.25
79	0.00	0.29	6.27	11.60	28.76	20.03	10.37	2.84	1.60	0.31	0.24
80	0.00	1.29	7.47	28.94	18.09	26.30	15.37	6.23	1.21	0.53	0.03
81	0.06	3.77	9.99	14.16	22.78	17.34	19.48	8.40	6.57	1.30	0.59
82	0.48	3.50	42.96	11.73	14.55	17.31	13.09	10.07	7.27	3.10	0.35
83	0.00	2.13	13.26	31.79	21.37	20.75	12.29	11.83	4.88	3.05	3.07
84	0.00	0.27	10.35	25.02	37.33	34.66	14.96	8.06	9.16	3.24	0.66
85	0.00	2.76	8.36	19.26	30.28	37.06	33.44	10.00	3.46	1.01	1.44
86	0.47	2.48	4.99	11.38	17.48	25.80	53.12	25.59	7.35	0.96	1.48
87	0.57	0.76	4.50	12.62	17.07	25.20	19.33	20.95	7.54	1.65	1.20
88	3.82	6.43	10.25	19.51	44.97	34.67	36.66	19.52	15.66	11.07	1.33
89	0.50	2.43	23.00	32.94	25.90	25.35	23.63	13.59	9.33	9.66	5.88
90	0.18	4.20	9.74	36.59	18.25	12.72	7.76	5.10	2.95	1.50	2.05
91	2.44	2.38	13.27	24.35	35.63	21.93	7.07	3.49	3.09	1.14	0.99
92	0.68	0.82	5.15	14.66	17.70	10.59	3.31	1.24	0.80	0.36	0.29
93	1.44	1.25	7.71	9.70	14.29	19.30	11.33	4.91	1.59	0.66	0.32
94	3.66	0.92	2.88	8.59	12.32	11.93	15.34	7.57	3.62	1.20	0.56

Table 2: Mean numbers per tow at age for cod in the western part of 4T taken during September groundfish surveys 1971-94.

	Age										
Year	0	1	2	3	4	5	6	7	8	9	10
71	0.00	0.06	0.59	9.45	12.24	10.58	7.97	5.55	1.63	0.45	0.43
72	0.00	0.83	4.69	9.54	20.64	8.90	7.42	4.68	3.20	0.55	0.44
73	0.04	0.14	8.26	16.01	8.26	12.82	6.53	4.42	3.38	2.14	0.50
74	0.00	0.23	4.02	16.76	14.16	5.09	7.79	3.18	2.06	2.09	0.75
75	0.00	0.15	6.14	8.17	10.84	8.33	2.23	2.25	1.52	0.86	0.29
76	0.00	6.53	9.97	41.80	11.83	10.01	4.17	1.16	0.80	0.48	0.51
77	0.00	1.51	39.61	33.24	22.89	7.74	4.83	2.25	0.75	0.70	0.32
78	0.00	1.75	12.22	80.68	56.63	27.76	7.01	4.19	1.06	0.57	0.71
79	0.11	0.13	47.85	40.74	84.48	48.33	18.63	4.73	1.72	1.09	0.28
80	0.48	1.56	6.21	47.35	37.26	68.30	31.27	11.04	1.87	0.85	0.56
81	0.13	6.46	28.02	25.07	85.91	76.68	76.03	33.34	16.20	2.11	0.95
82	0.27	4.77	35.17	27.06	32.30	31.88	73.99	36.43	16.74	3.67	0.58
83	0.01	10.75	29.67	61.64	64.67	26.66	21.55	17.68	15.28	7.01	2.99
84	0.00	2.83	11.86	13.34	35.06	58.52	16.80	10.75	11.26	5.44	2.97
85	6.74	14.26	17.99	49.06	44.28	90.06	87.60	16.63	8.99	6.95	2.43
86	2.38	9.49	34.74	51.39	42.52	43.02	43.41	34.09	10.77	3.13	3.20
87	0.28	0.93	17.59	31.91	25.64	35.04	25.94	37.14	13.14	2.99	2.08
88	0.32	2.14	19.44	96.02	72.71	60.30	35.99	20.15	23.84	13.02	2.61
89	0.17	17.13	27.41	30.29	32.34	29.22	33.42	18.42	11.41	10.69	7.48
90	0.27	0.93	4.99	34.66	30.77	22.21	16.80	11.82	6.57	4.13	4.41
91	0.79	2.65	5.04	11.48	32.54	28.12	12.28	7.67	4.52	2.07	1.08
92	0.59	2.52	4.29	7.63	12.39	12.69	8.41	3.34	1.34	1.06	0.33
93	0.23	0.30	5.83	9.36	13.99	14.95	10.72	5.00	1.65	0.67	0.40
94	0.04	0.46	1.26	7.15	7.38	8.50	10.31	7.85	2.43	1.12	0.35

Table 3: Mean numbers per tow at age for cod in 4Vn taken during July groundfish surveys 1971-93.

