

**Estimation of Standardized
Otter Trawl Effort, Landings
per Unit Effort, and
Landings at Age
for Gulf of Maine
and Georges Bank Cod**

by

**R. K. Mayo, T. E. Helser, L. O'Brien,
K. A. Sosebee, B. F. Figuerido,
and D. Hayes**

NOAA/National Marine Fisheries Service
Northeast Fisheries Science Center
Conservation and Utilization Division
Woods Hole, MA 02543

May 1994

The Northeast Fisheries Science Center Reference Documents are a series of informal reports produced by the Center for timely transmission of results obtained through work at the various NEFSC labs. The documents are reviewed internally before publication, but are not considered formal literature. The National Marine Fisheries Service does not endorse any proprietary material, process, or product mentioned in these reports. To obtain additional copies of this report contact, Information Services Unit, Northeast Fisheries Science Center, Woods Hole, MA 02543 (508-548-5123, ext. 260).

The correct citation for the document is: Mayo, R. K., T. E. Helser, L. O'Brien, K. A. Sosebee, B. F. Figuerido, and D. Hayes. 1994. Estimation of standardized otter trawl effort, landings per unit effort, and landings at age for Gulf of Maine and Georges Bank cod. NOAA/NMFS/NEFSC: Woods Hole, MA. *NEFSC* [Northeast Fisheries Science Center] *Ref. Doc.* 94-12.

TABLE OF CONTENTS

Abstract	1
Introduction	1
Methods	1
Data sources	1
Effort Standardization	4
Landings at Age Estimates	5
Results	5
Effort Standardization	5
Landings at Age Estimates	11
Discussion	12
Literature Cited	17

List of Tables

Table 1.	Georges Bank cod GLM effort standardization	6
Table 2.	Nominal and standardized (GLM) Georges Bank cod landings (metric tons), effort (days fished) and landings per day fished (LPUE)	6
Table 3.	Gulf of Maine cod GLM effort standardization	7
Table 4.	Nominal and standardized (GLM) Gulf of Maine cod landings (metric tons), effort (days fished) and landings per day fished (LPUE)	7
Table 5.	Landings at age of Georges Bank cod (thousands of fish, metric tons) and mean weight (kilograms) at age for the otter trawl subfleet, ages 2 -9+, 1978-1992	10
Table 6.	Landings at age of Gulf of Maine cod (thousands of fish, metric tons) and mean weight (kilograms) at age for the otter trawl subfleet, ages 2 -9+, 1982-1992	11
Table 7.	Total commercial landings at age of Atlantic cod (thousands of fish) from Georges Bank and South, ages 1-10+, 1978-1992	12
Table 8.	Total commercial landings at age of Atlantic cod (thousands of fish) from the Gulf of Maine, ages 2-10+, 1982-1992	12

List of Figures

Figure 1.	Trends in \log_e CPUE of Georges Bank cod by vessel tonnage class, 1978-1992	2
Figure 2.	Trends in \log_e CPUE of Gulf of Maine cod by vessel tonnage class, 1982-1992	3
Figure 3.	Fishing effort estimated for Georges Bank cod from Serchuk <i>et al.</i> (1993) and from the GLM standardization procedure, 1978-1992	8
Figure 4.	Fishing effort estimated for Gulf of Maine cod from Mayo <i>et al.</i> (1993) and from the GLM standardization procedure, 1982-1992	8
Figure 5.	Landings per unit effort (LPUE) estimated for Georges Bank cod from Serchuk <i>et al.</i> (1993) and from the GLM standardization procedure, 1978-1992	9
Figure 6.	Landings per unit effort (LPUE) estimated for Gulf of Maine cod from Mayo <i>et al.</i> (1993) and from the GLM standardization procedure, 1982-1992	9

Figure 7. Percent age composition of Georges Bank cod from the full landings at age matrix and the effort subfleet landings at age martix for ages 2-9+, 1978-1992 13

Figure 8. Percent age composition of Gulf of Maine cod from the full landings at age matrix and the effort subfleet landings at age martix for ages 2-9+, 1982-1992 15

Figure 9. Trends in commercial standardized LPUE and NEFSC research vessel spring bottom trawl survey biomass index (mean weight per tow) for Georges Bank cod, 1978-1992 16

Figure 10. Trends in commercial standardized LPUE and NEFSC research vessel spring bottom trawl survey biomass index (mean weight per tow) for Gulf of Maine cod, 1982-1992 16

ABSTRACT

Standardized effort series for Gulf of Maine and Georges Bank cod were estimated using General Linear Models (GLM) incorporating year, area, quarter, and vessel tonnage class. Landings and effort data included in the models were derived from interviewed trips using otter trawl gear. Annual commercial landings per unit effort indices were computed for the interviewed subfleets based on the standardized effort estimates. Annual landings at age estimates corresponding to the effort subfleets were also derived as a basis for computing landings per unit effort at age.

For both cod stocks, standardized fishing effort increased throughout most of the 1980s. Effort peaked in 1987 in the Gulf of Maine, declined through 1990 but increased again in 1991 and 1992. On Georges Bank, effort has increased continuously since 1978. Commercial landings per unit effort (LPUE) for both stocks consequently declined through the mid-1980s. LPUE increased sharply in the Gulf of Maine in 1989 and 1990, but declined in 1991 and 1992. On Georges Bank, commercial LPUE declined continuously through 1987, but increased slightly between 1988 and 1991 before declining again in 1992.

Comparison of standardized effort and LPUE trends from the GLM analyses with those computed by various means in previous studies indicated good overall agreement, although differences evident in the latter years may be due to recent changes in the degree of directivity of the cod fisheries in both areas.

Landings at age estimates indicated a very strong 1987 year class in the Gulf of Maine which supported a sharp increase in landings and LPUE in this region in 1989 and 1990. On Georges Bank, recruitment was distributed more evenly among several year classes, particularly those produced in 1983, 1985 and 1987. Age compositions of the otter trawl effort subfleets were generally similar to the total landings at age estimates for each stock, although the otter trawl fleets tended to take a slightly higher proportion of 2- and 3-year-old cod.

INTRODUCTION

At the 15th Northeast Regional Stock Assessment Workshop (15th SAW), the Stock Assessment Review Committee (SARC) noted that commercial landings per unit effort (LPUE) at age based on multigear landings derived by multiplying the retransformed year factor obtained from a General Linear Model (GLM) based on otter trawl landings per day fished by the estimated total multi-gear effort may not reflect actual standardized fishing effort or the actual age composition of otter trawl trips from which effort was derived. Furthermore, it was suggested that this approach may not capture changes in effort patterns for other gears. It was recommended that standardization of effort be conducted separately for individual gears (NEFSC 1993).

In preparing the 1993 assessments for Gulf of Maine and Georges Bank cod, we recomputed the landings per day fished for the otter trawl subfleets alone. Also, we reconstructed the landings at age matrices based on landings that corresponded to the otter trawl effort subfleet which was used to compute the standardized annual effort. The following report summarizes the methods used to select landings, effort, and length and age

sample data, and presents both the results of the GLM used to compute standardized effort for each stock and comparisons between the annual age compositions estimated for the entire fishery and for the effort subfleets.

METHODS

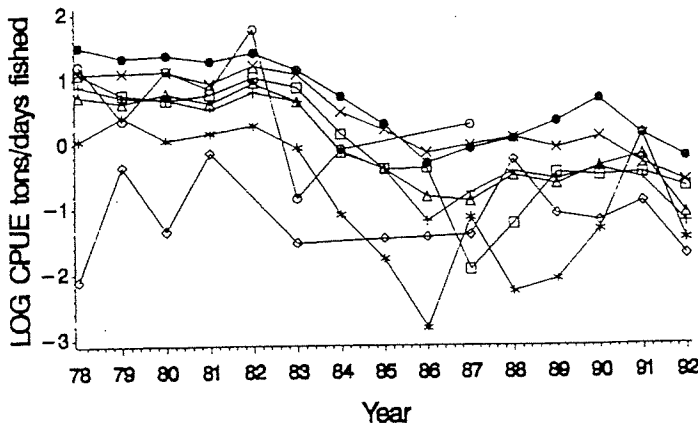
DATA SOURCES

Landings and effort data for each stock were obtained from the Northeast Fisheries Science Center (NEFSC) Commercial Fisheries Database (CFDBS) master files covering the period 1978-1992 for Georges Bank cod and from 1982-1992 for Gulf of Maine cod. A data base that included only records for interviewed otter trawl trips (excluding shrimp trawls, pair trawls, *etc.*), inclusive of valid tonnage classes that appeared in the data consistently over time, was constructed for each stock (statistical areas 521, 522, 523/561, 524/562, 525, and 526 for Georges Bank cod and areas 511, 512, 513, 514, 515 for Gulf of Maine cod).

