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A Report of the 22nd Northeast Regional Stock Assessment Workshop

Length-Cohort Analyses of U.S. American Lobster Stocks

by

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This report is a product of the 22nd Northeast Regional Stock Assessment Workshop (22nd SAW). Proceedings and products of the 22nd SAW are scheduled to be documented and released as issues of the *Northeast Fisheries Science Center Reference Document* series. Tentative titles for the 22nd SAW are:

Estimation of catch and description of sampling programs for American lobster in the U.S. Northwest Atlantic

Length-cohort analyses of U.S. American lobster stocks

Report of the 22nd Northeast Regional Stock Assessment Workshop (22nd SAW): Public Review Workshop

Report of the 22nd Northeast Regional Stock Assessment Workshop (22nd SAW): Stock Assessment Review Committee (SARC) consensus summary of assessments

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INTRODUCTION

The Steering Committee of the 22nd SAW provided terms of reference for the current lobster stock assessment which included estimating abundance and mortality rates and addressing recommendations of the Lobster Review Panel regarding assessment techniques. The Lobster Review Panel concluded that work on length-cohort analysis (LCA)"should continue in order to evaluate its utility and accuracy; to facilitate a rigorous comparison with the DeLury results; and to develop a long term historical analysis of how fishing mortality on American lobster has changed in relation to changes in fishing effort" (ASMFC 1996).

LCA was developed by Jones (1974, 1981) to estimate abundance and mortality from size distribution of landings. LCA is a modification of Pope's (1972) cohort analysis, which assumes that abundance at the end of year i can be estimated by initial abundance (N_i), a half-year of natural mortality (M), catch (C) at mid-year, and natural mortality for the remainder of the year:

$$(N_i\, e^{-0.5M} - C_i)\, e^{-0.5M} = N_{i+1}$$

A sequence of cohort abundance over several ages can provide estimates of instantaneous fishing mortality (F). The equation can be rearranged to begin the sequence with the oldest age in the catch record and work backward toward the youngest age, which is the most common and advantageous direction of sequential population analysis:

$$C_i\, e^{0.5M} + N_{i+1}\, e^{M} = N_i$$

Jones (1974) modified Pope's catch equation from an annual model, which tracked abundance from year i to year i+1, to a sequential model with variable-length time intervals, which tracked abundance from time t to time t+Δt:

$$C_t\, e^{0.5M\Delta t} + N_{t+\Delta t}\, e^{M\Delta t} = N_t$$

Jones used size distribution of landings (catch at a sequence of length classes) to estimate catch at a sequence of time intervals. He used vonBertalanffy growth parameters to estimate the time to grow from one size class to the next (Δt). Using a single-year length frequency, which comprises several cohorts, to estimate abundance of a single cohort over time assumes that all cohorts in the catch were equally abundant at the time of recruitment to the fishery (i.e., recruitment is constant).

The Lobster Technical Committee of the Atlantic States Marine Fisheries Commission applied LCA to U.S. stocks of American lobster through Northeast Regional Stock Assessment Workshops and individual state analyses. Initial applications to American lobster adopted Jones' (1974, 1981) model to pooled-sex length frequencies within sampling regions (ICES 1979, Estrella and Cadrin 1989, Estrella and McKiernan 1989).

The Committee expanded samples to total landings, combined sampling regions within states, and treated males and females separately in the 1992 stock assessment (SAW 14; Estrella and Cadrin 1992, NEFSC 1992, Krouse et al., 1993). Sensitivity analyses showed that F estimates were robust to assumptions of M and F for the largest size (F_t), but were largely determined by vonBertalanffy parameters, which are inappropriate and poorly estimated for lobsters (Estrella and Cadrin 1992).

In the 1993 stock assessment (SAW 16; NEFSC 1993), the Committee incorporated a quadratic growth curve derived from molt increment and molt probability estimates at size to calculate Δt at size, the Committee analyzed landings at length for the entire Gulf of Maine stock, used 3-year average size distributions to stabilize recruitment variation, and modified the difference equation so that catch occurred later in the year. As in all earlier lobster LCAs, F estimates for Gulf of Maine females were greater than 1.0. Discrepancy with F estimates from DeLury analyses may have resulted from underestimating and poorly characterizing offshore landings in the Gulf of Maine.

