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J. Northw. Atl. Fish. Sci., Vol. 25: 133–140

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

S. E. Wigley, J. M. Burnett, and P. J. Rago
National Marine Fisheries Service
Woods Hole, MA 02543 USA

Abstract

Biological sampling of fish during research vessel survey cruises is often conducted using length-stratified age sampling schemes. Maturity-at-length or age 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 (NEFSC) modified the length-stratified age sampling protocol used during semi-annual research vessel bottom trawl surveys. 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-at-length or age 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 complicated by the sexually 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.

Key words: length-stratified sampling, maturity-at-length

Introduction

Biological sampling of fish during research vessel surveys is often accomplished by using length-stratified 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, MS 1986; Anon., MS 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 which have been 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, MS 1992) with the new protocols, no systematic evaluation of the effects of the sampling change on maturity-at-length or age has been performed.

In this study, the effects of the 1992 change in sampling protocol on estimated maturity parameters for two groundfish species, haddock (*Melanogrammus aeglefinus*) and American plaice (*Hippoglossoides platessoides*) are assessed. A

TABLE 1. Sampling protocols for length-stratified sampling of haddock and American plaice used during Northeast Fisheries Science Center research vessel bottom trawl surveys, 1963–91 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	5 fish	
	31–40 cm	25 fish	
	> 40 cm	20 fish	

Monte Carlo-type simulation model was developed which allowed re-sampling of survey catches of these species prior to 1992 and after 1992 using both sampling schemes. 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 1987–96 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 a pre-1992 length stratum of 26–50 cm was relatively wide and encompassed fish sizes for which observed proportions mature ranged from 30 to 100% (O'Brien *et al.*, 1993). American plaice was selected because it exhibits sexually dimorphic growth and maturation rates; males maturing at a smaller size and younger age than females (O'Brien *et al.*, 1993).

Size at maturation was evaluated using data collected prior and close to the time of spawning (Halliday, 1987). Maturity data for both species were derived from NEFSC spring research vessel bottom trawl surveys. The data were pooled into two five-year blocks, 1987–91 and 1992–96 (representing equal number of years of data collection under each sampling scheme). Probit analyses (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 blocks of pooled data were compared using Chi-square analysis (Sokal and Rohlf, 1981). The expected distribution of the total numbers caught at length during 1992–96 period was derived by multiplying the observed proportions sampled at length in 1987–91 by the estimated total numbers caught at length. The null hypothesis in this procedure is that the realized distribution sampled in 1992–96 was equivalent to what would have been sampled under the 1987–91 sampling protocol.

A Monte Carlo-type simulation model was constructed to evaluate the effects of the sampling protocols on estimated maturity parameters 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 derived. Baseline maturity estimates were produced for each five-year period by repeating the procedure outlined above using the sampling design that actually existed during the period. 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.

The simulation approach applied to evaluate effects of sampling protocol is summarized below:

	Sampling scheme	
Maturity data	1987–91	1992–96
1987–91	Baseline	Alternative
1992–96	Alternative	Baseline

where maturity data are 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 1987–91 and 1992–96 periods is summarized in Table 2. The percentage of survey stations sampled were comparable under both sampling schemes, and similar numbers of fish sampled in both periods for each species.

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
	92% 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	343
	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

Significantly different maturity ogives between the two five-year periods were obtained for female Georges Bank haddock and for both sexes of American plaice (Fig. 1 and 2). For haddock, maturation occurred at smaller sizes in the 1987–91 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 Georges Bank haddock during 1987–91 and 37.5 cm during 1992–96. For American plaice, maturation of males occurred at smaller sizes in the 1992–96 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 1987–91 and 1992–96 periods respectively, and 28.2 cm and 29.8 cm, respectively, for female plaice.

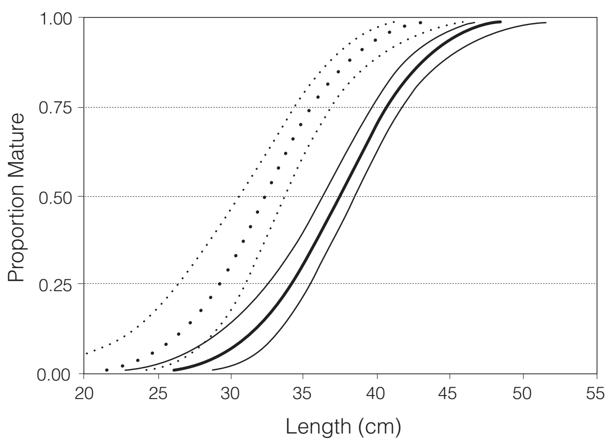

Fig. 1. Maturity ogives of proportions mature at length (cm, and associated 95% Confidence Intervals) for female Georges Bank haddock derived from probit analyses of maturity observations collected during NEFSC spring research vessel bottom trawl surveys in 1987–91 (dotted line) and 1992–96 (solid line).