Standardized fishing effort (days fished) was derived for all interviewed trips that landed cod

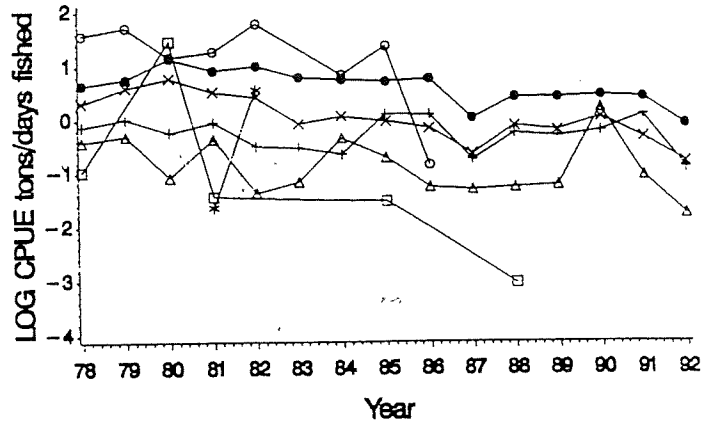
AREA 521 - Tonclass (CPUE mt/days) on Year

Diamond = T23 Star = T24 Square = T25 Triangle = T31 Plus = T32 X = T33 Dot = T41 Circle = T42



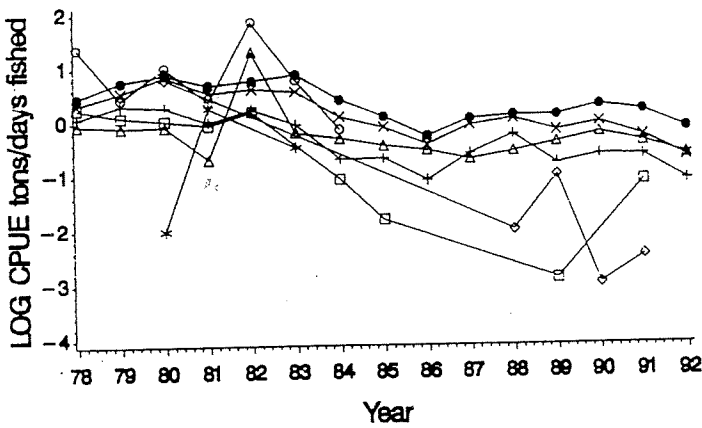
AREA 524 - Tonclass (CPUE mt/days) on Year

Diamond = T23 Star = T24 Square = T25 Triangle = T31 Plus = T32 X = T33 Dot = T41 Circle = T42



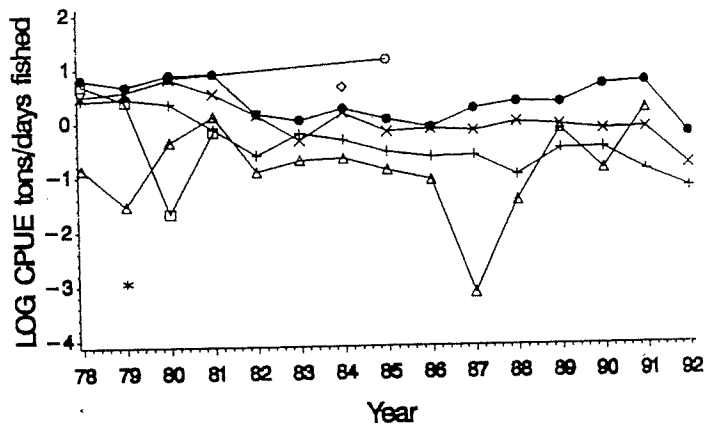
AREA 522 - Tonclass (CPUE mt/days) on Year

Diamond = T23 Star = T24 Square = T25 Triangle = T31 Plus = T32 X = T33 Dot = T41 Circle = T42



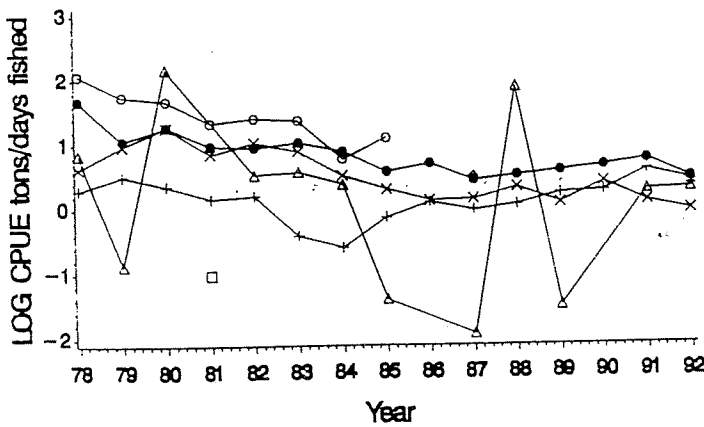
AREA 525 - Tonclass (CPUE mt/days) on Year

Diamond = T23 Star = T24 Square = T25 Triangle = T31 Plus = T32 X = T33 Dot = T41 Circle = T42



AREA 523 - Tonclass (CPUE mt/days) on Year

Diamond = T23 Star = T24 Square = T25 Triangle = T31 Plus = T32 X = T33 Dot = T41 Circle = T42



AREA 526 - Tonclass (CPUE mt/days) on Year

Diamond = T23 Star = T24 Square = T25 Triangle = T31 Plus = T32 X = T33 Dot = T41 Circle = T42

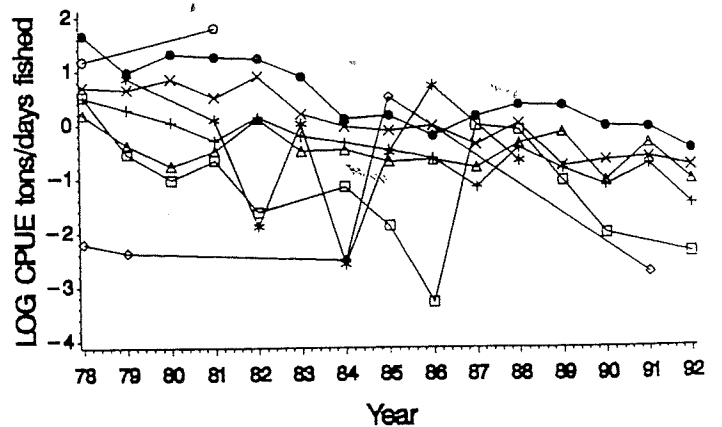


Figure 1. Trends in log_e CPUE of Georges Bank cod by vessel tonnage class, 1978-1992.

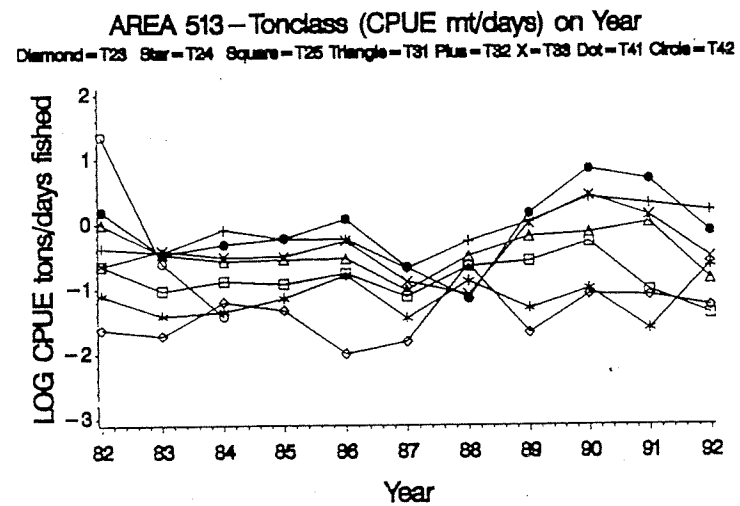
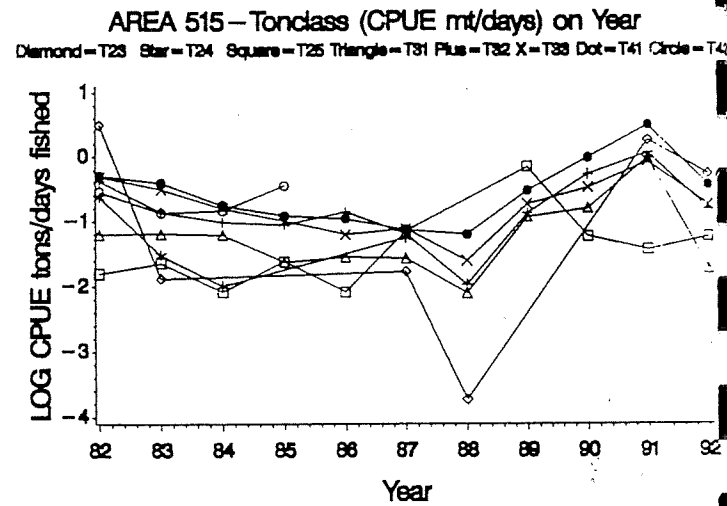
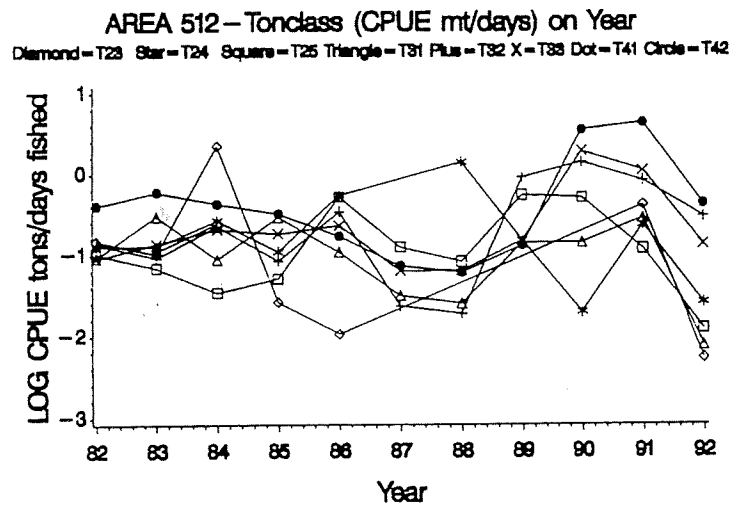
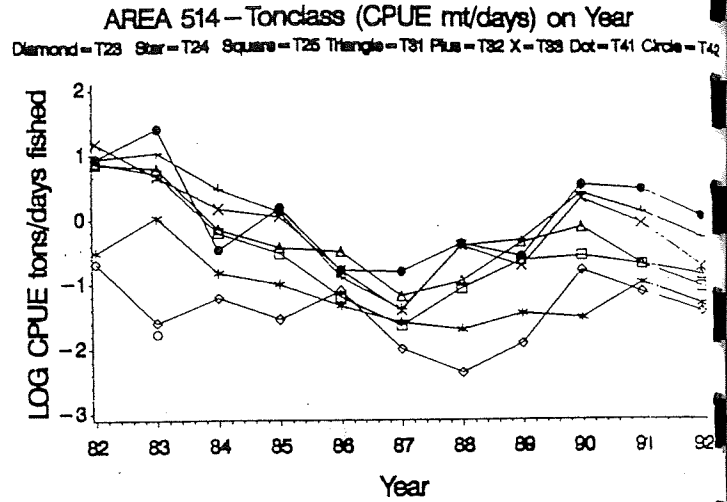
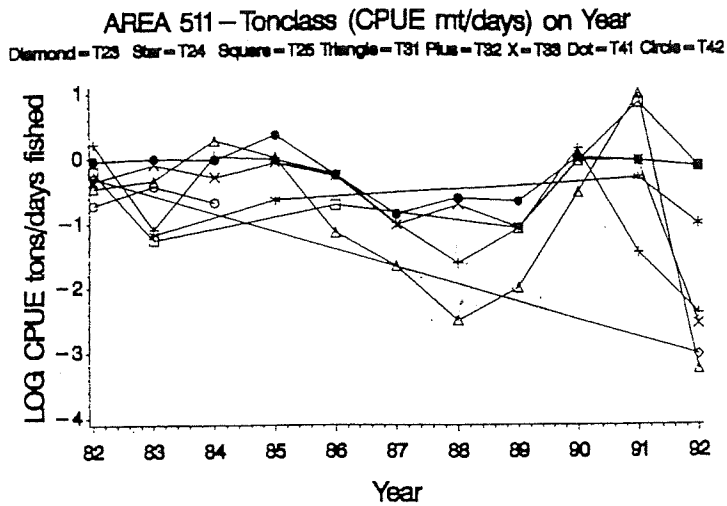