Subsequent to the last stock assessment, representation of lobster landings from the central portion of the Gulf of Maine has improved. Canvas data have been re-analyzed to provide more accurate estimates of landings, and at least 11 directed lobstering trips in offshore areas of the Gulf of Maine have been sea sampled per year from 1992 to 1995 by NEFSC. This working paper represents revised LCAs for Gulf of Maine female lobsters and complete analyses for both sexes from all U.S. stocks.

METHODS

Lobster landings information was compiled by the 22nd SAW Invertebrate Subcommittee (Rago et al. 1996). Landings by region and quarter were estimated using NEFSC canvass data, MADMF annual catch reports, CTDEP logbooks, and NYDEC annual catch reports. Landings-at-size by sex was estimated using NEFSC port sampling, NEFSC sea sampling, MEDMR port sampling, MADMF sea sampling, RIF&W sea sampling, and CTDEP sea sampling. Three stock units were assessed: Gulf of Maine, Georges Bank/offshore, and inshore southern New England (see NEFSC 1996 for stock delineations). Smaller geographic regions (coastal Maine, coastal Massachusetts in the Gulf of Maine, and central-western Long Island Sound) were also analyzed separately as sub-areas. Total catch was assumed to equal landings, because discard mortality was assumed to be negligible.

The present LCAs were modified from the SAW 16 lobster assessment to improve the temporal comparability to DeLury model output by analyzing "survey years" rather than calendar years. Quarterly landings by sex and size were used to derive landings by survey years (i.e., the 4th quarter of the survey year plus the 1st three quarters of the next year, NEFSC 1996).

As in SAW 16 LCAs, catch was assumed to occur in August (i.e., T_c=0.8 for a survey year), and M was assumed to be 0.1. F for the largest size class was estimated from SAW 16 DeLury estimates of fully-recruited female F and state-specific landings restrictions (Table 1).

Molt increment-molt probability growth curves were used to estimate Δt at size. Growth trajectories were used to derive quadratic growth curves starting at 80 mm carapace length (CL); all regressions had R^2s >0.991. Growth trajectories for Gulf of Maine and Georges Bank/offshore females (Figure 1) were derived by egg-per-recruit models (Idoine and Fogarty 1993). Growth trajectories for males from all stocks and inshore southern New England females (Figure 1) were estimated according to deterministic estimates of molt increment and molt probability at size (Table 2).

RESULTS

Estimates of F from LCAs are summarized in Tables 3-5 (examples of complete model output are provided in Appendix Tables A1-A6).

Gulf of Maine

Analyses of Gulf of Maine female lobsters showed that F ranged from 1.1 to 1.3, averaged 1.2, increased from 1981 to 1987, and decreased to 1.2 in 1993 (Table 3, Figure 2). Mean abundance of females greater than legal size fluctuated from 10 million to 15 million over the entire time series, but increased after 1987. Cumulative annual landings exceeded average abundance indicating an intensive fishery which is dependent primarily upon new recruits. The general exploitation pattern at size (Figure 2) was full recruitment at legal size, decreasing vulnerability at approximately 100 mm CL, presumably due to protection of ovigerous and V-notched females, and low partial recruitment (0.1) above 130 mm CL (due to the 5" maximum size in Maine).

LCA estimates of male F in the Gulf of Maine was greater than that on females, presumably due to fewer restrictions on landings. F ranged 1.5-1.7, averaging 1.6, increased from 1981 to 1987, and decreased to 1.5 in 1993 (Table 3, Figure 2). Mean abundance was less than cumulative annual landings and increased from 9 million in 1981 to 13 million in 1993. Males were fully-recruited up to 100 mm CL, and had low partial recruitment >130 mm CL due to the 5" maximum size in Maine (Figure 2).

Gulf of Maine size distributions were very similar among years. F estimates were stable among years, and 3 year averaged length frequencies produced negligible change in F estimates. These results suggest that equilibrium recruitment may be a fair assumption for American lobster.

LCA estimates of F for Gulf of Maine lobsters were greater than DeLury estimates, which ranged 0.5-0.8 for females and 0.3-0.7 for males (NEFSC 1996). Sensitivity analyses were conducted to evaluate the effect of invalid assumptions on estimates of F for Gulf of Maine female lobsters (Figures 3 and 4). The 1992 LCA of 3-year averaged length frequency, in which the estimate of weighted average F was 1.2, was used to evaluate sensitivity. A range of F_t from 0.1 to 3.0 produced negligible change in the weighted average F, because there were many size classes, high F, and a predominance of landings at smaller sizes.