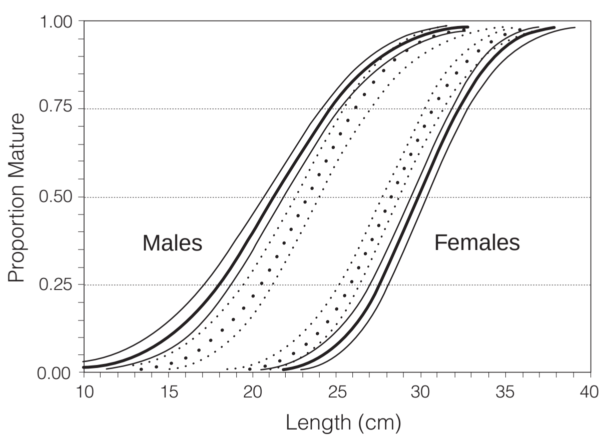

Fig. 2. Maturity ogives of proportions mature at length (cm, and associated 95% Confidence Intervals) for male and female American plaice derived from probit analyses of maturity observations collected during NEFSC spring research vessel bottom trawl surveys in 1987–91 (dotted line) and 1992–96 (solid line).

The empirical pooled length frequency catch and sampling distribution for each five-year period are presented in Fig. 3 for haddock and Fig. 4 for American plaice. Significant differences were obtained in the sampled distributions between periods for each species (for haddock, $X^2 = 725.84$, $p < 0.01$, 54 df; for American plaice, $X^2 = 191.97$, $p < 0.01$, 48 df).

Figure 5a–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) alternative sampling of 1987–91 data; b) baseline run for 1987–91; c) alternative sampling of 1992–96 data; and d) baseline run for 1992–96. 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 6–8 present simulation estimates of L_{10}–L_{90} for Georges Bank haddock and male and female American plaice, respectively. For haddock (Fig. 6), 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. 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 1987–91 period overlap with the 80% confidence intervals from the

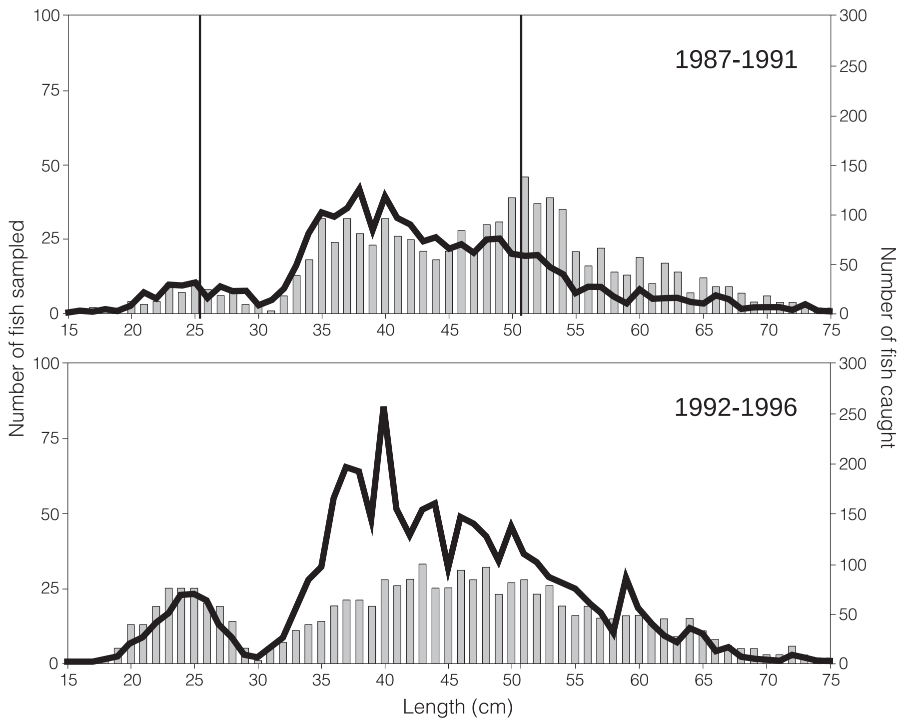

Fig. 3. Length frequency distributions of the total catch (solid lines) and sampled catch (bars) of Georges Bank haddock during NEFSC spring research vessel bottom trawl surveys in 1987–91 and 1992–96. Vertical lines represent length strata in the 1987–91 sampling period (see Table 1).