Figure 2. Trends in log_e CPUE of Gulf of Maine cod by vessel tonnage class, 1982-1992.

between 1978 and 1992. Factors incorporated in the effort standardization analyses were year, quarter, depth zone, statistical area, and tonnage class. To reduce the number of levels of each factor and to provide a more balanced statistical design, depth zones and tonnage classes appearing infrequently in the data set were either eliminated or combined. Levels within a given factor were eliminated when that level was not represented well in the levels of the other factors included in the analysis.

An example of this is shown in Figure 1 for the Georges Bank fleet, where tonnage classes 23-25 and 42 are not represented in all years in each statistical area. As such, these levels of the tonnage class factor were eliminated from further analysis. Similarly, tonnage classes 23-24 and 42 were eliminated as levels in the tonnage class factor for the Gulf of Maine cod analysis (Figure 2). Levels within a factor were combined when reasonably well represented in the levels of other factors and an initial GLM analysis (which included all levels within a factor) indicated little or no difference in the estimated parameters. The combinations resulted in three levels for the depth factor and four levels in the tonnage class factor in the Georges Bank analysis, and four levels of depth and five levels of tonnage class in the Gulf of Maine analysis.

A standard category was chosen for each factor in both Georges Bank and Gulf of Maine cod analyses. In the Georges Bank analysis, year = 1978, quarter = 2, tonnage class = 33 and statistical area = 521; in the Gulf of Maine analysis, year = 1982, quarter = 2, tonnage class = 25 and statistical area = 514.

The age composition of the landings corresponding to the effort subfleets from Georges Bank and the Gulf of Maine was estimated and used with standardized effort estimates to calculate a LPUE at age index. Landings from Georges Bank were restricted to areas 521-526, tonnage class (TC) vessels 31-33, and 41, and depth zones less than 183 m. Landings from the Gulf of Maine were restricted to areas 511-515, TC vessels 25, 31-33, and 41 in depth zones less than 274 m.

EFFORT STANDARDIZATION

Relative harvesting efficiency varies markedly among different vessel size classes, seasons, and areas. To account for these differences, we standardized nominal fishing effort using a general linear model approach (e.g. Robson 1966; Gavaris 1980; Kimura 1981, 1988) based on the

multiplicative model:

$$U_{ijklmn} = \alpha_i \beta_j \gamma_k \delta_l \rho_m (qB) \epsilon_{ijklmn}$$

where U_{ijklmn} is the CPUE for the i^{th} year, j^{th} statistical area, k^{th} quarter, l^{th} ton class, m^{th} depth, and n^{th} observation; α_i , β_j , γ_k , δ_l , and ρ_m represent year, area, quarter, tonnage class and depth effects respectively, q is the catchability coefficient, B represents mean population biomass and ϵ_{ijklmn} is a log-normally distributed random error term with mean 1.0 and constant variance. Because the population biomass is not directly known, the term qB is replaced by the mean CPUE (μ) and all coefficients are estimated relative to an arbitrarily defined standard (described previously). Least squares estimates of the model coefficients were made under the constraints:

$$\sum \log_e \alpha_i = \sum \log_e \beta_j = \sum \log_e \gamma_k = \sum \log_e \delta_l = \sum \log_e \rho_m = 0$$

for the linearized model:

$$\log_e U_{ijklmn} = \log_e \mu + \log_e \alpha_i + \log_e \beta_j + \log_e \gamma_k + \log_e \delta_l + \log_e \rho_m + \log_e \epsilon_{ijklmn}$$

In this model, the year coefficient (α_i) absorbs both changes in cod abundance and technological improvements in fleet efficiency over time. These factors could be separated in future analyses by incorporating an independent measure of abundance, such as the NEFSC bottom trawl survey index, as a covariate in the model as described by Mayo *et al.* (1992).

Retransformation of the model coefficients to linear scale was made after correction for bias following Granger and Newbold (1977). We tested for interactions among all main effects in the model, and found several interactions to be statistically significant. In each case, however, the proportion of variance explained by the interaction terms was small relative to the main effects (< 9%). Accordingly, we considered only main effects models in subsequent analyses. The large number of degrees of freedom in the model increased the probability of detecting significant interactions, but the practical significance of these interactions seems to be minor.

Standardized effort for each area-quarter-tonnage class-depth category was estimated by multiplying the sum of the nominal effort for that cell by the product of the retransformed GLM coefficients for each factor. The estimated standardized effort was then accumulated over all categories to provide annual estimates.

LANDINGS AT AGE ESTIMATES

Numbers landed at age were estimated by applying quarterly commercial age-length keys to the quarterly commercial numbers landed at length by market category using NEFSC BIostat software. Market category samples were combined to three categories: small, medium, and large. Length frequency samples were reviewed, mis-coded market category samples were re-coded and very small sublegal size fish that appeared to be mis-coded were eliminated from the analyses. Age-length samples were also reviewed and perceived outliers were either moved within the age-key or eliminated from the key.

RESULTS

EFFORT STANDARDIZATION

Results from the GLM analysis for the Georges Bank and Gulf of Maine cod stocks are given in Tables 1-2 and 3-4, respectively. In both analyses, the five-factor model accounted for approximately 22 to 26% of the total sums of squares. For each data set, year, area, tonnage class, quarter, and depth effects were highly significant ($P < 0.01$). In general, the contribution of the interaction terms to the model sums of squares was minimal. Coefficients for the area, quarter, tonnage class, and depth effects, retransformed and converted to linear scale, are given in Tables 1 and 3. Relative to the chosen standard statistical area (521), cod catch rates on Georges Bank are lower in all other areas; but in general, rates are approximately twice as great on Northern Georges Bank (SA 521-523) (Table 1). Such a pronounced difference in standardized cod catch rates by area is not as apparent in the Gulf of Maine, where area coefficients are nearly equal (Table 3). Tonnage class coefficients for both Georges Bank and Gulf of Maine analyses generally increase with vessel size. Vessel classes 33 and 41 exhibit an almost twofold increase in fishing power over those smaller vessels on Georges Bank, while in the Gulf of Maine vessel classes 33 and 41 exhibit two to four times greater fishing power. Standardized cod catch rates were higher in shallower depths and in the first two quarters of the year for the Georges Bank and Gulf of Maine analyses.

