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An Evaluation of Maturity Estimates Derived from Two Different Sampling Schemes: Are the Observed Changes Fact or Artifact?

by

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Abstract

Biological sampling of fish during research vessel survey cruises is often conducted using length-stratified age sampling schemes. Maturity analyses may be affected by changes in sampling protocols, and may potentially result in biased estimates of maturation patterns. In such cases, these estimates may be artifacts of the sampling activities and not accurate estimators of stock dynamics.

In 1992, the Northeast Fisheries Science Center modified the length-stratified age sampling protocol used during research vessel bottom trawl surveys conducted semi-annually since the 1960s. While demonstrable gains in the precision of age-length keys for many species have been obtained with the new protocols, no systematic evaluation of the effects of the sampling protocol change upon maturity analyses has been performed.

In this study, potential effects of changes in sampling protocol were assessed for two groundfish species, haddock (*Melanogrammus aeglefinus*) and American plaice (*Hippoglossoides platessoides*). Over the critical size range of maturity for both species, significantly different length frequency sampling was obtained from each sampling scheme during the 10-year study period. Analyses for American plaice were further complicated by the dimorphic growth. Simulation techniques were employed to assess whether the observed changes in maturity estimates were a result of the changed sampling protocols. The simulations suggested that these changes were real phenomena and not artifacts caused by changes in sampling.

Introduction

Biological sampling of fish during research vessel survey cruises is often accomplished using by length-stratified age sampling schemes. These schemes are designed to derive satisfactory relationships between length and age, but may not always produce data suitable for estimation of other population parameters such as growth or maturation rates (Armstrong and Ilardia, 1986; Anon., 1994; Morgan and Hoenig, 1997). Moreover, changes in protocols during a sampling time series may potentially result in biased estimates of population patterns. In such cases, these estimates may be artifacts of the sampling activities and not accurate estimators of stock dynamics.

In 1992, the Northeast Fisheries Science Center (NEFSC) modified the length-stratified sampling protocol used during research vessel bottom trawl surveys conducted since 1963. Prior to 1992, target numbers of fish to be sampled within broad (several cm) length strata were specified for each 6-hour watch of the survey cruise. In 1992, the sampling procedure was revised to sampling one fish at each cm interval per tow (Table 1). While demonstrable gains in the precision of age-length keys for various species have been obtained (NEFSC, 1992) with the new protocols, no systematic evaluation of the effects of the sampling change on maturity analyses has been performed.

In this study, the effects of the 1992 change in sampling protocol in estimating maturity parameters for two groundfish species, haddock (*Melanogrammus aeglefinus*) and American plaice (*Hippoglossoides platessoides*) were assessed. A Monte Carlo-type simulation model was developed which allowed re-sampling of survey catches of these species prior to 1992 using the post-1992 sampling scheme, and *vice versa*. The effects of the two sampling schemes were then compared using the simulated estimates of maturity at length *versus* those obtained empirically.

Methods

NEFSC research vessel bottom trawl survey data from 1987-1996 were examined for cases in which changes in length-stratified age sampling in 1992 might have resulted in biased maturity estimates for certain species. The evaluation involved two considerations: 1) situations in which length strata in the pre-1992 sampling scheme were relatively broad, and 2) of these, length strata which encompassed the critical size range associated with the onset of maturation. Two species, Georges Bank haddock and American plaice were selected for examination. Georges Bank haddock was chosen because the pre-1992 length stratum of 26-50 cm was relatively wide and encompassed fish sizes for which observed proportions mature ranged between 30 and 100% (O'Brien *et al.*, 1993). American plaice was selected because it exhibits dimorphic growth and maturation rates; males mature at a smaller size and younger age then females (O'Brien *et al.*, 1993).

Following the recommendation of Halliday (1987) to assess size and age at maturation using data collected prior and close to the time of spawning, maturity data for both species were derived from NEFSC spring bottom trawl surveys, pooled into the five-year blocks 1987-1991 and 1992-1996 (representing equal years of data collection under each sampling scheme). Probit analysis (Finney, 1971) of proportions mature at length were used to derive maturity ogives and associated 95% confidence intervals for female haddock and male and female American plaice for each study period.

To evaluate whether the 1992 change in sampling protocol resulted in differing sampling distributions, the frequency distribution of fish sampled at each centimeter in the two five-year block of pooled data were compared using Chi-square analysis (Sokal and Rohlf, 1981). The expected distribution of the 1992-1996 period was derived by multiplying the observed proportions sampled at length in 1987-1991 by the estimated total numbers caught at length. The null hypothesis in this procedure is that the realized sampled in 1992-1996 is equivalent to what would have been sampled under the 1987-1991 sampling protocol.

A Monte Carlo-type simulation model was constructed to evaluate the effects of the sampling protocols on maturation analyses for each species. Numbers of fish at length were drawn from each of the pooled five-year blocks of catch at length data using the sampling protocol associated with the opposite five-year period, i.e. alternative sampling. The maturity status of each sampled fish was considered as the outcome of a Bernoulli trial in which the underlying probability of being mature was derived from a probit analysis of the original sampled data. Probit analysis was applied to each simulated data set and the process was repeated 500 times for each comparison. The primary statistics of interest were the estimated lengths at which 10, 25, 50, 75, and 90% of the population was mature (i.e. L_{10}, L_{25}, L_{50}, L_{75}, and L_{90}), respectively. Frequency distributions and associated median values of maturity estimates corresponding to L_{10}, L_{25}, L_{50}, L_{75}, and L_{90} were plotted. The procedure was also repeated using the sampling protocol and maturity probability distribution from the same five-year block; the two runs therefore constituted a baseline of maturity estimates for each period. The simulation approach is summarized below; the model sequence is illustrated in Fig. 1. Median values of maturity estimates obtained from alternative sampling were then evaluated with respect to the 80% confidence intervals of the corresponding estimates derived from the baseline runs.

Simulation approach:

	Sampling scheme	
Maturity data	1987-1991	1992-1996
1987-1991	Baseline	Alternative
1992-1996	Alternative	Baseline

where maturity data is the proportion mature at length and the sampling scheme is the number of fish sampled at length in each time block.

Results

Sampling intensity for haddock and American plaice during the 1987-1991 and 1992-1996 periods is summarized in Table 2. The percentage of survey stations sampled was comparable under both sampling schemes, and similar numbers of fish sampled in both periods for each species.

Significantly different maturity ogives between the two five-year periods were obtained for female haddock and for both sexes of American plaice (Fig. 2 and 3). For haddock, maturation occurred at smaller sizes in the 1987-1991 period although at about the same rate (i.e. slope of the ogive). Estimates of L_{50}, the median length at maturity, was 32.5 cm for female haddock during 1987-1991 and 37.5 cm during 1992-1996 (Table 3). For American plaice, maturation of males occurred at smaller sizes in the 1992-1996 period, but females matured at greater sizes for that same period. Values of L_{50} for male plaice were 23.2 cm and 21.3 cm for the 1987-1991 and 1992-1996 periods respectively, and 28.2 cm and 29.8 cm, respectively, for female plaice (Tables 4 and 5).

The empirical pooled length frequency catch and sampling distribution for each study period are presented in Fig. 4 for haddock and Fig. 5 for American plaice. Significant differences were obtained in the sampled distributions between periods for each species (for haddock, $c^2 = 725.84$, $p < 0.01$, 54 df; for American plaice, $c^2 = 191.97$, $p < 0.01$, 48 df).

Figure 6a-d provides an example of the simulation results for female Georges Bank haddock. The frequency distributions and medians of estimates of L_{10} obtained from the 500 probit analyses are plotted for each of the four simulation scenarios: a) baseline run for 1987-1991; b) alternative sampling of 1987-1991 data; c) baseline run for 1992- 1996; and d) alternative sampling of 1992-1996 data. Median estimates from the baseline runs at each level L_{10} - L_{90} were within 0.1 cm of the corresponding values from the original maturity ogives for each species in each time period.