	Age										
Year	0	1	2	3	4	5	6	7	8	9	10
70	0.00	0.00	5.04	1.33	3.77	8.51	8.55	3.70	2.10	0.69	0.00
71	0.00	0.00	0.77	33.95	8.08	21.23	12.94	8.53	2.87	1.58	0.43
72	0.00	0.00	0.42	0.23	1.88	0.24	1.27	1.18	0.31	0.21	0.20
73	0.00	0.00	0.00	2.10	3.59	14.91	2.19	2.45	2.33	0.37	0.18
74	0.00	0.00	0.00	0.49	1.09	2.25	2.61	0.26	0.43	0.18	0.18
75	0.00	0.00	0.58	5.27	6.86	3.78	0.70	0.80	0.46	0.18	0.28
76	0.00	0.00	5.19	1.80	1.19	1.54	1.24	0.58	1.43	1.32	1.12
77	0.00	0.00	0.32	5.01	3.21	2.19	1.52	0.57	0.17	0.20	0.11
78	0.00	0.00	0.53	7.28	15.37	4.48	3.55	1.24	0.94	0.35	0.35
79	0.00	0.00	1.04	0.63	4.12	2.01	0.47	1.37	0.45	0.24	0.12
80	0.00	0.00	1.50	8.41	3.18	18.88	13.14	4.13	0.93	0.36	0.30
81	0.00	0.27	3.36	13.66	29.18	9.62	20.36	9.20	1.01	0.74	0.69
82	0.00	0.00	2.03	1.39	4.62	8.18	6.09	7.40	2.73	1.06	0.36
83	0.00	0.00	4.38	22.16	7.91	10.66	10.11	1.74	3.45	1.52	0.66
84	0.00	2.83	7.25	10.02	10.48	13.51	8.75	3.58	1.81	1.58	0.85
85	0.00	0.00	0.48	3.75	19.10	125.95	52.13	22.38	7.26	1.44	0.77
86	0.00	0.00	1.33	6.36	11.13	8.11	17.55	6.38	4.92	2.17	1.02
87	0.00	0.00	0.21	3.70	4.14	5.13	8.89	6.63	2.80	1.18	0.62
88	0.00	0.61	0.55	2.49	17.05	13.17	31.86	26.43	18.92	6.24	1.70
89	0.00	0.00	4.60	4.39	11.60	29.78	17.65	32.10	25.55	8.26	1.30
90	0.00	0.00	0.24	15.07	9.03	3.29	3.87	2.05	2.29	0.73	0.81
91	0.00	0.34	1.25	0.63	13.88	6.67	4.01	0.92	0.87	0.18	0.37
92	0.00	0.00	0.66	3.44	5.13	44.36	15.15	4.88	3.66	1.31	0.82
93	0.00	0.00	0.40	3.18	6.18	5.70	14.67	7.36	1.74	0.50	0.05

Table 4: Mean numbers per tow at age for cod in 4Vs taken during July groundfish surveys 1971-93.