Because effort standardization procedures differed here from those used in earlier cod assessments, we compared our standardized effort

series with those of Serchuk *et al.* (1993) for the Georges Bank cod stock (Figure 3) and Mayo *et al.* (1993) for the Gulf of Maine cod stock (Figure 4). These authors computed U. S. fishing effort for the Georges Bank and Gulf of Maine cod stocks in two different ways: 1) from an average LPUE across tonnage classes weighted by tonnage class landings termed 'calculated', and 2) from a five-factor GLM in which year coefficients were used to adjust nominal effort relative to a standard year termed 'standardized'. The standardized subfleet effort derived from our present analysis differed from the earlier series in that, although year was included in the model as a factor, the year coefficients themselves were not used explicitly as a multiplier with the other factor's coefficients, nor were subsequent years adjusted relative to the base year. We then computed annual U. S. fishing effort for each stock by raising the estimated subfleet effort by the ratio of subfleet landings to total U. S. landings in each year (Tables 2 and 4). On Georges Bank, the effort subfleet generally accounted for about 50 to 60% of the total U. S. landings whereas in the Gulf of Maine, the subfleet often accounted for only 25 to 30% of the total U. S. landings. This is due, in part, to the large amount of gillnet catch in this area.

Effort trends in each of the series were similar for both the Georges Bank and Gulf of Maine cod stocks. On Georges Bank (Figure 3), total U. S. standardized effort has increased almost continuously since 1978, whereas the subfleet effort declined after 1988. This decline in the subfleet effort is the likely result of a lower proportion of trips being included in the subfleet analysis in recent years. Hence, our raised standardized effort series provides a more complete view of trends in actual fishing effort. Our standardized effort series suggests that the 'calculated' effort of Serchuk *et al.* (1993) provided a more consistent indicator of overall effort than that given by their 'standardized' effort series.

The various effort series for the Gulf of Maine cod stock appear to be more consistent than those for Georges Bank, although the subfleet effort is considerably less than the total effort estimated by each of the previous methods (Figure 4). The 'calculated' and 'standardized' effort series computed by Mayo *et al.* (1993) are consistent with the trends indicated by our standardized effort estimates. Each series indicates a peak in effort in 1987, followed by a decline. The raised standardized effort increases again after 1990 while the 'standardized' series computed by Mayo *et al.* (1993) indicated an increase after 1989.

Table 1. Georges Bank cod GLM effort standardization.

SAS General Linear Models Procedure

Dependent Variable: LNCPUEDF

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	27	28516.42490940	1056.16388553	675.36	0.0001
Error	52179	81599.90019330	1.56384561		
Corrected Total	52206	110116.32510271			

	R-Square	C.V.	Root MSE	LNCPUEDF Mean
	0.258966	-646.8736	1.25053813	-0.19332033

Source	DF	Type I SS	Mean Square	F Value	Pr > F
YEAR	14	10439.97027882	745.71216277	476.85	0.0001
AREA	5	5174.90711295	1034.98142259	661.82	0.0001
QTR	3	3745.70569133	1248.56856378	798.40	0.0001
TONCLASS	3	5672.12786313	1890.70928771	1209.01	0.0001
DEPTHCD	2	3483.71396317	1741.85698159	1113.83	0.0001

Source	DF	Type III SS	Mean Square	F Value	Pr > F
YEAR	14	13140.20128030	938.58580574	600.18	0.0001
AREA	5	7474.17955441	1494.83591088	955.87	0.0001
QTR	3	2875.21677184	958.40559061	612.85	0.0001
TONCLASS	3	5933.08867445	1977.69622482	1264.64	0.0001
DEPTHCD	2	3483.71396317	1741.85698159	1113.83	0.0001

Parameter	Estimate	T for H0: Parameter=0	Pr > T	Std Error of Estimate	Retransformed Estimate
INTERCEPT	0.724000592	B 25.20	0.0001	0.02872607	
AREA	522 -0.445165897	B -28.67	0.0001	0.01552672	0.640795
	523 -0.018132063	B -0.86	0.3872	0.02097022	0.982247
	524 -0.744920018	B -40.73	0.0001	0.01828704	0.474852
	525 -0.857301608	B -36.51	0.0001	0.02348380	0.424422
	526 -1.204446759	B -59.93	0.0001	0.02009898	0.299918
	521 0.000000000	B			1.000000
QTR	1 -0.059039765	B -3.88	0.0001	0.01522176	0.942778
	3 -0.596095117	B -38.64	0.0001	0.01542695	0.551024
	4 -0.434279166	B -26.84	0.0001	0.01617803	0.647816
	2 0.000000000	B			1.000000
TONCLASS	31 -0.783352144	B -31.65	0.0001	0.02474775	0.457012
	32 -0.543263442	B -33.55	0.0001	0.01619049	0.580926
	41 0.417412098	B 31.34	0.0001	0.01331944	1.518163
	33 0.000000000	B			1.000000
DEPTHCD	1 0.729218401	B 46.49	0.0001	0.01568675	2.073714
	2 0.375635575	B 24.34	0.0001	0.01543178	1.459090
	3 0.000000000	B			1.000000

Table 2. Nominal and standardized (GLM) Georges Bank cod landings (metric tons), effort (days fished) and landings per day fished (LPUE).

Year	USA Landings (mt)		Nominal		Standardized		
	Total	Subfleet	Effort	LPUE	Effort	LPUE	Raised Effort
1978	26579	15776	8078	1.953	5982	2.637	10079
1979	32645	20584	9547	2.156	7788	2.643	12394
1980	40053	25213	10217	2.468	8600	2.932	13661
1981	33849	18340	9149	2.005	8113	2.260	14977
1982	39333	23292	10051	2.317	8859	2.629	14961
1983	36756	22072	11668	1.892	10456	2.111	17412
1984	32915	19669	14641	1.343	12495	1.574	20912
1985	26828	18012	16447	1.095	14892	1.209	22190
1986	17490	11572	12520	0.924	11834	0.978	17883
1987	19035	12731	14945	0.852	13791	0.923	20622
1988	26310	19010	17769	1.070	16911	1.124	23407
1989	25097	15557	15834	0.983	15407	1.010	24849
1990	28193	18358	15882	1.156	14836	1.237	22791
1991	24175	14173	14857	0.954	14917	0.950	25447
1992	16855	8786	13606	0.646	12845	0.684	24642

Table 3. Gulf of Maine cod GLM effort standardization.

SAS General Linear Models Procedure						
Dependent Variable: LNCPUEDF						
Source	DF	Sum of Squares	Mean Square	F Value	Pr > F	
Model	24	10042.42776453	418.43449019	271.01	0.0001	
Error	22417	34610.87206235	1.54395646			
Corrected Total	22441	44653.29982688				
	R-Square	C.V.	Root MSE	LNCPUEDF Mean		
	0.224898	-116.8327	1.24256045	-1.06353847		
Source	DF	Type I SS	Mean Square	F Value	Pr > F	
YEAR	10	4172.47634712	417.24763471	270.25	0.0001	
AREA	4	213.43028101	53.35757025	34.56	0.0001	
QTR	3	1091.33076950	363.77692317	235.61	0.0001	
TONCLASS	4	2804.09441832	701.02360458	454.04	0.0001	
DEPTHCD	3	1761.09594858	587.03198286	380.21	0.0001	
Source	DF	Type I II SS	Mean Square	F Value	Pr > F	
YEAR	10	3864.47552921	386.44755292	250.30	0.0001	
AREA	4	337.52113256	84.38028314	54.65	0.0001	
QTR	3	1077.53586173	359.17862058	232.64	0.0001	
TONCLASS	4	3365.93344569	841.48336142	545.02	0.0001	
DEPTHCD	3	1761.09594858	587.03198286	380.21	0.0001	
PParameter		Estimate	T for H0: Parameter=0	Pr > T	Std Error of Estimate	Retransformed Estimate
INTERCEPT		-0.966438423	B -22.51	0.0001	0.04293803	
AREA	511	0.352862172	B 6.04	0.0001	0.05840734	1.425565
	512	0.093390087	B 2.64	0.0083	0.03535865	1.098576
	513	0.282590501	B 11.13	0.0001	0.02540134	1.326990
	515	-0.026414709	B -0.84	0.4026	0.03155861	0.974416
	514	0.000000000	B			1.000000
QTR	1	-0.450275482	B -17.99	0.0001	0.02503570	0.637652
	3	-0.555648751	B -23.76	0.0001	0.02338944	0.573857
	4	-0.471084150	B -20.69	0.0001	0.02276910	0.624487
	2	0.000000000	B			1.000000
TONCLASS	31	0.470024146	B 18.66	0.0001	0.02519506	1.600541
	32	0.854568967	B 33.24	0.0001	0.02571061	2.351138
	33	0.896470299	B 32.09	0.0001	0.02793882	2.451894
	41	1.301746565	B 43.24	0.0001	0.03010851	3.677377
	25	0.000000000	B			1.000000
DEPTHCD	1	0.593978838	B 18.13	0.0001	0.03275947	1.812153
	2	0.324741394	B 12.86	0.0001	0.02525790	1.384114
	4	-0.636948746	B -24.01	0.0001	0.02652370	0.529090
	3	0.000000000	B			1.000000

Table 4. Nominal and standardized (GLM) Gulf of Maine cod landings (metric tons), effort (days fished) and landings per day fished (LPUE)

Year	U. S. Landings (metric tons)		Nominal		Standardized		
	Total	Subfleet	Effort	LPUE	Effort	LPUE	Raised Effort
1982	13582	3395	3158	1.075	4953	0.686	19799
1983	13981	3698	3791	0.975	5782	0.640	21845
1984	10806	2423	3798	0.638	5495	0.441	24503
1985	10693	3012	5294	0.569	8489	0.355	30121
1986	9664	2794	5568	0.502	8745	0.320	30200
1987	7527	1708	5100	0.335	7836	0.218	34528
1988	7958	2060	4753	0.433	7994	0.258	30845
1989	10397	2316	3524	0.657	6125	0.378	27505
1990	15154	4916	4053	1.213	7663	0.641	23641
1991	17781	5432	4737	1.147	8829	0.615	28912
1992	10891	2777	4978	0.558	8003	0.347	31386