Figures 7-9 present simulation estimates of L_{10}-L_{90} for haddock and male and female American plaice, respectively. For haddock (Fig. 7), all median values of proportions mature at length generated from the alternative sampling simulations lie within the 80% confidence interval of the baseline runs. Median values of alternative sampling become more similar to baseline values at increasing levels of proportions mature at length. The variability in the distribution of estimates for both alternative sampling and baseline simulations was greatest at the upper and lower tails (i.e., L_{10} and L_{90}) than for L_{50}. In no instance did the median maturity estimates from the 1987-1991 period overlap with the 80% confidence intervals from the 1992-1996 period. This indicates that the change in sampling scheme had no effect upon the maturity estimates, and that the difference in maturation rates between the two time periods is real and not an atrifact. Similar results and conclusions were obtained for male and female American plaice (Figures 8 and 9, respectively).

Discussion

In spite of significantly different length distributions of sampled fish in 1987-1991 *vs.* 1992-1996 due to a change in sampling protocol implemented in 1992 in the NEFSC bottom trawl surveys, results from the Monte Carlo-type simulations indicate no bias was introduced in deriving maturity parameters for haddock and American plaice. However, simulation results did identify areas in which improved data collection might increase the precision of maturity analyses. The observation of increased variability in simulation estimates for L_{10} and L_{90} (the lower and upper tails of the maturity ogive) is one such example; additional sampling beyond that provided by length-stratified age sampling is a possible solution to better estimate this portion of the ogive. On the other hand, estimates of L_{50} appeared to be extremely robust with respect to the sampling scheme used, suggesting that this important parameter is well-established in the population and less susceptible to the vagaries of sampling than the upper and lower tail regions.

This study did not address the effect of length-stratified age sampling on maturity at age (see Morgan and Hoenig, 1997), or the sex ratios of sampled fish effecting maturity parameters. In both the pre-1992 and post-1992 NEFSC sampling schemes, the sex of an individual fish is not determined until after the fish has been selected for sampling. In this study, results for haddock were probably not affected since sex ratios for most gadoid species are 1:1 across the size range, and growth rates are similar for each sex. However, for American plaice, sex ratios became severely skewed towards females above 30 cm (Fig. 10), suggesting that for species exhibiting sexually dimorphic growth and maturation rates sampling modifications should be made. Causes for the different responses between male and female American plaice are unknown and pose interesting scientific issues. Results of this study, however, are sufficient to reject the hypothesis that changes in sampling protocols are responsible for the shifts.

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Table 1. Sampling protocols for length-stratified age sampling of haddock and American plaice used during NEFSC research vessel bottom trawl surveys from 1963-1991 and 1992-present.

	Pre-1992		Post-1992
	per 6 hour watch		per tow
Haddock	< 8 cm	10 fish	1 fish per cm
	9-25 cm	5 fish	
	26-50 cm	15 fish	
	> 50 cm	45 fish	
American plaice	< 20 cm	all fish	1 fish per cm
	21-30 cm	15 fish	
	31-40 cm	25 fish	
	> 40 cm	20 fish	

Table 2. *Sampling intensity of haddock and American plaice for five-year time blocks prior to and* subsequent to the change in NEFSC research vessel bottom trawl survey length-stratified age sampling protocol in 1992.

	Number of stations		Number of fish	
	Caught	Sampled	Caught	Sampled
Georges Bank Haddock				
1987	23	20	409	96
1988	26	21	249	149
1989	31	30	588	251
1990	23	23	723	246
1991	21	20	322	184
	91% coverage		926 fish	
1992	23	23	139	105
1993	25	25	265	153
1994	22	22	933	124
1995	19	19	796	208
1996	28	28	1 827	3443
	100% coverage		933 fish	
American plaice				
1987	49	42	523	349
1988	51	50	513	360
1989	52	43	680	367
1990	57	53	818	384
1991	54	50	874	486
	90% coverage		1 946 fish	
1992	61	60	567	383
1993	58	58	649	363
1994	65	63	814	376
1995	67	65	1 203	514
1996	65	62	954	380
	97% coverage		2 016 fish	

Table 3. Estimates of proportions mature at length (cm) for female Georges Bank haddock obtained from probit analysis of maturity observations collected during NEFSC research vessel spring bottom trawl surveys for the periods 1987-1991 and 1992-1996 (with associated 95% Confidence Intervals).

1987 - 1991 period				1992 - 1996 period			
		95% Limits				95% Limits	
Probability	Length	Lower	Upper	Probability	Length	Lower	Upper
0.01	21.27	15.92	24.47	0.01	26.36	22.63	28.82
0.02	22.58	17.68	25.53	0.02	27.66	24.27	29.91
0.03	23.41	18.79	26.20	0.03	28.49	25.31	30.61
0.04	24.04	19.63	26.71	0.04	29.11	26.09	31.13
0.05	24.55	20.31	27.12	0.05	29.62	26.73	31.56
0.06	24.98	20.89	27.47	0.06	30.05	27.27	31.92
0.07	25.36	21.39	27.78	0.07	30.42	27.74	32.24
0.08	25.70	21.85	28.06	0.08	30.76	28.16	32.53
0.09	26.01	22.26	28.31	0.09	31.07	28.55	32.79
0.10	26.29	22.64	28.55	0.10	31.35	28.90	33.03
0.15	27.47	24.20	29.52	0.15	32.52	30.35	34.03
0.20	28.41	25.44	30.29	0.20	33.45	31.50	34.84
0.25	29.21	26.49	30.97	0.25	34.25	32.48	35.54
0.30	29.93	27.43	31.58	0.30	34.97	33.35	36.18
0.35	30.60	28.29	32.15	0.35	35.64	34.14	36.78
0.40	31.23	29.10	32.70	0.40	36.27	34.89	37.35
0.45	31.85	29.88	33.24	0.45	36.88	35.60	37.92
0.50	32.45	30.64	33.79	0.50	37.48	36.28	38.50
0.55	33.06	31.38	34.34	0.55	38.08	36.96	39.09
0.60	33.67	32.12	34.92	0.60	38.69	37.62	39.70
0.65	34.31	32.87	35.54	0.65	39.32	38.29	40.35
0.70	34.98	33.63	36.21	0.70	39.98	38.98	41.06
0.75	35.70	34.42	36.97	0.75	40.70	39.69	41.85
0.80	36.50	35.27	37.85	0.80	41.50	40.46	42.76
0.85	37.43	36.20	38.93	0.85	42.43	41.33	43.84
0.90	38.62	37.32	40.34	0.90	43.60	42.39	45.24
0.91	38.90	37.58	40.69	0.91	43.89	42.64	45.58
0.92	39.21	37.86	41.08	0.92	44.19	42.91	45.96
0.93	39.55	38.16	41.50	0.93	44.53	43.21	46.37
0.94	39.93	38.50	41.98	0.94	44.91	43.54	46.83
0.95	40.36	38.88	42.53	0.95	45.34	43.92	47.36
0.96	40.87	39.32	43.19	0.96	45.85	44.35	47.98
0.97	41.50	39.86	43.99	0.97	46.47	44.89	48.75
0.98	42.33	40.56	45.08	0.98	47.30	45.60	49.78
0.99	43.64	41.65	46.80	0.99	48.60	46.70	51.41

Table 4. Estimates of proportions mature at length (cm) for male American plaice obtained from probit analysis of maturity observations collected during NEFSC research vessel spring bottom trawl surveys for the periods 1987-1991 and 1992-1996 (with associated 95% Confidence Intervals).