A range of M from 0.01 to 0.30 produced changes in weighted average F from 1.3 to 0.7, respectively. Weighted average F was sensitive to assumptions of T_c (time of year when the catch was harvested). A range of T_c from 0 to 1 produced weighted average F from 2.8 to 1.1, respectively.

Changing estimates of Δt from 0.5x the estimated value to 1.5x the estimated value produced weighted average Fs of 2.5 to 0.8, respectively. Despite more appropriate growth models for lobsters, LCA is still very sensitive to accurate estimates of Δt.

The Invertebrate subcommittee suspected that offshore Gulf of Maine (area 515) lobster landings may be underestimated. Sensitivity to the magnitude of 515 landings was evaluated by increasing the magnitude of 515 landings by factors of 1x-10x (Figure 4); weighted average F was decreased to 0.9 when area 515 landings were increased by a factor of 10.

Analyses of inshore Gulf of Maine lobster landings illustrated that inshore landings are so proportionately high that they largely determine F estimates for the entire Gulf of Maine stock. Female F for coastal Maine generally increased from 1975 to 1993, ranged 1.0 to 1.4, and averaged 1.2. F estimates for Massachusetts females increased from 1.5 to 1.8 from 1981 to 1993.

Inshore Southern New England

Inshore southern New England female F increased from 1.0 in 1982 to a peak 1.3 in 1986, decreased to 1.0 in 1990, and increased again to 1.2 in 1993 (Table 4, Figure 5). Mean abundance ranged 2.8-5.7 million and increased through the time series. Partial recruitment was maximum at minimum legal size and decreased to 0.2 of maximum at approximately 120 mm CL (Figure 5).

Inshore southern New England male F was greater, increasing from 1.8 in 1982 to a peak of 2.1 in 1986, and decreasing to 1.9 in 1993 (Table 4, Figure 5). Mean abundance of males also increased from 1982 to 1993, and ranged 0.8-2.2 million Males were fully-recruited from 81 to 100 mm CL, and partial recruitment declined to approximately 0.2 above 120 mm CL (Figure 5).

Unlike results for Gulf of Maine lobsters, LCA results for inshore southern New England were comparable to those from the DeLury analysis, which averaged 1.1 for females and 1.4 for males (NEFSC 1996). Sensitivity of LCAs to the use of outer Cape Cod sea samples to characterize landings in the eastern portion of area 538 was investigated by using only Buzzards Bay samples to characterize all area 538 landings. Results from the sensitivity runs were slightly greater than those reported in Table 4: female F ranged 1.0-1.4, and male F ranged 1.8-2.0.

LCAs of the sub-area, central-western Long Island Sound, confirmed estimates of F for the entire inshore southern New England stock: female F ranged 0.9-1.3, and male F ranged 1.5-2.0.

Georges Bank/offshore

Offshore female F fluctuated from 0.7 to 1.5 and averaged 1.0 (Table 5, Figure 6). Mean abundance of legal sized females fluctuated from 2.2 to 3.7 million without trend. Partial recruitment declined to 0.3 at 100 mm CL (partly due to egger protection) and declined to lower values at sizes greater than 150 mm CL (Figure 6).

F of offshore males was greater than F of offshore females. F ranged 0.8-2.2, averaged 1.6, and increased after 1983 (Table 5, Figure 6). Mean male abundance ranged 1.6-3.0 million without trend. Males were fully-recruited at minimum legal size, had 0.6 partial recruitment at 100 mm CL and lower partial recruitment at larger sizes.

LCA estimates of F for Georges Bank/offshore lobsters were generally twice as high as F estimates from DeLury analysis, which ranged 0.3-0.6 for females and 0.5-1.1 for males (NEFSC 1996). Interannual variation in F estimates result from large fluctuations in landings estimates. Large variation in offshore landings may be due to variable effort, poor landings estimates, or low sampling intensity rather than variable recruitment. Mean abundance estimates from LCA were much less variable; despite the limitation of LCA to single-year landings information, it appears that LCA can detect interannual changes in F.

DISCUSSION

The greater F on males for all three stocks is expected due to landings restrictions on mature females. Decreasing partial recruitment of females with size is also reasonable, because ovigerous and V-notched females are protected by regulation. These patterns suggest that LCA is providing reasonable estimates of F. However, comparisons with DeLury results, male partial recruitment patterns with size, and sensitivity analyses illustrate the dependence on accurate growth models to estimate F using LCA. Unless males are less vulnerable to the fishery at large sizes, F should be constant over all size classes (except in the Gulf of Maine where there is a 5" maximum size in Maine). Decreasing partial recruitment at size may be the result of systematic bias in Δt estimates. If growth is underestimated at larger size, F will decrease as an artifact of the growth model.