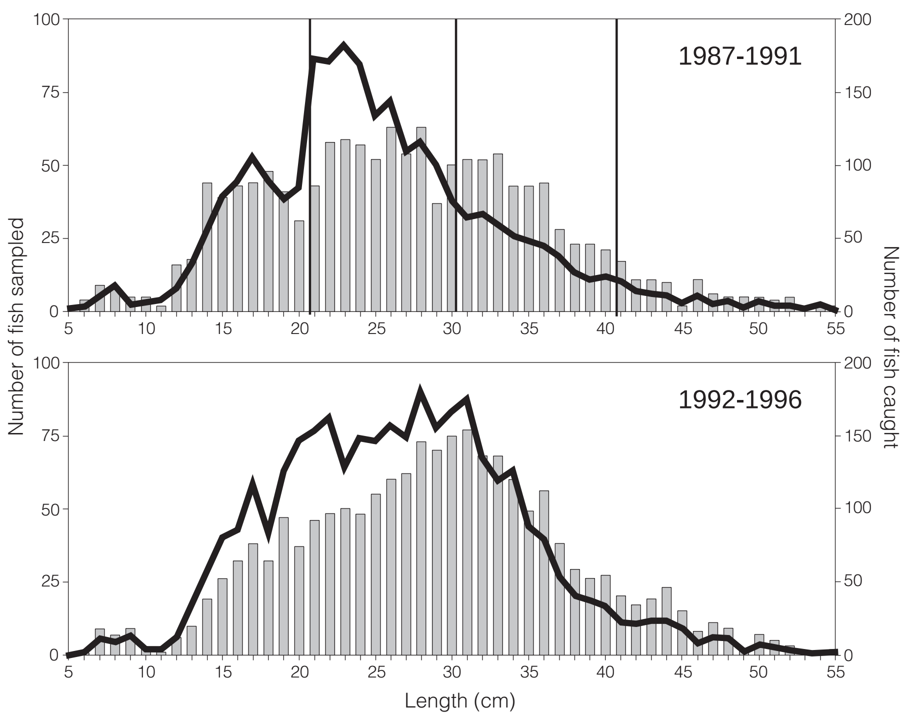

Fig. 4. Length frequency distributions of the total catch (solid lines) and sampled catch (bars) of American plaice during NEFSC spring research vessel bottom trawl surveys in 1987–91 and 1992–96. Vertical lines represent length strata in the 1987–91 sampling period (see Table 1).