1987 - 1991 period				1992 - 1996 period			
		95% Limits				95% Limits	
Probability	Length	Lower	Upper	Probability	Length	Lower	Upper
0.01	13.60	11.59	15.11	0.01	9.81	7.93	11.32
0.02	14.73	12.91	16.09	0.02	11.15	9.44	12.53
0.03	15.44	13.75	16.72	0.03	12.00	10.39	13.30
0.04	15.98	14.37	17.19	0.04	12.64	11.11	13.87
0.05	16.42	14.88	17.58	0.05	13.16	11.70	14.35
0.06	16.79	15.32	17.91	0.06	13.61	12.19	14.75
0.07	17.11	15.69	18.20	0.07	13.99	12.63	15.11
0.08	17.40	16.03	18.46	0.08	14.34	13.02	15.42
0.09	17.67	16.34	18.69	0.09	14.66	13.37	15.70
0.10	17.91	16.62	18.91	0.10	14.95	13.70	15.97
0.15	18.93	17.79	19.82	0.15	16.16	15.04	17.07
0.20	19.73	18.71	20.55	0.20	17.11	16.11	17.95
0.25	20.42	19.49	21.19	0.25	17.94	17.02	18.71
0.30	21.04	20.18	21.76	0.30	18.68	17.83	19.39
0.35	21.61	20.81	22.31	0.35	19.36	18.58	20.03
0.40	22.16	21.40	22.83	0.40	20.01	19.28	20.64
0.45	22.68	21.97	23.35	0.45	20.64	19.96	21.24
0.50	23.20	22.51	23.87	0.50	21.26	20.62	21.84
0.55	23.72	23.05	24.39	0.55	21.87	21.27	22.44
0.60	24.25	23.58	24.94	0.60	22.50	21.92	23.06
0.65	24.79	24.12	25.52	0.65	23.15	22.59	23.71
0.70	25.36	24.68	26.14	0.70	23.84	23.28	24.41
0.75	25.98	25.27	26.82	0.75	24.57	24.01	25.17
0.80	26.67	25.92	27.58	0.80	25.40	24.81	26.04
0.85	27.48	26.66	28.49	0.85	26.35	25.73	27.07
0.90	28.49	27.58	29.64	0.90	27.56	26.86	28.38
0.91	28.73	27.80	29.92	0.91	27.85	27.13	28.70
0.92	28.99	28.04	30.23	0.92	28.17	27.43	29.05
0.93	29.29	28.30	30.57	0.93	28.52	27.75	29.43
0.94	29.61	28.59	30.94	0.94	28.91	28.12	29.86
0.95	29.99	28.92	31.37	0.95	29.35	28.52	30.35
0.96	30.42	29.31	31.88	0.96	29.87	28.99	30.93
0.97	30.96	29.79	32.51	0.97	30.51	29.58	31.64
0.98	31.67	30.42	33.34	0.98	31.36	30.36	32.59
0.99	32.80	31.40	34.66	0.99	32.70	31.58	34.09

Table 5. Estimates of proportions mature at length (cm) for female American plaice obtained from probit analysis of maturity observations collected during NEFSC spring research vessel bottom trawl surveys for the periods 1987-1991 and 1992-1996 (with associated 95% Confidence Intervals).

1987 - 1991 period				1992 - 1996 period			
		95% Limits				95% Limits	
Probability	Length	Lower	Upper	Probability	Length	Lower	Upper
0.01	19.82	18.41	20.93	0.01	21.82	20.49	22.87
0.02	20.80	19.53	21.82	0.02	22.76	21.56	23.71
0.03	21.43	20.23	22.38	0.03	23.35	22.23	24.24
0.04	21.90	20.77	22.81	0.04	23.80	22.74	24.65
0.05	22.28	21.20	23.15	0.05	24.16	23.15	24.97
0.06	22.61	21.56	23.45	0.06	24.47	23.50	25.25
0.07	22.89	21.89	23.71	0.07	24.74	23.81	25.50
0.08	23.15	22.17	23.94	0.08	24.99	24.08	25.72
0.09	23.38	22.43	24.15	0.09	25.21	24.33	25.92
0.10	23.59	22.67	24.35	0.10	25.41	24.56	26.11
0.15	24.48	23.66	25.16	0.15	26.26	25.50	26.88
0.20	25.18	24.44	25.81	0.20	26.93	26.24	27.50
0.25	25.79	25.11	26.37	0.25	27.51	26.88	28.03
0.30	26.33	25.70	26.88	0.30	28.02	27.44	28.52
0.35	26.83	26.25	27.36	0.35	28.50	27.96	28.97
0.40	27.31	26.76	27.82	0.40	28.95	28.44	29.41
0.45	27.77	27.25	28.26	0.45	29.39	28.91	29.84
0.50	28.23	27.72	28.71	0.50	29.82	29.36	30.27
0.55	28.68	28.19	29.17	0.55	30.25	29.80	30.70
0.60	29.14	28.66	29.64	0.60	30.69	30.24	31.15
0.65	29.62	29.14	30.13	0.65	31.15	30.69	31.63
0.70	30.12	29.63	30.66	0.70	31.62	31.16	32.13
0.75	30.67	30.16	31.23	0.75	32.14	31.65	32.68
0.80	31.27	30.73	31.88	0.80	32.72	32.20	33.31
0.85	31.97	31.40	32.65	0.85	33.39	32.83	34.04
0.90	32.86	32.22	33.63	0.90	34.23	33.61	34.98
0.91	33.07	32.42	33.86	0.91	34.43	33.80	35.21
0.92	33.31	32.63	34.12	0.92	34.65	33.99	35.45
0.93	33.56	32.87	34.41	0.93	34.90	34.22	35.73
0.94	33.85	33.13	34.72	0.94	35.17	34.47	36.03
0.95	34.17	33.43	35.09	0.95	35.48	34.75	36.38
0.96	34.56	33.78	35.52	0.96	35.84	35.08	36.79
0.97	35.03	34.20	36.05	0.97	36.29	35.48	37.29
0.98	35.65	34.77	36.75	0.98	36.88	36.02	37.97
0.99	36.64	35.66	37.86	0.99	37.82	36.86	39.03