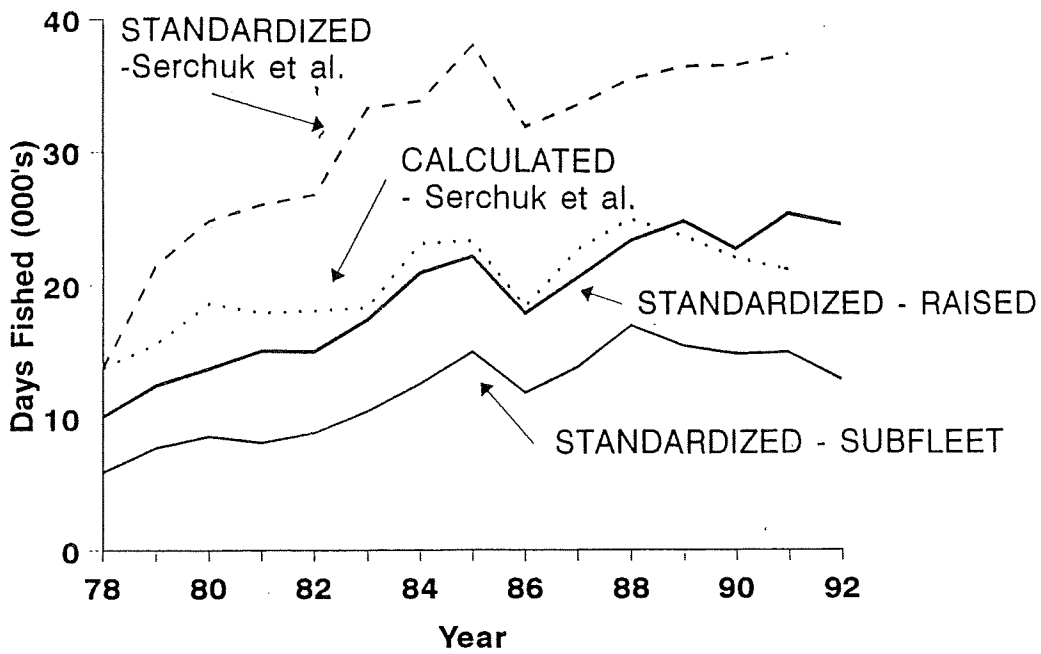


Figure 3. Fishing effort estimated for Georges Bank cod from Serchuk *et al.* (1993) and from the GLM standardization procedure, 1978-1992.

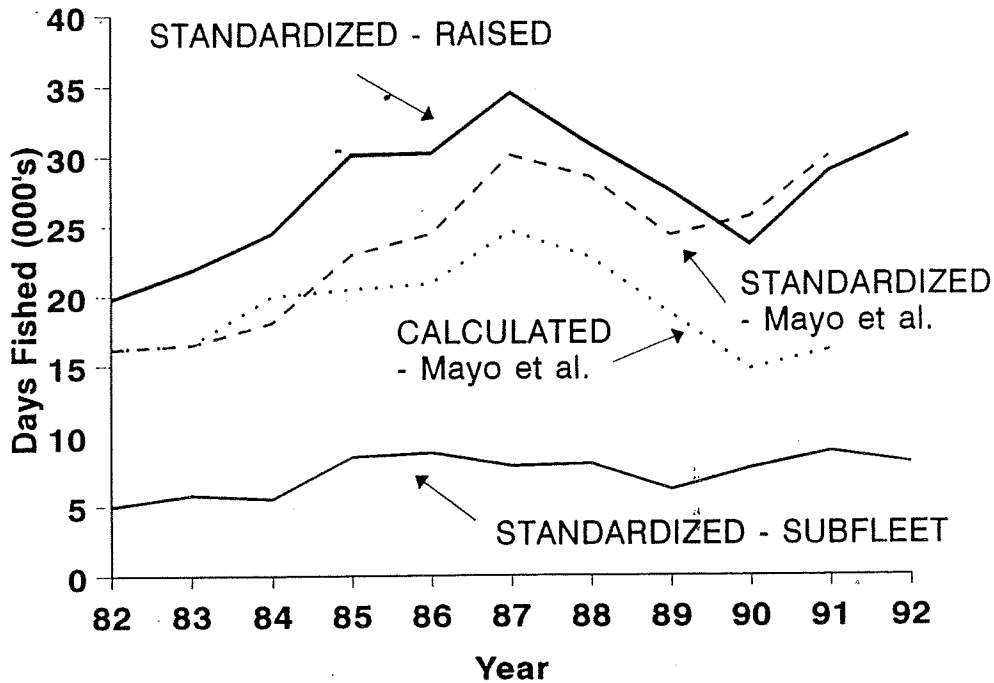


Figure 4. Fishing effort estimated for Gulf of Maine cod from Mayo *et al.* (1993) and from the GLM standardization procedure, 1982-1992.

We also compared our LPUE series with those obtained by Serchuk *et al.* (1993) and Mayo *et al.* (1993) for the Georges Bank and Gulf of Maine cod stock, respectively. Our standardized LPUE, computed by dividing the standardized effort series into landings, was quite similar to the 'calculated' LPUE obtained by Serchuk *et al.* (1993) for the Georges Bank cod stock (Figure 5),

except in the earlier years when our standardized LPUE index peaks more distinctly. However, the sharp decline in the Serchuk *et al.* 'standardized' LPUE compared to their 'calculated' LPUE and our standardized LPUE explains the large difference in total effort estimated by this index (Figure 3). Although Serchuk *et al.* (1993) conclude that their 'calculated' series may be underestimating

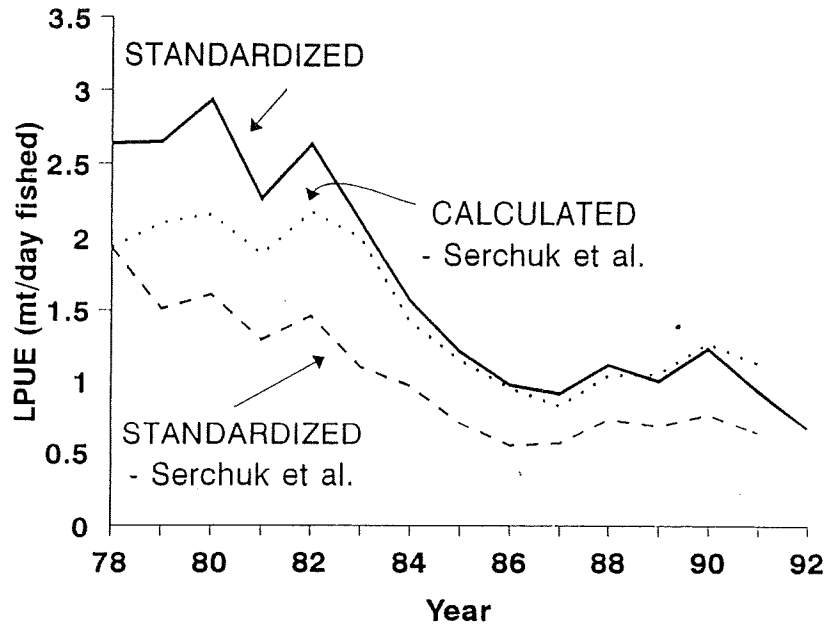


Figure 5. Landings per unit effort (LPUE) estimated for Georges Bank cod from Serchuk *et al.* (1993) and from the GLM standardization procedure, 1978-1992.

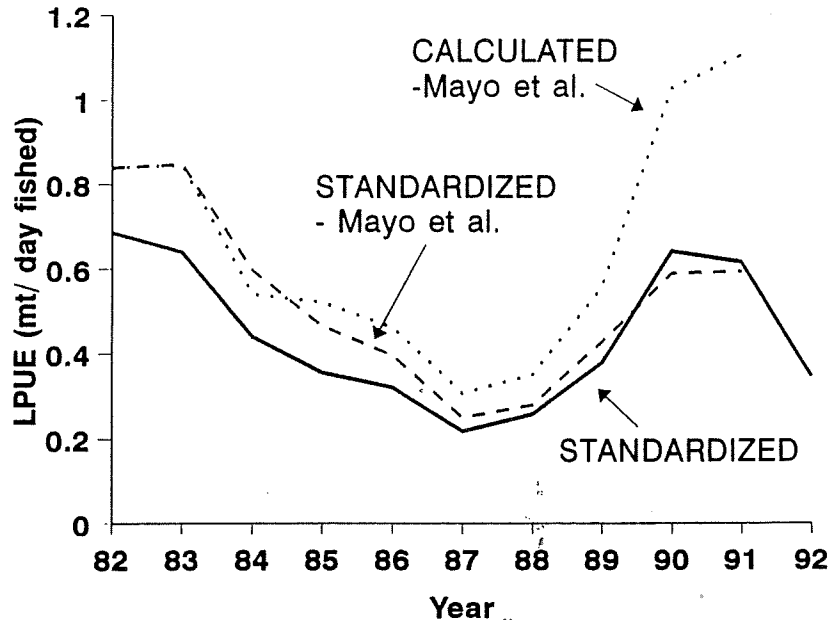


Figure 6. Landings per unit effort (LPUE) estimated for Gulf of Maine cod from Mayo *et al.* (1993) and from the GLM standardization procedure, 1982-1992.

effort due to recent changes in fleet directivity, our standardized series suggests that the sharp decline in the year effect in their model may have been influenced by factors not considered explicitly, resulting in an overestimate of fishing effort throughout most of the 1978-1991 period.