	Age										
Year	0	1	2	3	4	5	6	7	8	9	10
70	0.02	0.12	9.04	2.02	4.77	2.61	0.91	0.79	0.30	0.02	0.02
71	0.00	0.00	1.25	22.46	3.32	9.03	3.15	1.68	0.79	0.06	0.06
72	0.00	0.14	3.86	7.10	22.14	3.25	4.20	1.14	0.38	0.19	0.11
73	0.00	0.26	3.21	4.70	2.42	3.58	0.18	0.54	0.19	0.02	0.00
74	0.00	0.95	2.58	2.61	0.86	0.82	1.23	0.11	0.26	0.12	0.03
75	0.00	0.15	2.39	5.38	2.02	1.39	0.34	0.43	0.16	0.19	0.02
76	0.00	0.12	3.43	4.30	1.43	1.22	0.18	0.14	0.67	0.00	0.46
77	0.04	0.31	2.87	9.13	5.00	3.37	1.14	0.28	0.26	0.10	0.00
78	0.00	0.15	2.34	5.18	4.18	0.86	0.21	0.08	0.05	0.05	0.02
79	0.00	0.22	2.33	4.58	4.85	4.62	2.50	1.10	0.63	0.22	0.06
80	0.00	0.09	1.05	3.08	3.57	8.18	6.26	2.02	0.71	0.19	0.20
81	0.00	0.25	5.90	8.34	15.89	6.26	3.46	1.76	0.66	0.27	0.37
82	0.00	0.27	15.30	15.59	8.07	4.98	4.82	2.70	1.23	0.20	0.30
83	0.00	0.94	1.33	9.30	12.29	9.51	7.17	1.73	1.05	0.24	0.20
84	0.00	0.75	16.63	28.02	39.05	24.86	10.49	9.11	0.81	0.71	0.20
85	0.00	0.23	0.79	13.32	19.17	18.92	10.58	5.09	2.04	1.00	0.30
86	0.01	0.01	0.16	1.62	14.39	9.09	7.62	2.55	1.12	0.51	0.31
87	0.00	0.34	0.94	7.44	7.92	21.46	8.85	6.73	3.77	0.85	0.06
88	0.09	0.00	4.54	4.84	4.35	3.66	7.73	4.24	2.32	0.46	0.13
89	0.00	0.14	2.21	4.22	5.20	4.97	2.07	4.85	1.12	0.78	0.03
90	0.01	0.19	8.90	27.21	7.10	1.93	0.90	0.33	0.70	0.28	0.18
91	0.00	0.14	1.73	2.06	9.57	6.40	2.28	0.53	0.13	0.61	0.19
92	0.00	0.00	0.44	0.83	0.71	1.25	0.60	0.22	0.14	0.04	0.04
93	0.00	0.12	0.24	0.98	1.29	0.79	0.83	0.31	0.05	0.00	0.00

Table 5: Mean numbers per tow at age for cod in 4Vs taken during spring groundfish surveys 1979-84, 86-94.

	Age										
Year	0	1	2	3	4	5	6	7	8	9	10
79	0.00	0.37	1.37	0.47	0.83	1.64	0.98	0.77	0.29	0.03	0.09
80	0.00	0.31	3.66	1.29	1.09	1.38	0.95	0.55	0.10	0.03	0.02
81	0.00	0.00	5.09	5.67	6.22	5.41	7.09	3.84	2.25	0.22	0.26
82	0.00	0.00	5.09	5.67	6.22	5.41	7.09	3.84	2.25	0.22	0.26
83	0.00	1.51	3.11	11.65	5.98	3.02	4.58	1.03	0.55	0.36	0.21
84	0.00	0.12	2.07	2.40	11.61	9.65	5.52	4.64	1.58	1.28	0.41
86	0.00	0.03	0.46	1.01	14.52	11.34	15.59	7.28	1.90	1.50	0.42
87	0.00	0.40	1.67	5.61	10.32	23.42	10.95	6.37	2.22	0.44	0.23
88	0.00	1.06	5.06	1.33	0.51	0.49	2.43	1.23	1.73	0.42	0.22
89	0.00	0.12	34.81	2.32	0.93	1.08	0.57	0.70	0.42	0.28	0.06
90	0.00	0.12	1.51	9.49	4.42	0.82	0.22	0.08	0.70	0.24	0.27
91	0.00	0.03	0.89	0.50	1.11	0.75	0.35	0.10	0.02	0.14	0.01
92	0.00	0.00	0.34	0.38	0.31	0.61	0.42	0.23	0.07	0.03	0.00
93	0.00	0.07	5.91	3.87	0.95	0.29	0.10	0.05	0.00	0.02	0.00
94	0.00	0.06	0.17	0.11	0.12	0.44	0.32	0.29	0.39	0.10	0.00

Table 6: Summary of multiplicative analysis of research survey indices (ages 1-10) for 4T east and west, 4Vn July, 4Vs July, and 4Vs spring surveys. The columns Age and Year-class indicate the number of parameters estimated and the significance of the main effect (+ indicates $p<0.05$ and ++ indicates $p<0.01$), R^2 applies to the overall model, and N gives the number of observations.

	Age	Year-class	R^2	N
4T West	9, ++	26, ++	0.82	227
4T East	9, ++	26, ++	0.84	224
4Vn July	9, ++	26, ++	0.67	203
4Vs July	9, ++	26, ++	0.76	217
4Vs Spring	9, ++	17, ++	0.65	125

Table 7: Least square means estimates of ln mean catch per tow of ages 1-10 from multiplicative analyses of the five research vessel survey indices.