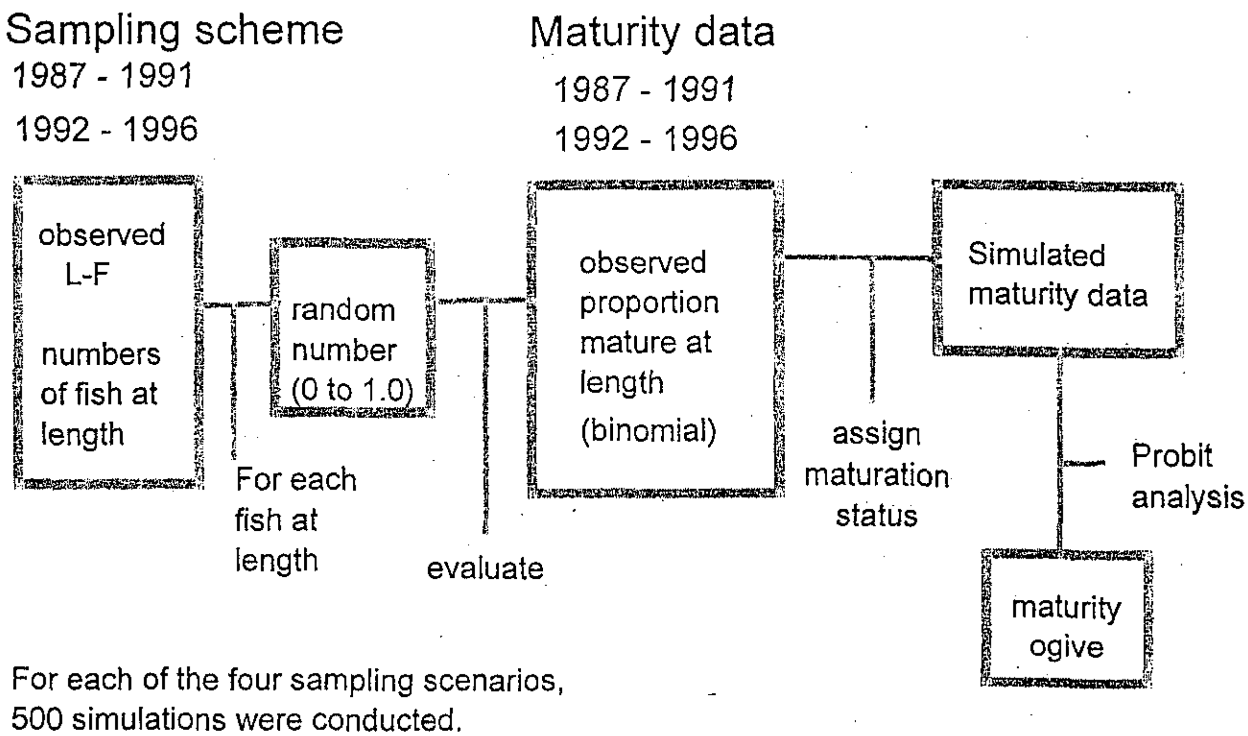

Fig. 1. Sequence of operations within the Monte Carlo-type simulation model used in this study, in which observed length frequencies of sampled fish were iteratively re-sampled to generate simulated maturity data for re-analysis and comparison.

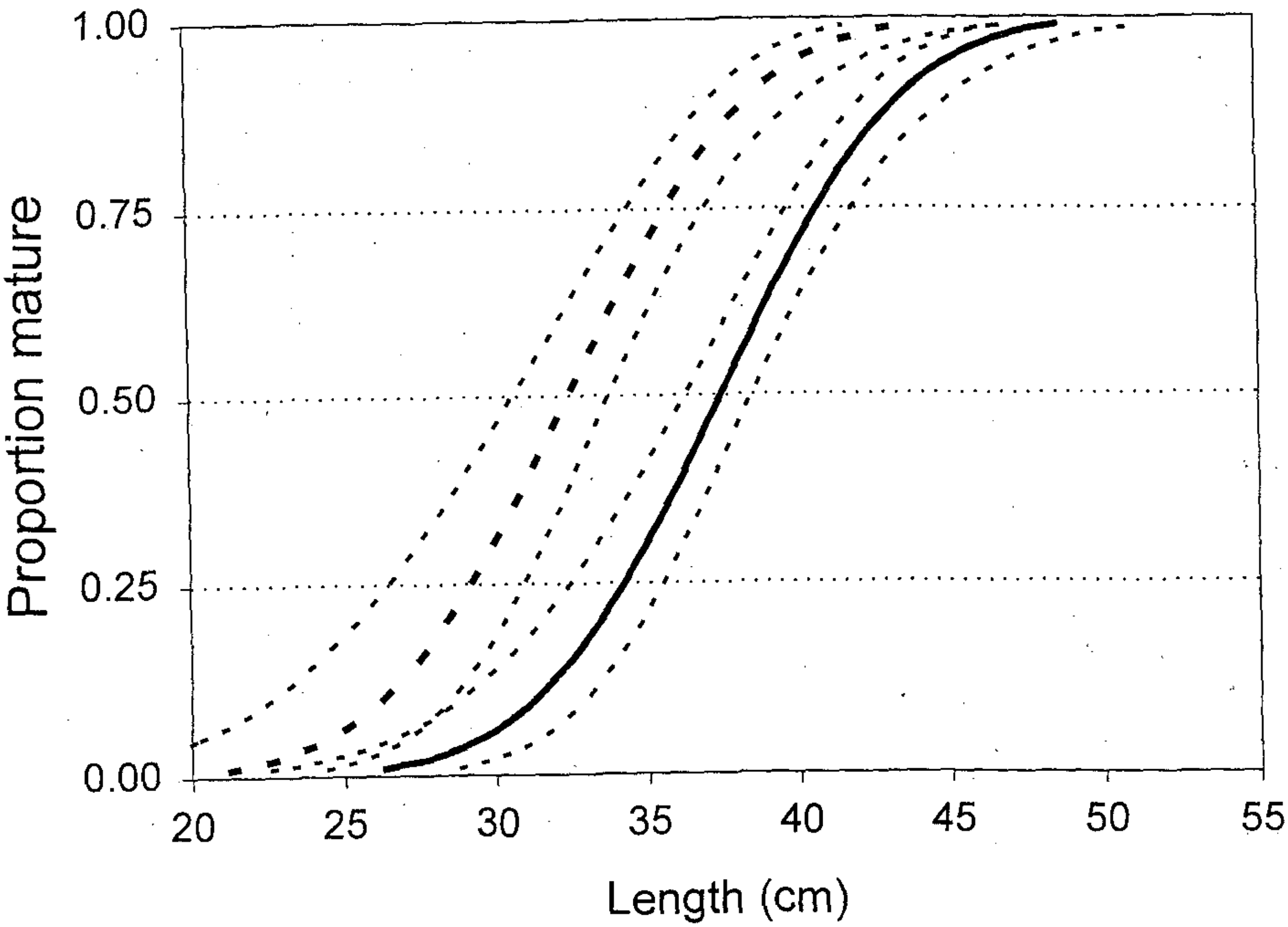

Fig. 2. Maturity ogives of proportions mature at length (cm, and associated 95% Confidence Intervals) for female haddock on Georges Bank derived from probit analysis of maturity observations collected during NEFSC spring research vessel bottom trawl surveys in 1987-1991 (dashed line) and 1992-1996 (solid line).