The 22nd Stock Assessment Review Committee (SARC) questioned whether the extremely high estimates of F by LCA were realistic (NEFSC 1996). Several aspects of field sampling corroborate high levels of exploitation in coastal areas: sea sampling observations show that fishing patterns target local molting events, and new recruits are quickly depleted; most inshore tagging returns have an average time-at-large of less than 10 days; and catches from Canadian fisheries, which are similar to U.S. fishing operations, are dominated by the first three weeks of their two to six month open season (NEFSC 1996).

The SARC suggested that future length-cohort analyses should assume values for M which correspond to the current egg-per-recruit estimates of M. Revised EPR models incorporated increased M for softshell mortality, and estimated M=0.15 for the range of observed F.

It is evident that better growth information is necessary for more accurate length-based estimates of F for lobsters. Growth information can be improved through stochastic growth models, more powerful statistical analyses, and more field observations of molt probability over a broad range of sizes.

ACKNOWLEDGEMENTS

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REFERENCES

ASMFC (Atlantic States Marine Fisheries Commission). 1996. A review of the population dynamics of American lobster in the Northeast. ASMFC Special Report No. 61.

Estrella, B.T. and S.X. Cadrin. 1989. Massachusetts coastal commercial lobster trap sampling program May-November, 1988. Mass. Div. Marine Fisheries Pub. No. 16,024.

Estrella, B.T. and S.X. Cadrin. 1992. Massachusetts coastal commercial lobster trap sampling program May-November, 1988. Mass. Div. Marine Fisheries Pub. No. 17,180.

Estrella, B.T. and D.J. McKiernan. 1989. Catch-per-unit-effort and biological parameters from the Massachusetts coastal lobster (*Homarus americanus*) resource: description and trends. NOAA Tech. Rep. NMFS 81.

Fogarty, M.J. and J.S. Idoine. Application of a yield and egg production model based on size to an offshore American lobster population. Trans. Am. Fish. Soc. 117:350-362.

ICES (International Council for the Exploration of the Sea). 1979. Report of the Homarus working group. ICES C.M. K:8.

Idoine, J.S. and M.J. Fogarty. 1993. Calculating biological reference points for American lobsters. NEFSC Ref. Doc. 93-20.

Jones, R. 1974. Assessing the long term effects of changes in fishing effort and mesh size from length composition data. ICES C.M. F:33.

Jones, R. 1981. The use of length composition data in fish stock assessments (with notes on VPA and cohort analysis). FAO Fish. Circ. No. 734.

Krouse, J.S., N.C. Bowie, K.H. Kelly, G.B. Nutting, D.B. Parkhurst, Jr., G.A. Robinson, and B.C. Scully. 1995. Maine Department of Marine Resources Lobster Stock Assessment. Project 3-IJ-61-3 Completion Report.

NEFSC (Northeast Fisheries Science Center). 1992. Report of the 14th northeast regional stock assessment workshop. NEFSC Ref. Doc. 92-07.

NEFSC (Northeast Fisheries Science Center). 1993. Report of the 16th northeast regional stock assessment workshop. NEFSC Ref. Doc. 93-08.

NEFSC (Northeast Fisheries Science Center). 1996. Report of the 22nd northeast regional stock assessment workshop. NEFSC Ref. Doc. 96-13.

Pope, J.G. 1972. An investigation of the accuracy of virtual population analysis using cohort analysis. ICNAF Res. Bull. 9:65-74.

Rago, P., J. Idoine, B. Estrella, S. Cadrin, and A. Richards. 1996. Estimation of catch and description of sampling programs for American lobster in the U.S. Northwest Atlantic. NEFSC Ref. Doc. (in prep).

Table 1. Terminal F (F_t) used in lobster length-cohort analyses.

Stock	Sex	DeLury F	F_t	Restrictions
GOM	male	0.8	0.4	5" maximum size in Maine
GOM	female	0.8	0.2	5" size, egger & V-notch protection
ISNE	male	1.5	1.5	none
ISNE	female	1.5	0.8	egger protection
GB/O	male	0.7	0.7	none
GB/O	female	0.7	0.4	egger protection

Table 2. Growth parameters used to estimate delta-t for lobster length-cohort analyses.