YC	4T east	4T west	4Vn July	4Vs July	4Vs Spr
1	0.597	1.285	0.336	0.164	0.288
2	5.385	9.756	0.940	2.125	2.744
3	11.012	21.824	3.236	4.906	2.194
4	12.323	24.903	5.857	4.454	2.051
5	11.157	21.427	6.975	3.362	1.743
6	7.501	14.296	5.458	1.647	1.229
7	4.146	7.840	2.947	0.777	0.589
8	2.460	3.959	1.854	0.396	0.363
9	1.077	1.961	0.771	0.185	0.142
10	0.731	0.967	0.474	0.080	0.052

Table 8: Least square means estimates of ln mean catch per tow of year-classes 1965-91 from multiplicative analyses of the five research vessel survey indices (ages 1-10).

YC	4T east	4T west	4Vn July	4Vs July	4Vs Spr
65	0.049	1.385	0.344	-0.518	
66	-0.467	1.185	0.178	0.263	
67	-0.637	0.899	-0.590	-1.214	
68	0.075	1.071	0.576	0.095	
69	-0.249	0.297	-0.802	-0.940	
70	-0.087	0.808	-0.387	-0.855	
71	0.257	1.277	-0.290	-0.448	
72	0.466	1.035	0.053	-0.145	
73	1.843	2.103	0.146	0.171	
74	1.780	2.462	1.227	0.408	0.619
75	1.893	3.184	1.104	0.499	0.409
76	1.520	2.728	0.441	0.506	0.249
77	1.581	2.571	1.313	0.588	0.587
78	1.693	1.980	1.420	0.690	0.543
79	2.457	3.047	1.493	0.822	0.662
80	2.853	3.201	1.926	1.300	1.163
81	2.228	2.528	1.611	0.824	0.029
82	1.834	2.403	1.280	1.073	0.490
83	1.334	2.183	0.691	-0.510	-1.529
84	1.429	2.102	0.829	-0.603	-1.669
85	1.380	2.077	0.370	-1.091	-1.356
86	1.607	1.826	0.960	-0.093	-0.759
87	2.266	2.071	1.849	0.002	-0.378
88	1.995	1.845	-0.217	-0.740	-1.766
89	1.930	1.155	0.744	-0.930	-1.622
90	1.561	1.322	0.493	-1.287	-2.093
91	1.400	1.543	-0.238	-2.342	-1.545

Table 9: Correlations between least square means year-class estimates from multiplicative analyses of the five research vessel survey indices (ages 1-10).

Survey 1	Survey 2	Correlation	Count	Signif Prob
4Twest	4Teast	0.8032	27	0.0000
4Vn	4Teast	0.7537	27	0.0000
4Vn	4Twest	0.7632	27	0.0000
4VsJul	4Teast	0.4221	27	0.0283
4VsJul	4Twest	0.6572	27	0.0002
4VsJul	4Vn	0.7179	27	0.0000
4VsSpr	4Twest	0.8049	18	0.0001
4VsSpr	4Teast	0.5294	18	0.0239
4VsJul	4VsSpr	0.8937	18	0.0000
4VsSpr	4Vn	0.7374	18	0.0005

Table 10: Summary of multiplicative analyses of research survey indices (ages 1-3) for 4T east and west, 4Vn July, 4Vs July, and 4Vs spring surveys. The columns Age and Year-class indicate the number of parameters estimated and the significance of the main effect (+ indicates $p<0.05$ and ++ indicates $p<0.01$), R^2 applies to the overall model, and N gives the number of observations.

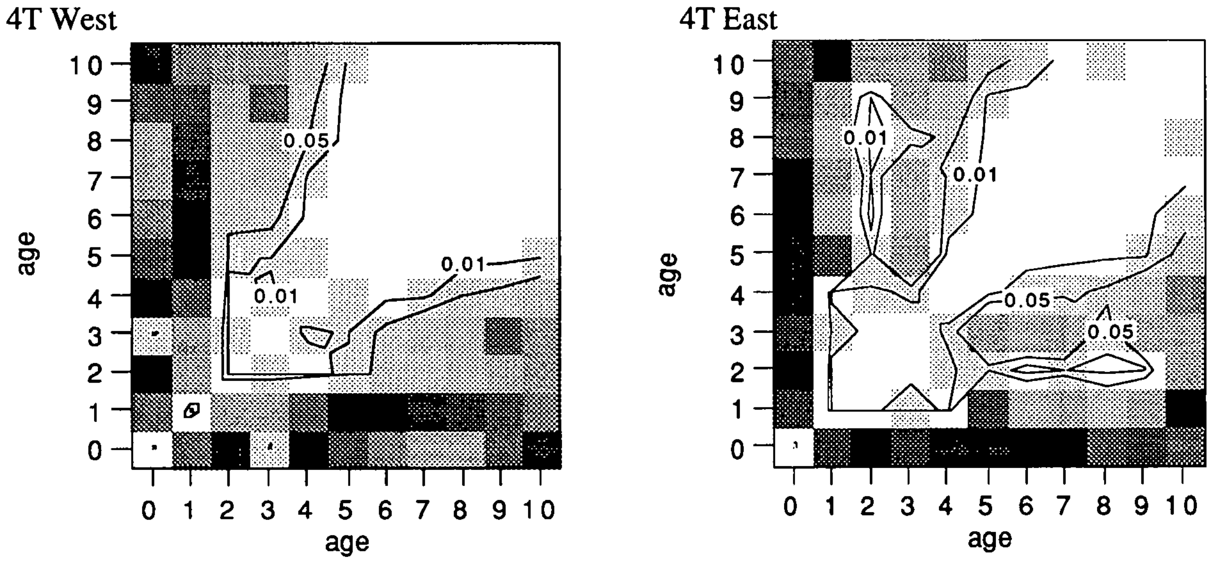
	Age	Year-class	R^2	N
4T West	2, ++	21, ++	0.80	66
4T East	2, ++	21, ++	0.88	65
4Vn July	2, ++	21	0.73	46
4Vs July	2, ++	21	0.81	64
4Vs Spring	2, ++	13, +	0.78	36