In the Gulf of Maine, each of the LPUE series was quite similar except for the sharp increase in

the 'calculated' LPUE after 1989 (Figure 6). This trend is inconsistent with the standardized indices given in the present study and those computed by Mayo *et al.* (1993). This rather large increase accounts for the relatively low estimates of total 'calculated' effort in the most recent years (Figure 4). Further, Mayo *et al.* (1993) noted that a substantial increase in 1991 effort compared to

Table 5. Landings at age of Georges Bank cod (thousands of fish, metric tons) and mean weight (kilograms) at age for the otter trawl subfleet, ages 2 -9+, 1978-1992

Year	Age								Total
	2	3	4	5	6	7	8	9+	
	Number (000s)								
1978	210	3530	1038	402	21	99	10	15	5325
1979	1748	391	2479	523	197	37	158	18	5551
1980	2508	3291	201	899	602	261	30	81	7873
1981	1704	2193	1161	95	377	177	51	54	5812
1982	5524	1552	965	669	60	237	56	50	9113
1983	2404	3512	720	493	379	41	105	100	7754
1984	921	2050	1772	292	241	225	16	131	5648
1985	3525	1228	610	844	162	92	97	58	6616
1986	765	2311	284	204	259	34	32	37	3926
1987	3591	624	868	109	106	96	25	25	5444
1988	1045	4051	648	787	125	70	57	30	6813
1989	1342	1876	2014	138	217	28	9	9	5633
1990	3621	2342	814	883	77	76	15	7	7835
1991	756	1641	1260	511	348	26	12	5	4559
1992	1577	725	343	459	109	76	5	9	3303
	Metric Tons								
1978	281	8705	3949	1807	95	687	64	186	15774
1979	3040	926	10506	2462	1454	332	1624	220	20565
1980	3830	7981	810	4929	4094	2054	327	1073	25098
1981	2648	5042	3794	610	2576	1496	525	836	17527
1982	7855	4212	3470	3564	412	2239	619	723	23094
1983	3572	8531	2415	2204	2339	318	1122	1433	21934
1984	1437	4815	6195	1487	1601	1949	153	1655	19293
1985	4977	2516	2389	4214	996	724	997	749	17563
1986	1122	5271	941	1101	1862	308	331	488	11424
1987	5092	1444	3370	592	804	820	236	304	12661
1988	1613	9362	1820	4000	801	534	493	357	18980
1989	2260	4210	6880	681	1438	244	86	99	15887
1990	5460	4967	2598	3984	450	614	153	70	18297
1991	1172	3971	4118	2423	2059	187	132	80	14141
1992	2427	1648	1193	2065	667	594	50	89	8733
	Mean Weight (kilograms)								
1978	1.338	2.466	3.804	4.496	4.530	6.936	6.366	12.421	
1979	1.739	2.369	4.238	4.708	7.383	8.969	10.281	12.222	
1980	1.527	2.425	4.031	5.483	6.801	7.869	10.897	13.247	
1981	1.554	2.299	3.268	6.416	6.834	8.453	10.301	15.481	
1982	1.422	2.714	3.596	5.327	6.863	9.447	11.054	14.460	
1983	1.486	2.429	3.354	4.471	6.171	7.755	10.685	14.330	
1984	1.560	2.349	3.496	5.091	6.644	8.663	9.592	12.634	
1985	1.412	2.049	3.917	4.993	6.151	7.866	10.274	12.914	
1986	1.467	2.281	3.314	5.396	7.188	9.064	10.339	13.189	
1987	1.418	2.314	3.882	5.435	7.582	8.536	9.444	12.160	
1988	1.544	2.311	2.809	5.082	6.406	7.629	8.643	11.900	
1989	1.684	2.244	3.411	4.934	6.628	8.714	9.532	11.000	
1990	1.508	2.121	3.192	4.512	5.844	8.079	10.200	10.000	
1991	1.550	2.420	3.268	4.741	5.916	7.202	10.971	16.000	
1992	1.539	2.273	3.478	4.498	6.115	7.822	10.084	9.889	

Table 6. Landings at age of Gulf of Maine cod (thousands of fish, metric tons) and mean weight (kilograms) at age for the otter trawl subfleet, ages 2-9+, 1982-1992

Year	Age								Total
	2	3	4	5	6	7	8	9+	
	Number (thousands)								
1982	449	446	272	131	16	20	15	20	1369
1983	337	777	298	148	87	6	17	8	1678
1984	222	300	296	79	37	21	4	12	971
1985	137	422	289	179	36	20	9	6	1098
1986	42	707	232	68	44	9	7	10	1119
1987	71	179	250	55	17	10	2	5	589
1988	139	470	231	89	14	3	3	1	950
1989	125	469	292	78	17	12	1	4	998
1990	99	1439	705	110	46	5	6	9	2419
1991	197	410	1374	220	40	11	6	2	2260
1992	144	167	133	496	50	14	1	4	1009
	Metric Tons								
1982	538	750	753	617	107	177	149	293	3383
1983	398	1225	692	527	503	37	174	124	3680
1984	237	509	771	276	220	185	37	163	2399
1985	170	714	791	773	195	158	95	100	2996
1986	52	1229	651	300	267	67	74	122	2764
1987	93	291	783	259	110	91	20	60	1705
1988	154	797	515	456	64	26	33	15	2059
1989	162	777	817	327	94	105	11	65	2358
1990	118	2230	1463	456	355	60	73	153	4908
1991	224	573	3221	879	288	109	75	48	5416
1992	211	302	336	1495	258	135	15	45	2798
	Mean Weight (kilograms)								
1982	1.198	1.681	2.767	4.710	6.698	8.835	9.955	14.650	
1983	1.181	1.576	2.322	3.561	5.783	6.210	10.256	15.500	
1984	1.069	1.697	2.604	3.500	5.935	8.831	9.351	13.583	
1985	1.244	1.692	2.737	4.319	5.422	7.903	10.521	16.667	
1986	1.245	1.739	2.808	4.416	6.063	7.487	10.605	12.200	
1987	1.304	1.623	3.131	4.702	6.485	9.075	9.756	12.000	
1988	1.110	1.696	2.228	5.118	4.559	8.708	10.889	14.638	
1989	1.298	1.657	2.799	4.187	5.504	8.771	11.085	16.250	
1990	1.192	1.550	2.075	4.146	7.717	12.000	12.167	17.000	
1991	1.139	1.397	2.344	3.995	7.191	9.873	12.474	24.000	
1992	1.468	1.806	2.530	3.014	5.161	9.652	14.952	11.250	

1990 was consistent with changes in estimated fishing mortality during that period, suggesting that both standardized effort series best reflect conditions in the fishery.

LANDINGS AT AGE ESTIMATES

The effort subfleet landings at age and mean weight at age matrices with sum of products for Georges Bank and Gulf of Maine cod are listed in Tables 5 and 6, respectively. The full landings at age matrices for each stock are listed in Tables 7 and 8, respectively. Percentage age composition of the landings (ages 2-9+) from each stock for the

full and subfleet components are presented in Figures 7 and 8. Although differences in percentage age composition between the full landings at age and the otter trawl effort subfleet do not appear to be substantial for either stock, younger cod, particularly at age 2, appear in higher proportions in the otter trawl effort subfleet. Differences in seasonal weighting of the quarterly age composition estimates are likely to have occurred when the fixed gear landings were eliminated from the subfleet data set. Despite these differences, the overall similarity between the two sets of age compositions implies that gill net and other gear are selecting age classes in similar proportions as the otter trawl gear. Therefore,

Table 7. Total commercial landings at age of Atlantic cod (thousands of fish) from Georges Bank and South, ages 1-10+, 1978-1992

Year	Age									
	1	2	3	4	5	6	7	8	9	10+
1978	2	393	7748	2303	830	131	345	47	40	15
1979	34	1989	900	4870	1212	458	77	253	4	48
1980	89	3777	5828	500	2308	1076	445	87	167	10
1981	27	3205	4221	2464	235	1406	417	123	130	62
1982	331	9138	3824	2787	2000	281	673	213	71	83
1983	108	4286	8063	2456	1055	776	95	235	100	65
1984	81	1307	3423	3336	840	516	458	44	171	121
1985	134	6426	2443	1368	1885	412	218	203	21	97
1986	156	1326	4573	797	480	627	87	72	47	29
1987	26	7473	1406	2121	279	252	270	63	38	24
1988	10	1577	8022	1012	1497	244	161	197	50	47
1989	0	2088	2922	4155	331	541	82	43	50	18
1990	7	4942	5042	1882	2264	229	245	36	17	38
1991	52	1525	3243	3281	1458	1088	126	70	23	23
1992	70	4177	2170	1038	1482	404	309	34	33	10

Table 8. Total commercial landings at age of Atlantic cod (thousands of fish) from the Gulf of Maine, ages 2-10+, 1982-1992

Year	Age								
	2	3	4	5	6	7	8	9	10+
1982	1380	1633	1143	633	69	91	61	41	37
1983	866	2357	1058	638	422	47	61	23	24
1984	446	1240	1500	437	194	74	19	15	28
1985	407	1445	991	630	128	78	32	4	22
1986	84	2164	813	250	177	39	24	20	12
1987	216	595	1109	277	66	51	9	8	11
1988	160	1443	953	406	43	9	17	1	3
1989	337	1583	1454	449	81	35	6	3	12
1990	205	3425	2064	430	157	27	30	10	32
1991	344	934	4161	851	143	41	30	6	2
1992	313	530	484	2018	202	62	7	12	3

both the full and the subfleet landings at age are representative of the fishery, and either matrix is applicable for calibrating the VPA.