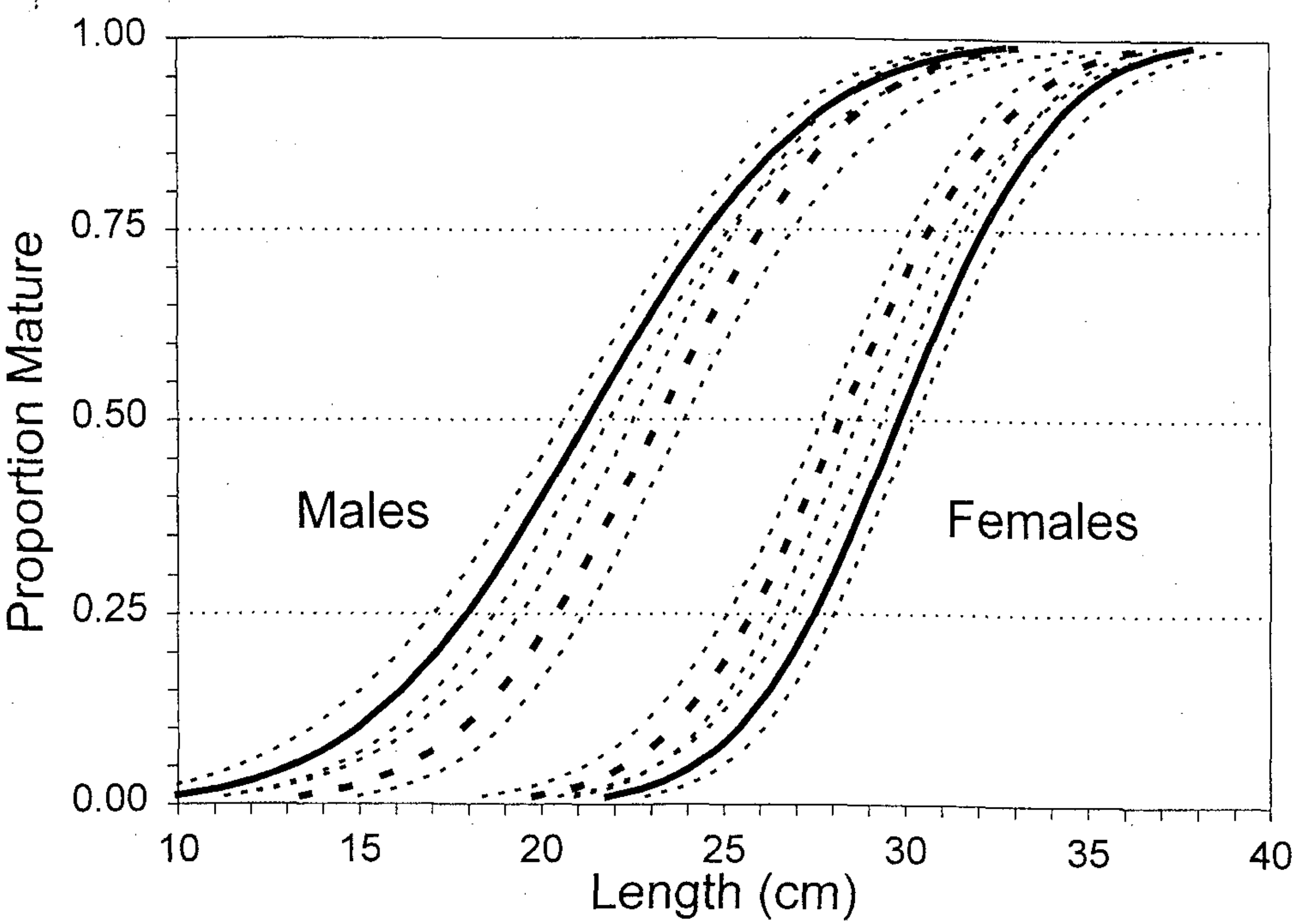

Fig. 3. Maturity ogives of proportions mature at length (cm, and associated 95% Confidence Intervals) for male and female American plaice derived from probit analysis of maturity observations collected during NEFSC spring research vessel bottom trawl surveys in 1987-1991 (dashed line) and 1992-1996 (solid line).

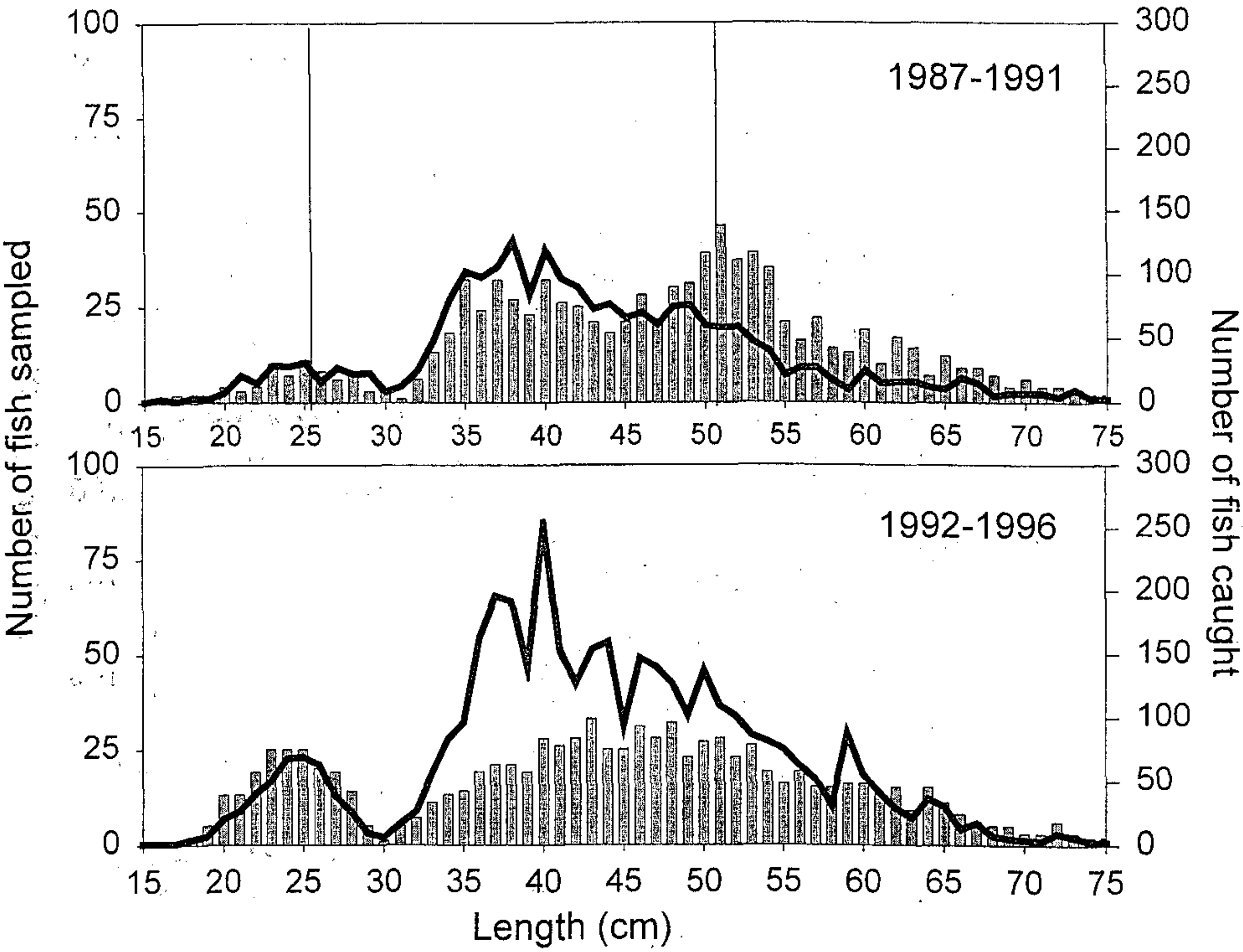

Fig. 4. Length frequency distributions of the total catch (solid lines) and sampled fish (bars) of haddock on Georges Bank during NEFSC spring research vessel bottom trawl surveys in 1987-1991 and 1992-1996. Vertical lines represent divisions between length strata in the 1987-1991 period (see Table 1).