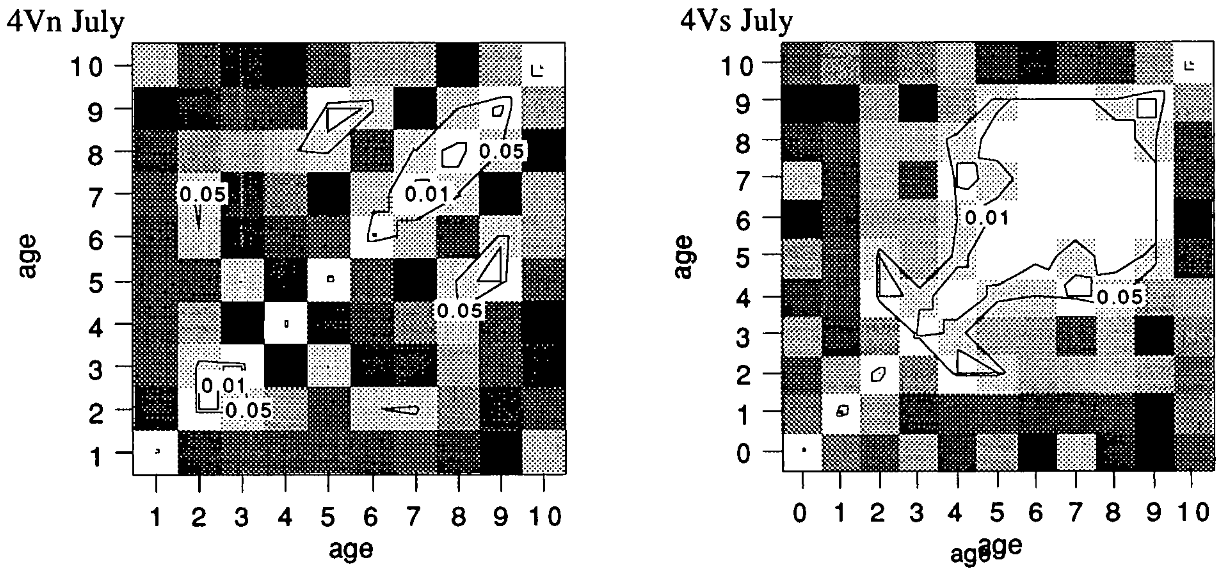
Table 11: Summary of multiplicative analyses of research survey indices (ages 4-6) for 4T east and west, 4Vn July, 4Vs July, and 4Vs spring surveys. The columns Age and Year-class indicate the number of parameters estimated and the significance of the main effect (+ indicates $p<0.05$ and ++ indicates $p<0.01$), R^2 applies to the overall model, and N gives the number of observations.