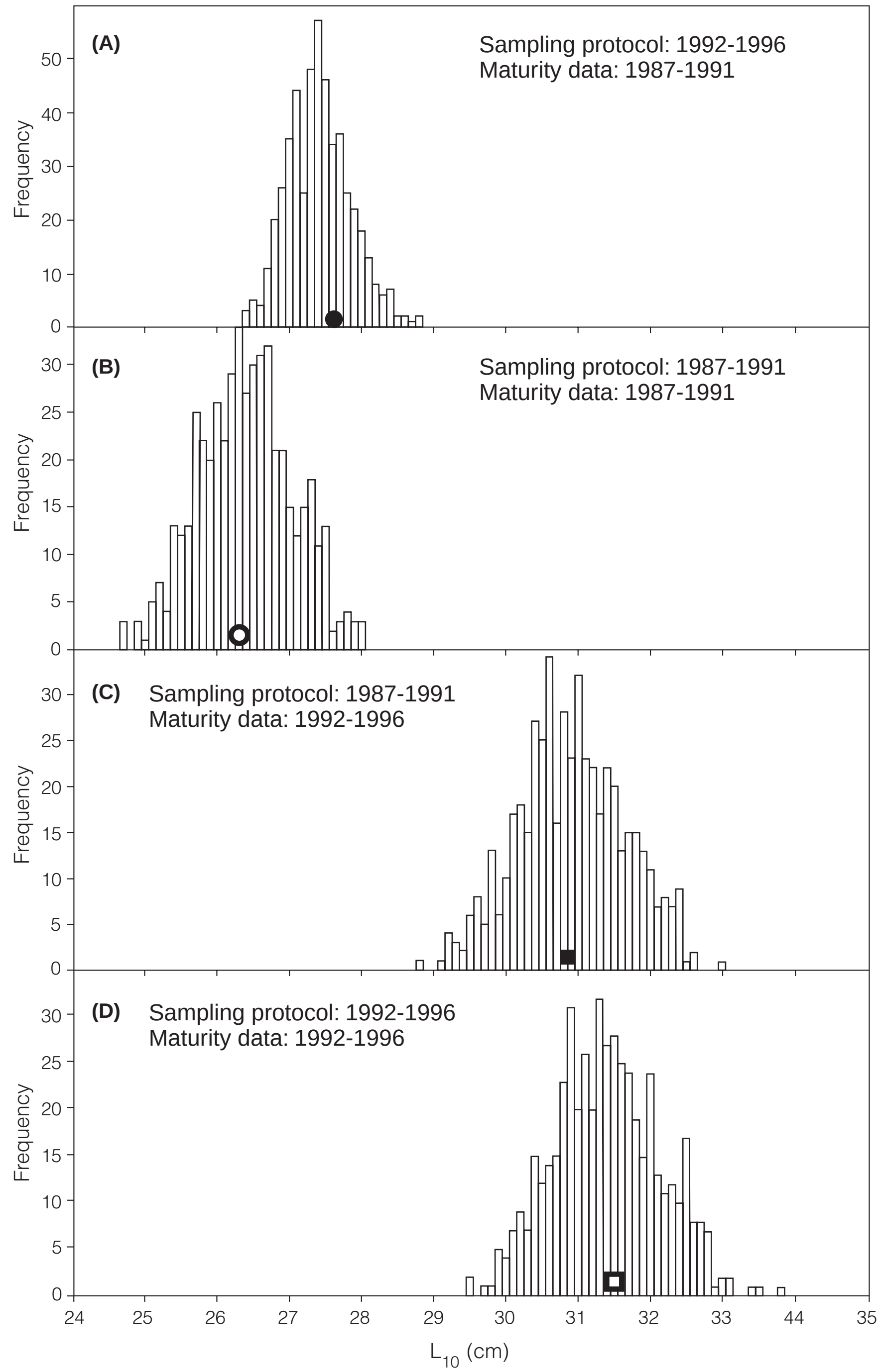

Fig. 5. Frequency distributions (bars) and medians (symbols) of estimated length at 10% maturity (L_{10}) for female Georges Bank haddock obtained from 500 bootstrap replications of probit analyses for each of the four simulation scenarios: a) alternative sampling of 1987–91 data; b) baseline run for 1987–91; c) alternative sampling of 1992–96 data; and d) baseline run for 1992–96.

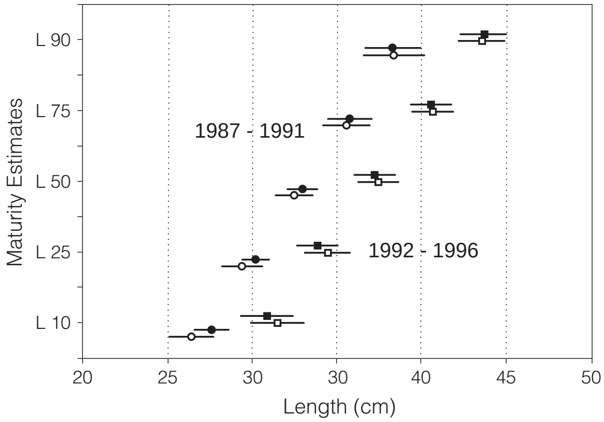

Fig. 6. Simulation results for Georges Bank haddock at levels of L_{10}, L_{25}, L_{50}, L_{75} and L_{90} for the four scenarios encompassing the periods 1987–91 and 1992–96; horizontal bars represent the 80% confidence interval of the frequency distributions associated with each estimate (see Fig. 6), symbols are the median values. Alternative sampling (closed symbol) results are positioned above baseline runs (open symbol) for each time period (circles represent estimates for the 1987–91, squares represent estimates for 1992–96).

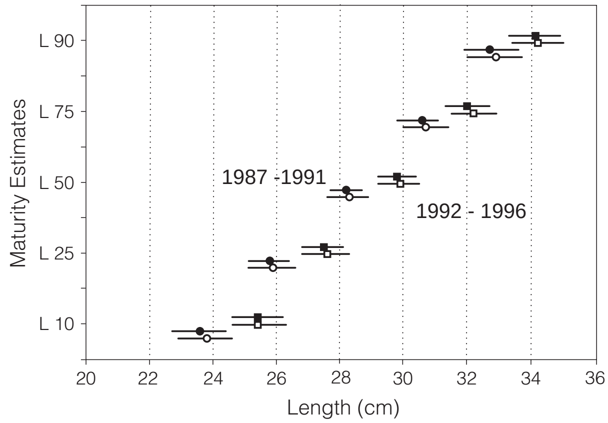

Fig. 8. Simulation results for male American plaice at levels of L_{10}, L_{25}, L_{50}, L_{75} and L_{90} for the four scenarios encompassing the periods 1987–91 and 1992–96; horizontal bars represent the 80% confidence interval of the frequency distributions associated with each estimate (see Fig. 6), symbols are the median values. Alternative sampling (closed symbol) results are positioned above baseline runs (open symbol) for each time period (circles represent estimates for the 1987–91, squares represent estimates for 1992–96).