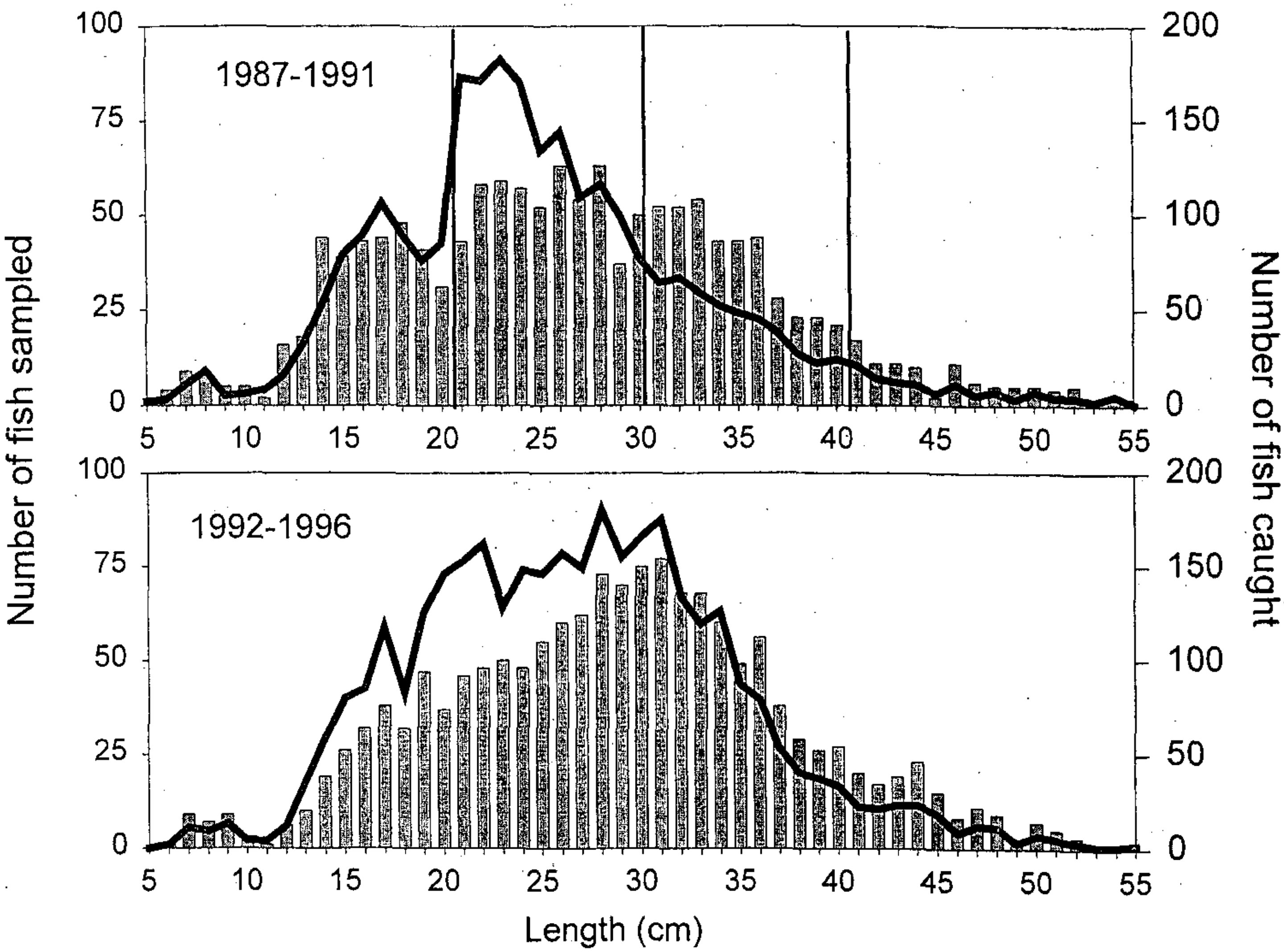

Fig. 5. Length frequency distributions of the total catch (solid lines) and sampled fish (bars) of American plaice during NEFSC spring research vessel bottom trawl surveys in 1987-1991 and 1992-1996. Vertical lines represent divisions between length strata in the 1987-1991 period (see Table 1).

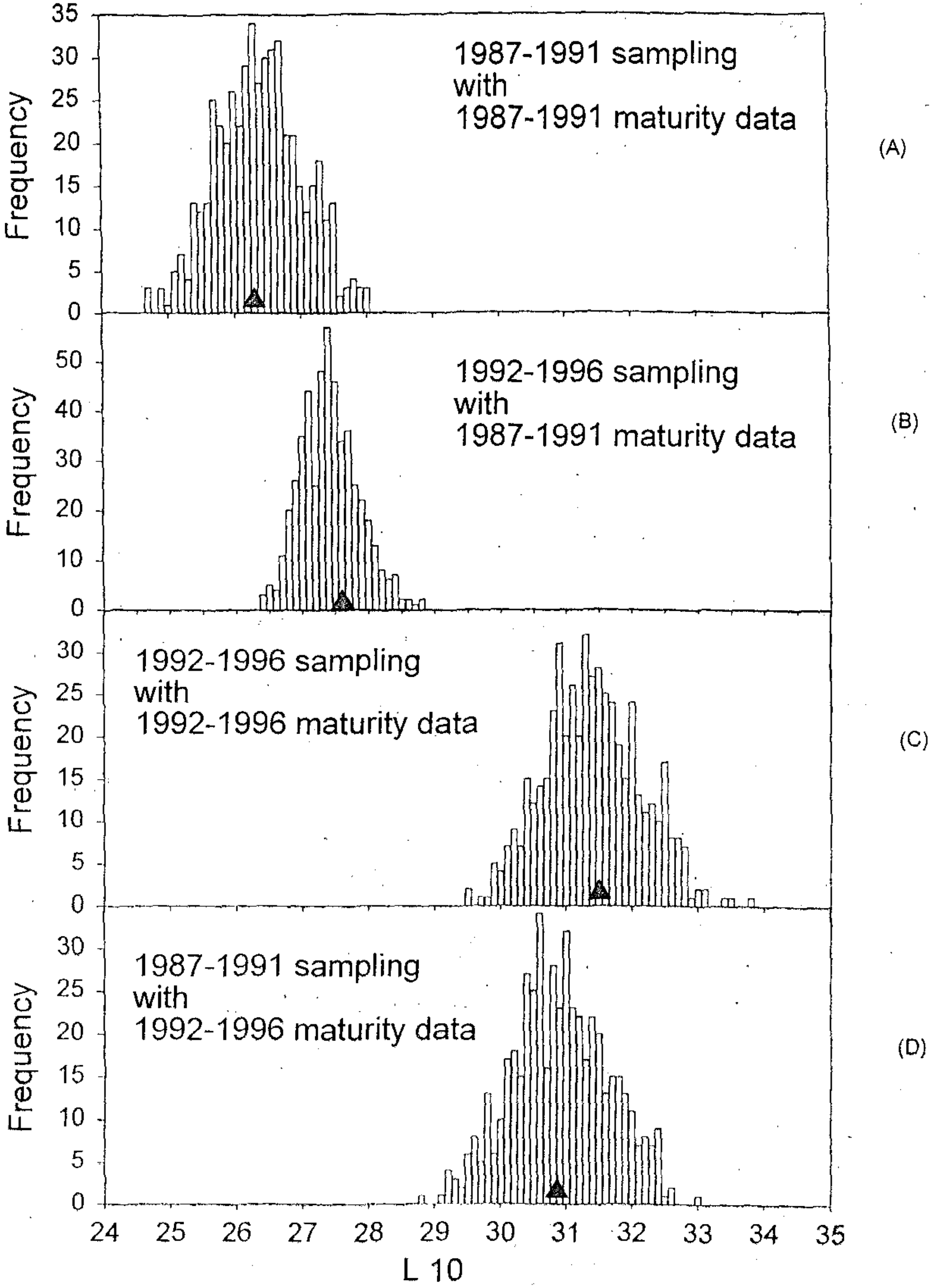

Fig. 6. Frequency distributions (bars) and medians (triangles) of estimates of L_{10} for female haddock on Georges Bank obtained from 500 probit analyses for each of the four simulation scenarios: a) baseline run for 1987-1991; b) alternative sampling of 1987-1991 data; c) baseline run for 1992-1996; and d) alternative sampling of 1992-1996 data.