DISCUSSION

Inclusion of the year effect in the GLM effort standardization models accounts for changes in cod abundance over time but does not allow separation of the confounding effect of increasing efficiency due to improvements in technology. Inclusion of an independent measure of stock abundance as a covariate in the GLM as illustrated by Mayo *et al.* (1992) would allow for such an adjustment. The impact of the covariate on the resulting standardized LPUE indices may be

inferred by comparison of trends in abundance as illustrated by the commercial LPUE and the NEFSC bottom trawl survey weight per tow indices; i.e., the greater the divergence between trends, the greater the adjustment to the standardized LPUE. These comparisons are provided in Figures 9 and 10.

On Georges Bank, there appears to be reasonable correspondence between the two series suggesting that there would be no appreciable impact of including the index as a covariate in the GLM. In the Gulf of Maine, however, agreement between the two series, while quite good between 1982 and 1988, deteriorates in the last four years. This period corresponds to the recruitment and rapid decline of the very large 1987 year class, particularly as it became fully recruited in

Full vs. Tuning Subset

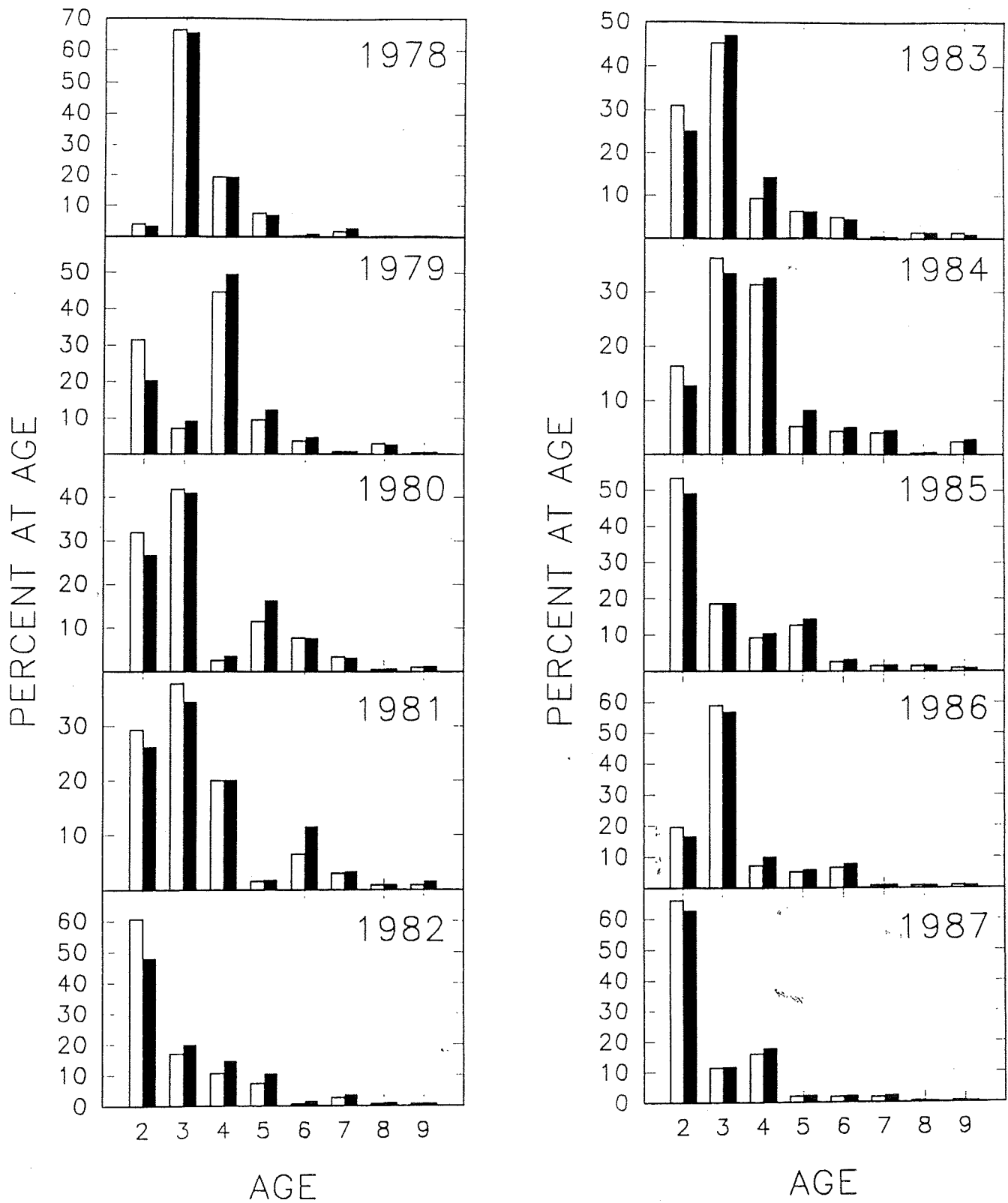




Figure 7. Percent age composition of Georges Bank cod from the full landings at age matrix and the effort subfleet landings at age matrix for ages 2-9+, 1978-1992.

Full  vs. Tuning Subset 

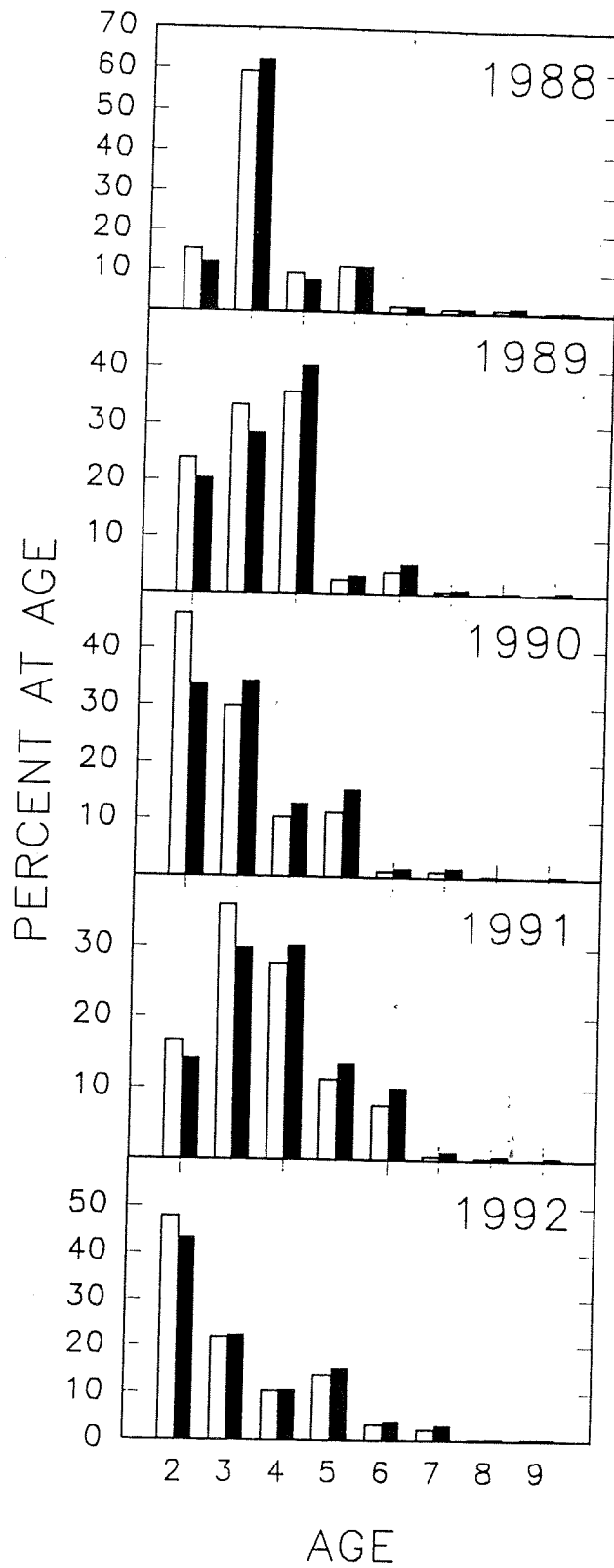


Figure 7. Continued.