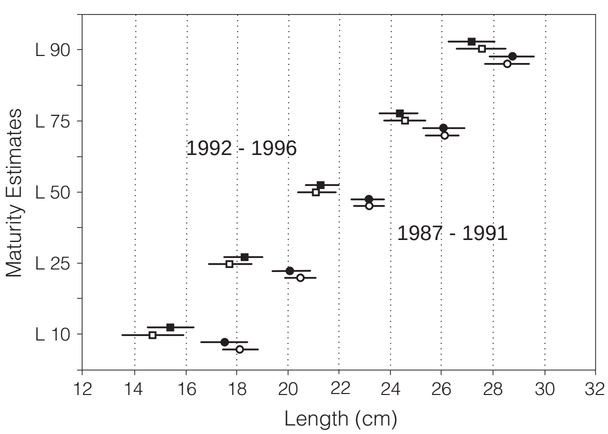

Fig. 7. Simulation results for male American plaice at levels of L_{10}, L_{25}, L_{50}, L_{75} and L_{90} for the four scenarios encompassing the periods 1987–91 and 1992–96; horizontal bars represent the 80% confidence interval of the frequency distributions associated with each estimate (see Fig. 6), symbols are the median values. Alternative sampling (closed symbol) results are positioned above baseline runs (open symbol) for each time period (circles represent estimates for the 1987–91, squares represent estimates for 1992–96).

1992–96 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 artifact. Similar results and conclusions were obtained for male and female American plaice (Fig. 7 and 8, respectively).

Discussion

The change in sampling scheme in 1992 resulted in significantly different length distributions of sampled fish after the change compared to 1987–91 period. Results from the Monte Carlo-type simulations indicate no bias was introduced in deriving maturity parameters for Georges Bank haddock and American plaice as a result of this change. However, simulation results did identify areas in which improved data collection might increase the precision of maturity analyses. Increased variability in simulation estimates for L_{10} and L_{90} (the lower and upper tails of the maturity ogive) suggests that additional sampling beyond that provided by length-stratified age sampling may provide better estimates for this portion of the ogive. Estimates of L_{50}

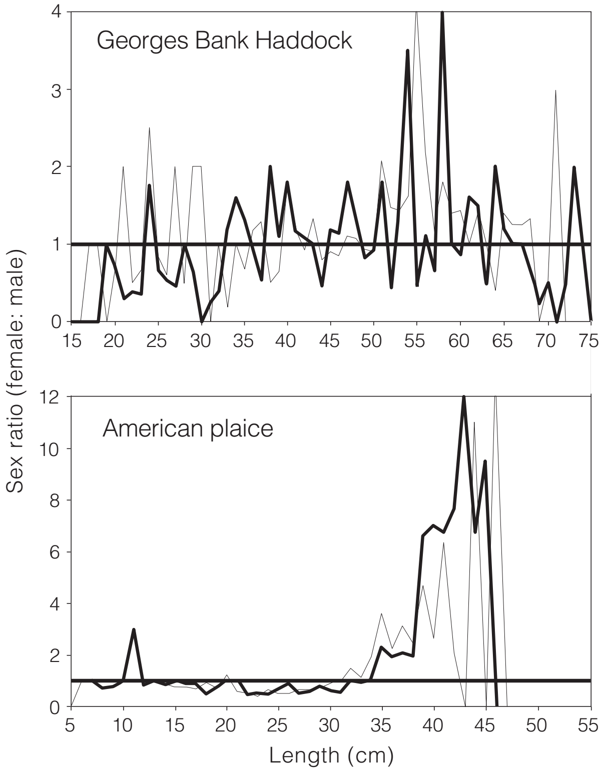

Fig. 9. Sex ratios (female:male) of Georges Bank haddock and American plaice sampled during NEFSC spring research vessel bottom trawl surveys, 1987–91 (thin line) and 1992–96 (thick line). Horizontal line denotes a 1:1 ratio.

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. 9), 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.

Acknowledgements

We thank all the scientific staff involved in the collection of NEFSC research vessel survey data, and F. M. Serchuk, S.A. Murawski and two anonymous reviewers for their helpful comments.

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