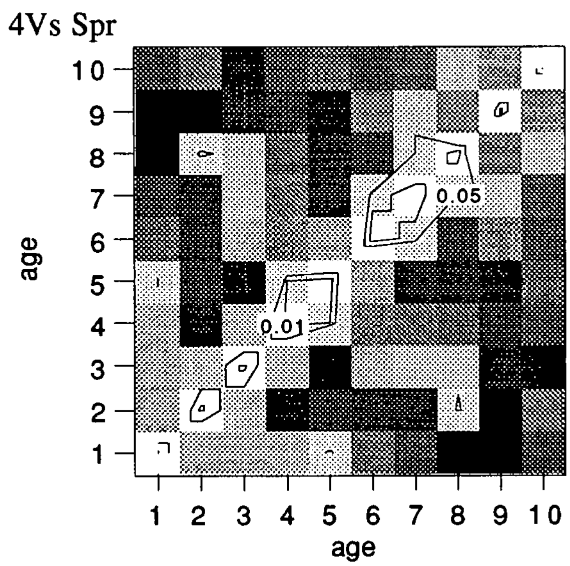
	Age	Year-class	R^2	N
4T West	2, ++	22, ++	0.88	68
4T East	2, ++	22, ++	0.89	68
4Vn July	2	22, ++	0.56	68
4Vs July	2, ++	22, ++	0.79	68
4Vs Spring	2	15, ++	0.76	42

Table 12: Correlations between least square means year-class estimates from multiplicative analyses of the five research vessel survey indices and two age groups, 1-3 and 4-6.

		Age 1-3			Age 4-6		
Survey 1	Survey 2	r	N	p	r	N	p
4T west	4T east	0.508	22	0.016	0.864	23	0.000
4Vn Jul	4T east	0.414	21	0.062	0.857	23	0.000
4Vn Jul	4T west	0.116	21	0.617	0.761	23	0.000
4Vs Jul	4T east	0.231	21	0.314	0.628	23	0.001
4Vs Jul	4T west	0.032	21	0.890	0.764	23	0.000
4Vs Jul	4Vn Jul	0.401	22	0.064	0.734	23	0.000
4Vs Spr	4T east	0.503	14	0.067	0.553	16	0.027
4Vs Spr	4T west	0.279	14	0.335	0.634	16	0.008
4Vs Spr	4Vn Jul	0.647	13	0.017	0.360	16	0.171
4Vs Spr	4Vs Jul	0.826	13	0.001	0.924	16	0.000







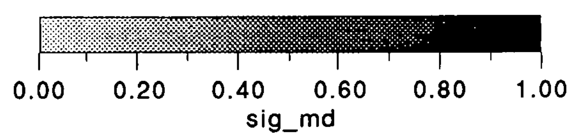


Figure 1: Significance (p-value) of age-by-age correlations of year-class estimates from RV surveys in 4T west, 4T east, 4Vn July, and 4Vs July

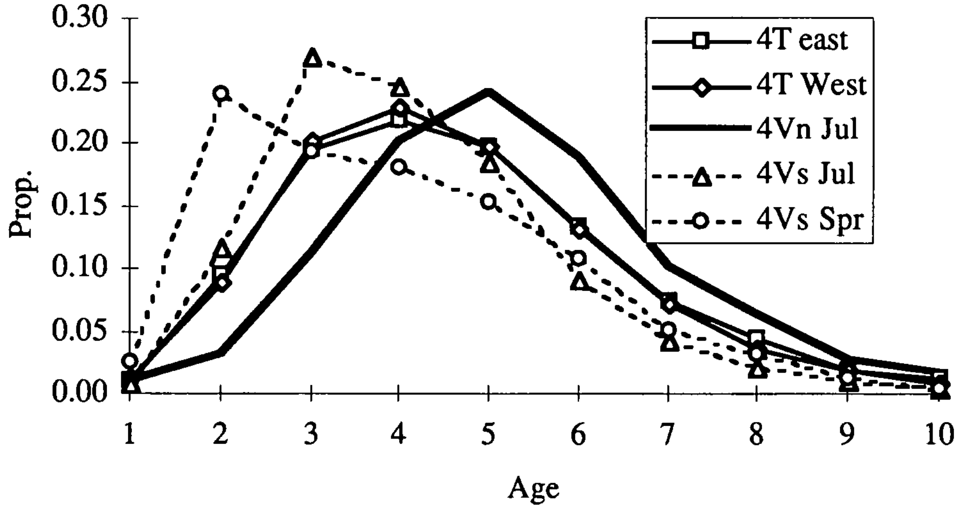


Figure 2: Estimated age effects from multiplicative analyses of research survey mean numbers per tow at age. The least square means estimates were retransformed and scaled to proportions at age.