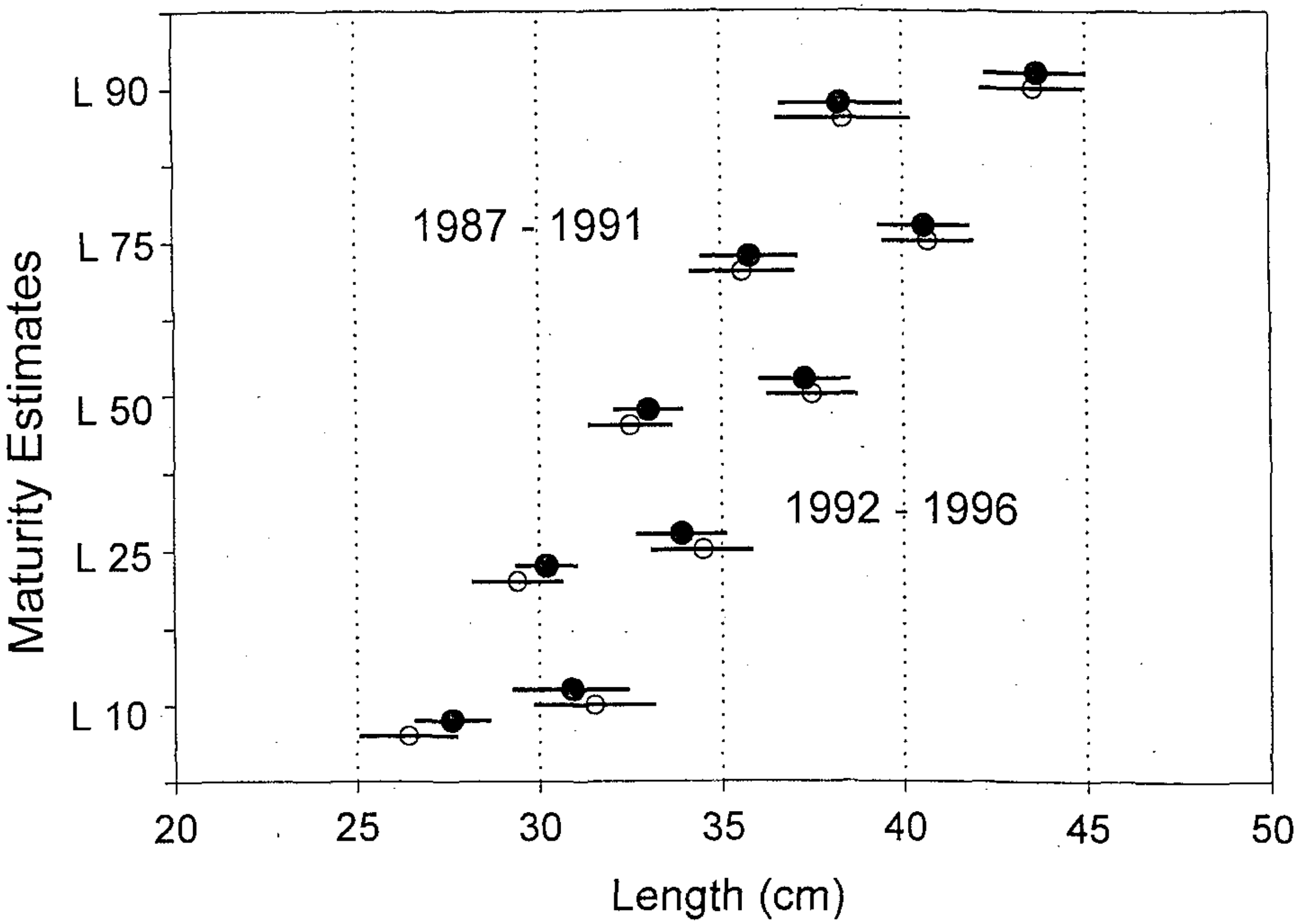

Fig. 7. Simulation results for haddock at levels of L_{10}, L_{25}, L_{50}, L_{75}, and L_{90} for the four scenarios encompassing the periods 1987-1991 and 1992-1996; horizontal bars represent the 80% confidence interval of the frequency distributions associated with each estimate (see Fig. 6), circles represent median values, with alternative sampling (closed circles) results positioned above baseline runs (open circles) for each time period.

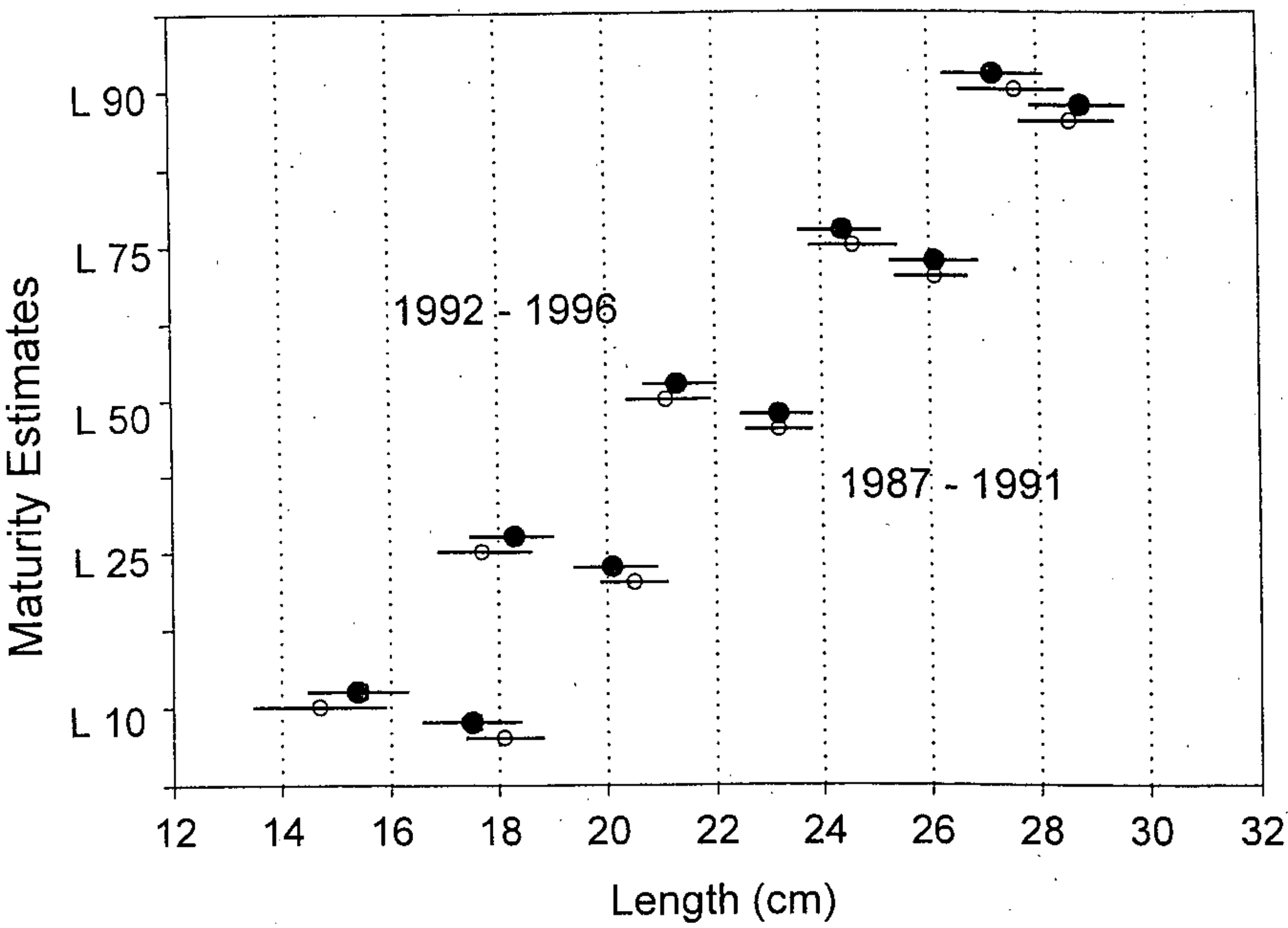

Fig. 8. Simulation results for male American plaice at levels of L_{10}, L_{25}, L_{50}, L_{75}, and L_{90} for the four scenarios encompassing the periods 1987-1991 and 1992-1996; horizontal bars represent the 80% confidence interval of the frequency distributions associated with each estimate (see Fig. 6), circles represent median values, with alternative sampling (closed circles) results positioned above baseline runs (open circles) for each time period.