Full vs. Tuning Subset

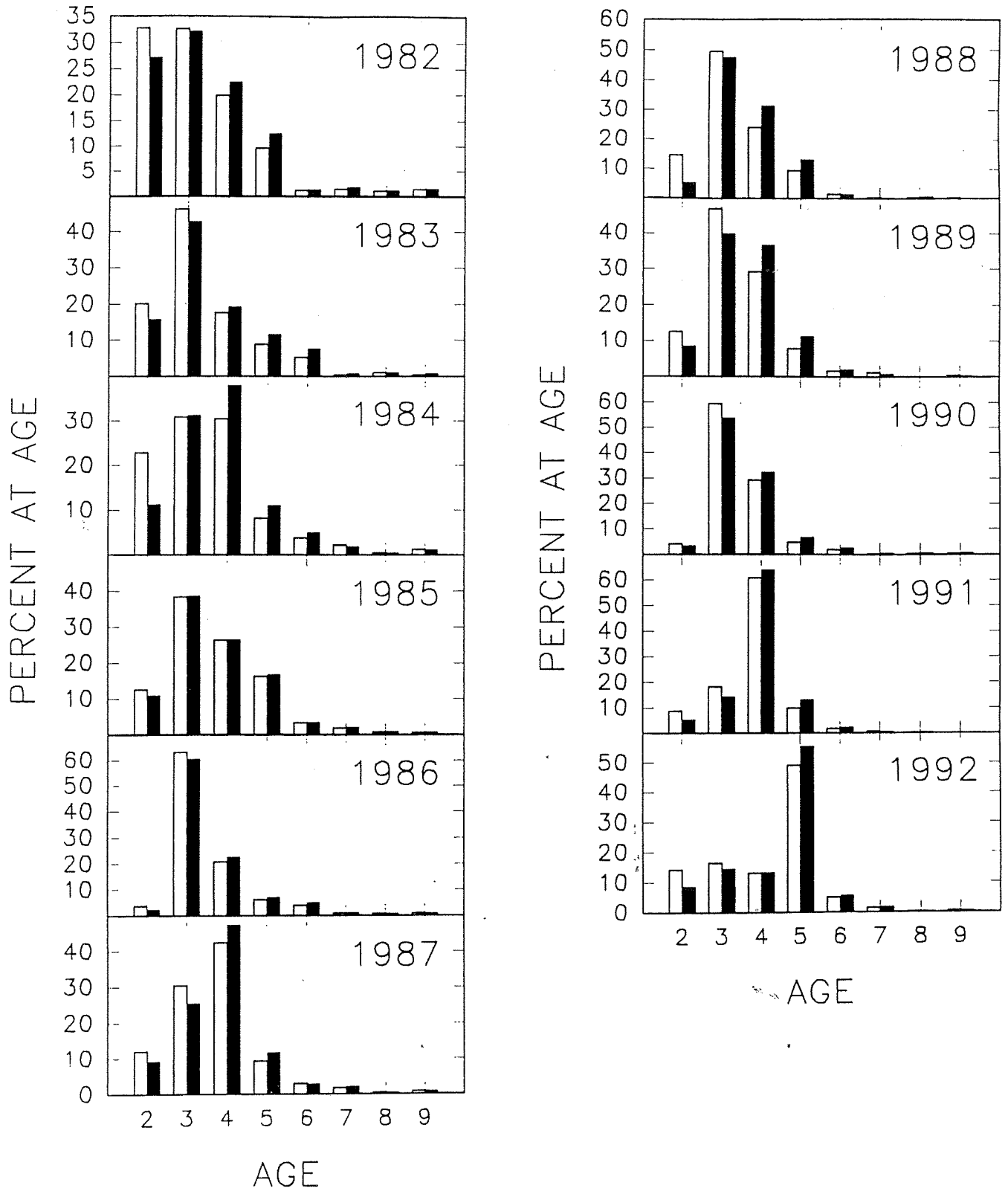


Figure 8. Percent age composition of Gulf of Maine cod from the full landings at age matrix and the effort subfleet landings at age matrix for ages 2-9+, 1982-1992.

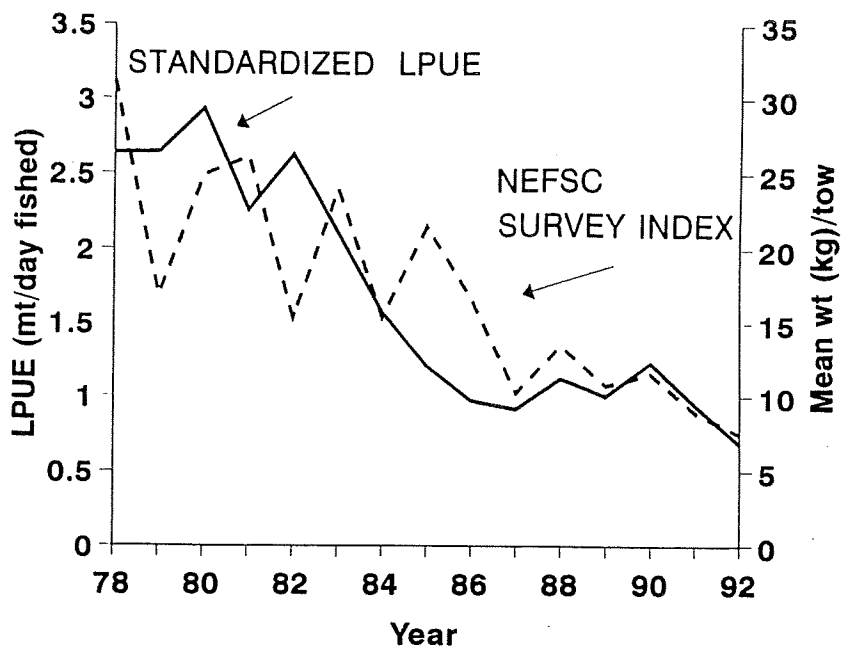


Figure 9. Trends in commercial standardized LPUE and NEFSC research vessel spring bottom trawl survey biomass index (mean weight per tow) for Georges Bank cod, 1978-1992.

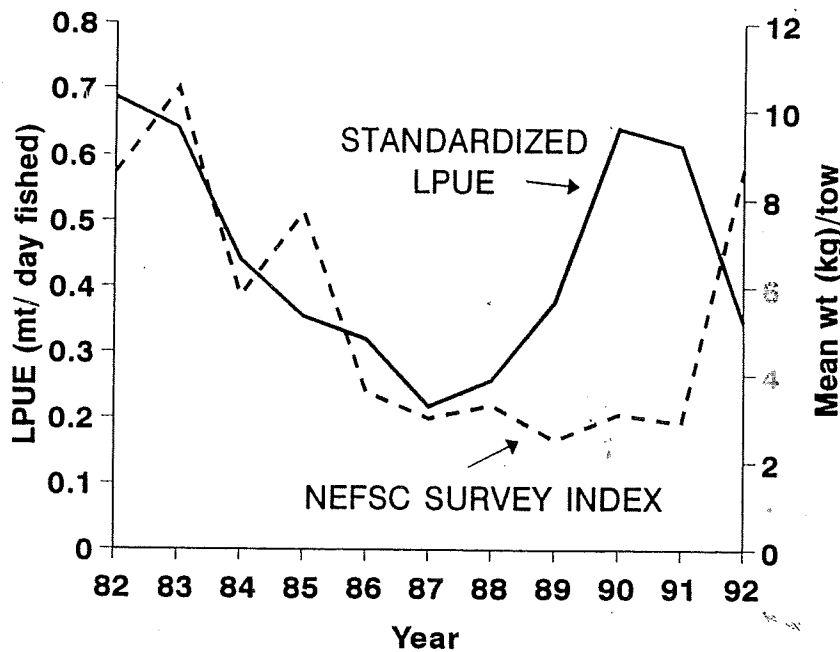


Figure 10. Trends in commercial standardized LPUE and NEFSC research vessel spring bottom trawl survey biomass index (mean weight per tow) for Gulf of Maine cod, 1982-1992.

1991. The discrepancy between LPUE and the survey index suggests a substantial increase in the degree of directivity in the Gulf of Maine cod fishery during 1989-1991 as the 1987 year class was targeted. The disparity evident in 1992 resulted from an increase in the mean weight of 1987 year class cod as they continued to dominate the survey catches. The overall result of this comparison indicates that LPUE may have overestimated abundance due to changes in directivity and that fishing effort was higher during 1989-1991 than indicated by the model.

REFERENCES

- Gavaris, S. 1980. Use of a multiplicative model to estimate catch rate and effort from commercial data. *Can. J. Fish. Aquat. Sci.* 37:2272-2275.
- Granger, C. W., and P. Newbold. 1977. Forecasting economic time series. New York: Academic Press.
- Kimura, D. K. 1981. Standardized measures of relative abundance based on modelling log (c.p.u.e), and their application to Pacific ocean perch. *ICES J. Cons.* 39:211-218.
- Kimura, D. K. 1988. Analyzing relative abundance indices with log-linear models. *No. Am. J. Fish. Manage.* 8:175-180.
- Mayo, R. K., M. J. Fogarty, and F. M. Serchuk. 1992. Aggregate fish biomass and yield on Georges Bank, 1960-87. *J. Northw. Atl. Fish. Sci.* 14:59-78.
- Mayo, R. K., L. O'Brien, and F. M. Serchuk. 1993. Assessment of the Gulf of Maine cod stock for 1992. Woods Hole, MA: NOAA/NMFS/NEFSC. *Center Ref. Doc.* 93-04.
- NEFSC [Northeast Fisheries Science Center]. 1993. Report of the 15th Northeast Regional Stock Assessment Workshop (15th SAW): Stock Assessment Review Committee (SARC) Consensus Summary of Assessments. Woods Hole, MA: NOAA/NMFS/NEFSC. *Center Ref. Doc.* 93-06.
- Robson, D. S. 1966. Estimation of the relative power of individual ships. *ICNAF Res. Bull.* 3:5-14.
- Serchuk, F. M., L. O'Brien, R. K. Mayo, and S. E. Wigley. 1993. Assessment of the Georges Bank cod stock for 1992. Woods Hole, MA: NOAA/NMFS/NEFSC. *Center Ref. Doc.* 93-05.