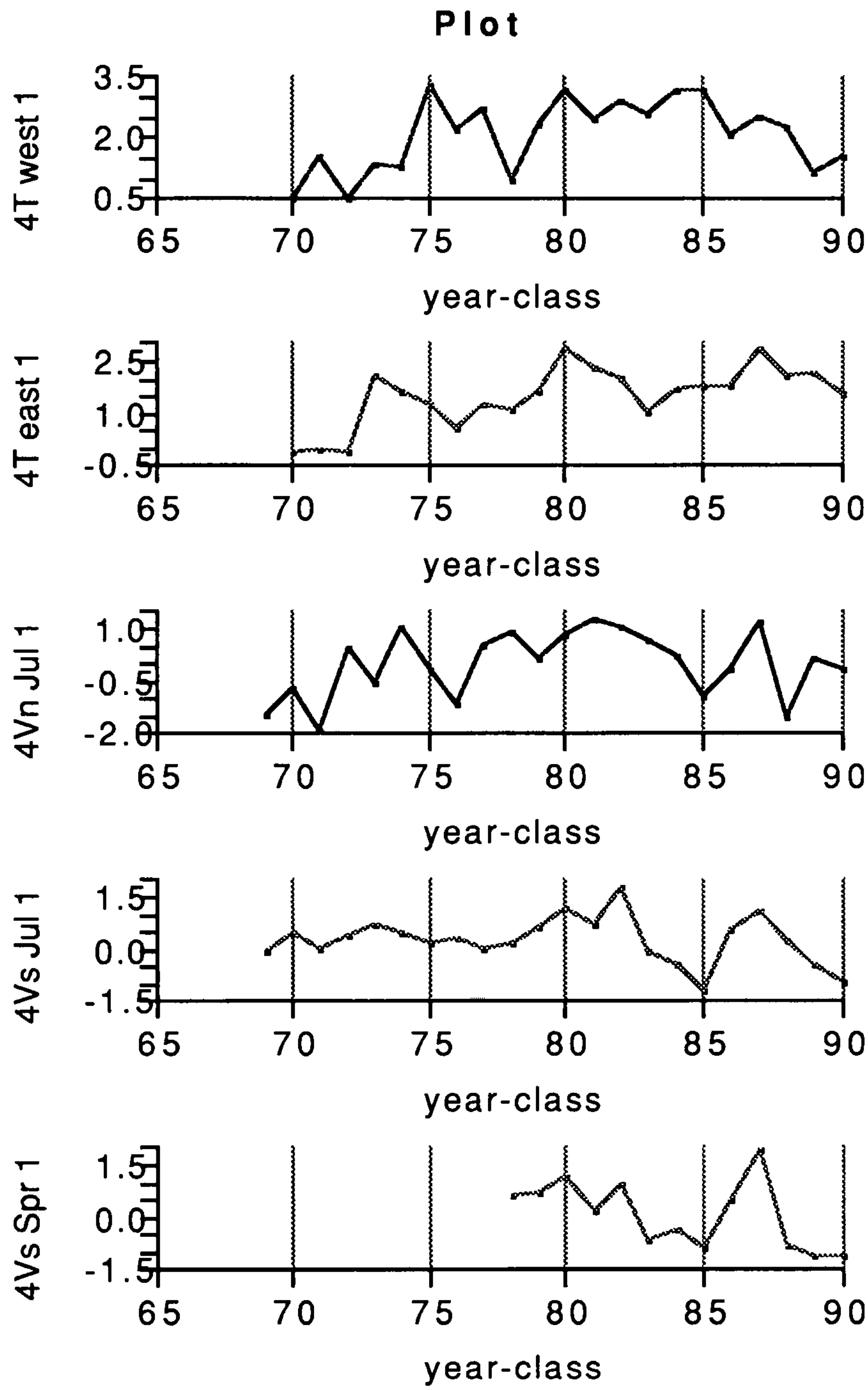


Figure 3: Least square mean year-class estimates from multiplicative analyses of ages 1-3 mean numbers per tow.