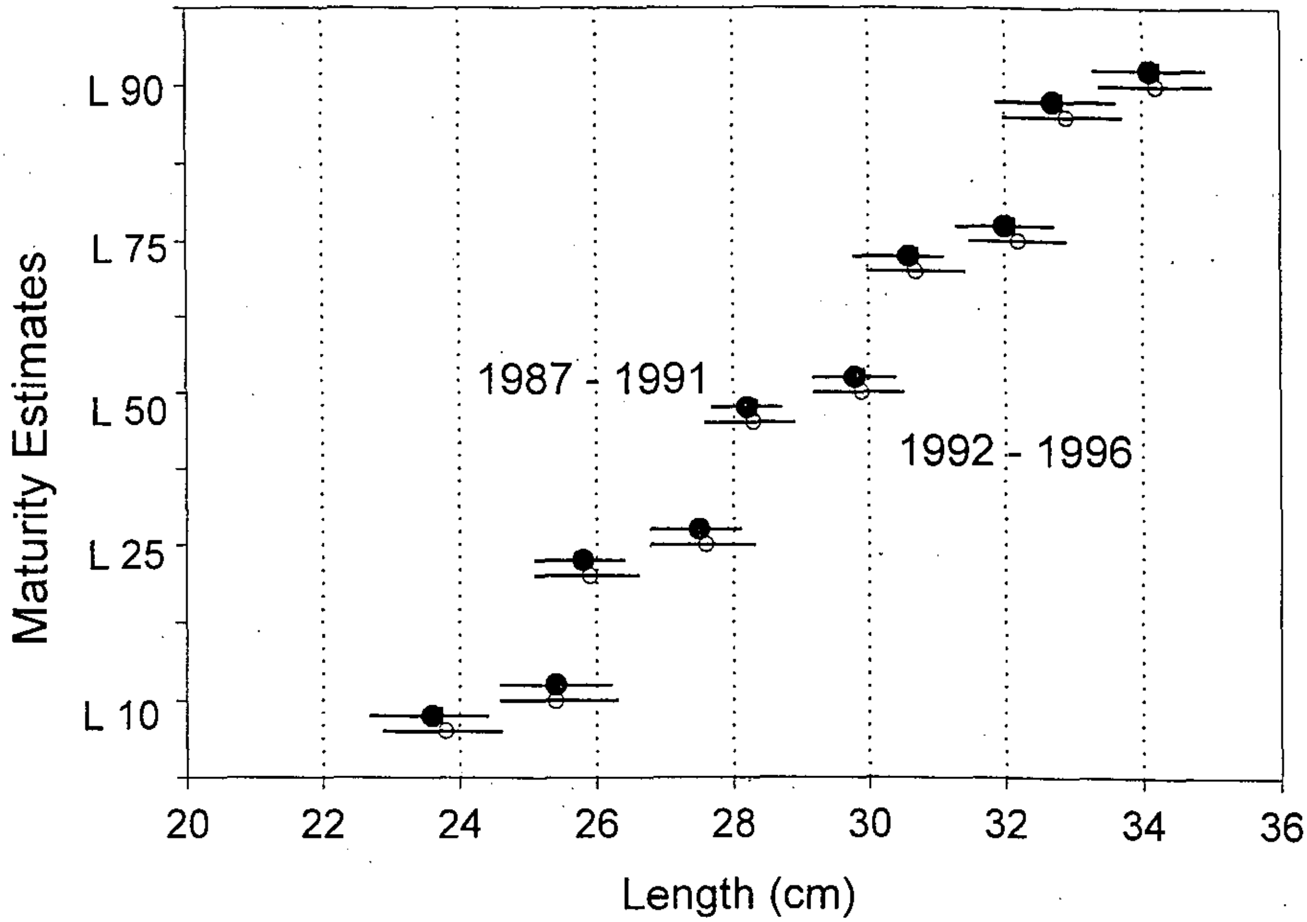

Fig. 9. Simulation results for female American plaice at levels of L_{10}, L_{25}, L_{50}, L_{75}, and L_{90} for the four scenarios encompassing the periods 1987-1991 and 1992-1996; horizontal bars represent the 80% confidence interval of the frequency distributions associated with each estimate (see Fig. 6), circles represent median values, with alternative sampling (closed circles) results positioned above baseline runs (open circles) for each time period.

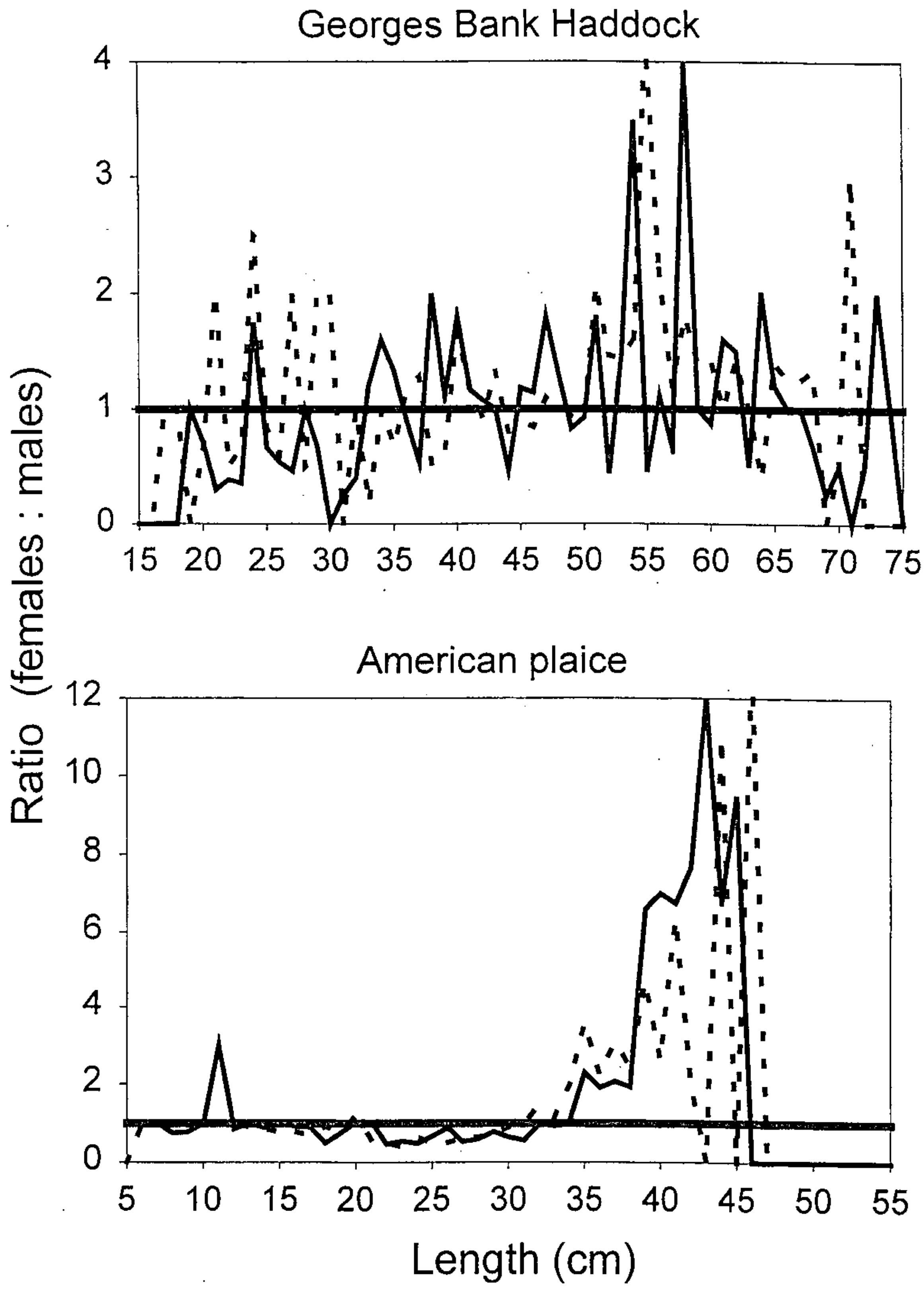

Fig. 10. Sex ratios (females : males) observed in this study for haddock and American plaice sampled during NEFSC bottom trawl surveys in 1987-1991 (dashed line) and 1992-1996 (solid line).