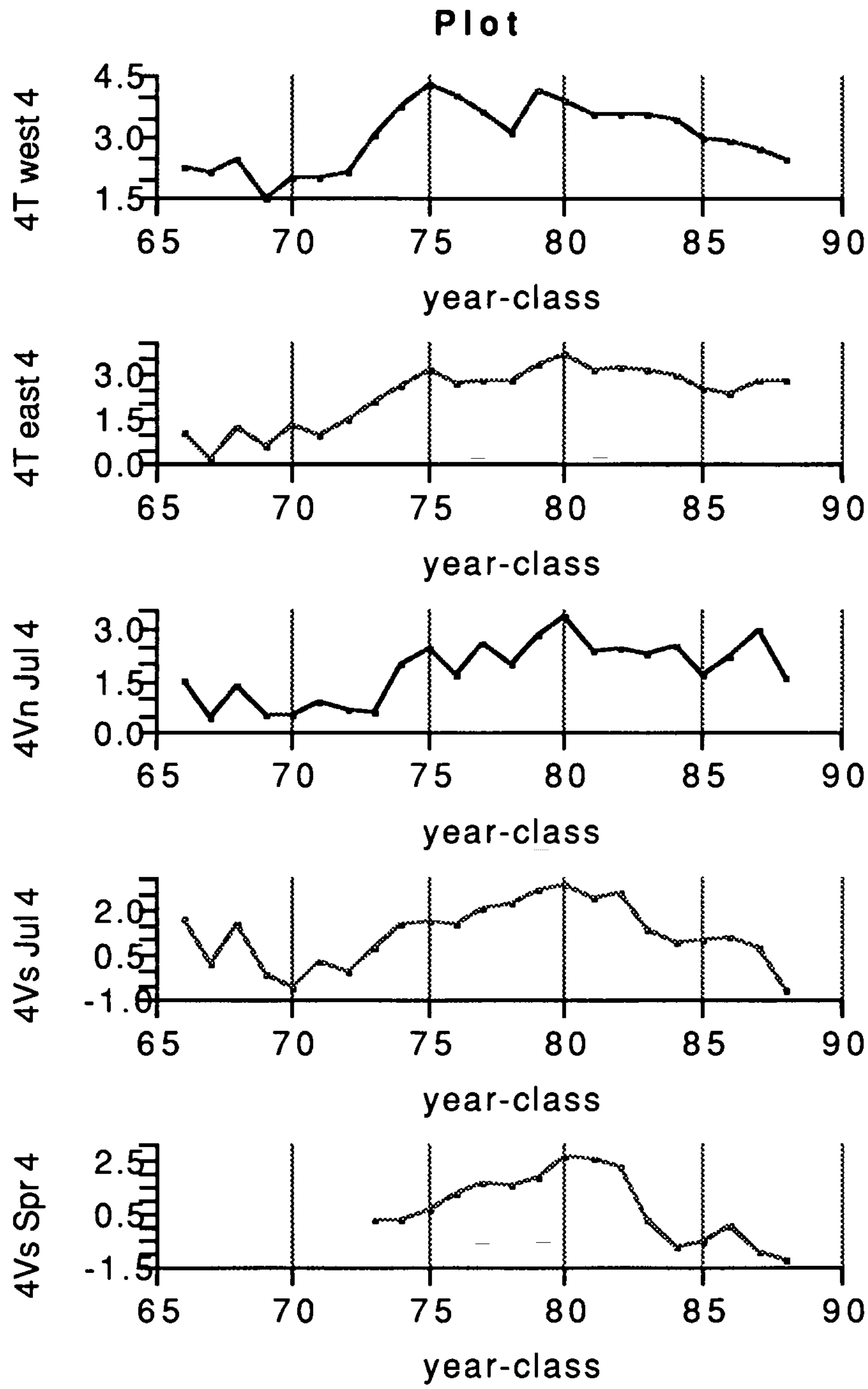


Figure 4: Least square mean year-class estimates from multiplicative analyses of ages 4-6 mean numbers per tow.

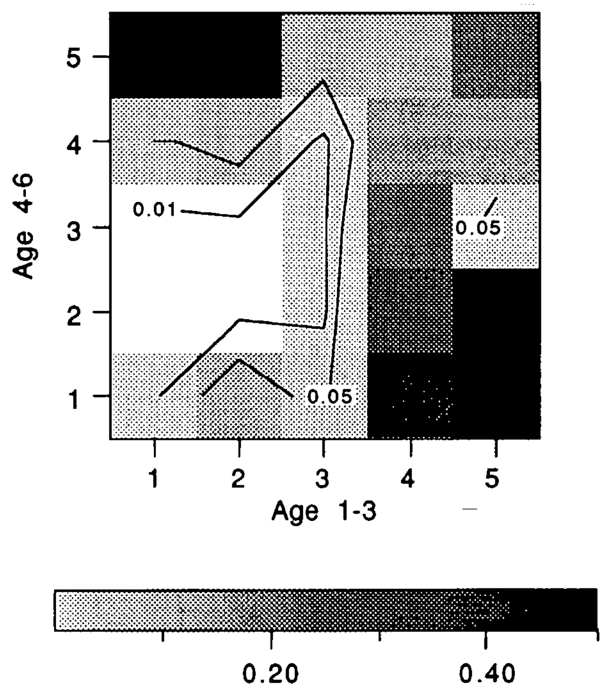


Figure 5: Significance values of correlations between age 1-3 and age 4-6 year-class estimates from multiplicative analyses. The survey areas are coded as follows, 1 - 4T west, 2 - 4T east, 3 - 4Vn July, 4 - 4Vs July, and 5 - 4Vs Spring.