Stock	Sex	Molt Increment (mm)	Molt Probability	Source
GOM	male	2.55+0.106CL	$e^{(7.787-.064CL)}/(1+e^{(7.787-0.064CL)})$	D. Pezzack
ISNE	female	11	$1/e^{(-9.72+0.103CL)}$	NEFSC 1993 M. Blake
ISNE	male	7.53+0.062CL	$1/e^{(-4.61+0.040CL)}$	T. Angel & P. Briggs M. Blake
GB/O	male	8.96+0.083CL	$1/e^{(-6.89+0.052CL)}$	Fogarty & Idoine 1988

Table 3. Summary statistics from length-cohort analyses of Gulf of Maine lobsters.

Survey Year	FEMALES Catch (numbers)	FEMALES Mean Number	FEMALES F	FEMALES 3 y avg size F	MALES Catch (numbers)	MALES Mean Number	MALES F	MALES 3 y avg size F
1981	13,448,128	12,677,206	1.097		12,983,792	9,552,327	1.503	
1982	13,000,082	12,784,187	1.095	1.109	13,448,643	9,753,260	1.507	1.496
1983	11,728,754	11,560,944	1.156	1.151	12,858,125	9,839,056	1.494	1.516
1984	14,003,225	12,389,805	1.218	1.213	14,207,712	10,011,707	1.561	1.522
1985	13,408,532	11,478,226	1.266	1.239	14,099,388	9,845,393	1.519	1.568
1986	12,000,998	10,478,723	1.236		12,958,616	8,387,923	1.639	
1987	12,295,383	9,979,441	1.342		13,657,921	8,379,864	1.708	
1988	13,653,899	12,306,160	1.267		14,137,668	9,360,513	1.646	
1989	14,366,691	12,339,501	1.277	1.275	16,409,238	11,099,265	1.579	1.612
1990	17,352,338	14,171,416	1.282	1.263	19,069,710	12,203,436	1.624	1.612
1991	15,184,973	13,482,514	1.233	1.230	16,440,644	10,570,307	1.635	1.614
1992	14,539,915	13,633,899	1.171	1.205	16,852,443	11,309,637	1.590	1.581
1993	16,312,972	14,867,455	1.210		19,128,133	13,257,556	1.537	
Mean	13,945,838	12,473,037	1.219	1.211	15,096,310	10,274,634	1.580	1.565

Table 4. Summary statistics from length-cohort analyses of inshore southern New England lobsters.

	FEMALES				MALES			
Survey Year	Catch (numbers)	Mean Number	F	3 y avg size F	Catch (numbers)	Mean Number	F	3 y avg size F
1982	2,552,716	3,282,114	0.973		2,048,701	1,160,391	1.847	
1983	3,132,246	3,343,230	1.064	1.049	2,083,190	1,152,665	1.858	1.850
1984	3,061,005	3,336,361	1.106	1.144	2,192,189	1,230,769	1.859	1.900
1985	3,122,812	3,046,684	1.280	1.223	1,724,307	887,068	2.022	1.994
1986	3,151,510	2,870,302	1.295	1.260	2,053,807	978,117	2.135	2.022
1987	3,288,121	2,960,807	1.216		2,393,535	1,259,929	1.939	
1988	4,178,341	4,719,930	1.087		2,630,755	1,358,694	1.976	
1989	4,989,376	5,768,871	1.006		3,303,225	1,801,842	1.884	
1990	4,813,488	5,364,601	1.002	0.999	3,931,714	2,242,214	1.782	1.809
1991	3,540,432	4,273,871	0.992	1.088	3,270,125	1,866,946	1.789	1.805
1992	4,561,052	4,594,099	1.172	1.139	3,951,377	2,186,874	1.855	1.839
1993	4,854,244	4,107,658	1.231		3,766,668	2,032,846	1.873	
Mean	3,770,445	3,972,377	1.117	1.129	2,779,133	1,513,196	1.902	1.888

Table 5. Summary statistics from length-cohort analyses of Georges Bank/offshore lobsters.

	FEMALES				MALES			
Survey Year	Catch (numbers)	Mean Number	F	3 y avg size F	Catch (numbers)	Mean Number	F	3 y avg size F
1981	1,667,616	2,322,794	0.818		1,919,438	1,582,940	1.346	
1982	1,565,765	2,227,202	0.764	0.744	2,373,953	2,440,021	1.019	1.031
1983	1,624,382	2,555,038	0.701	0.809	2,312,920	3,023,852	0.811	1.045
1984	2,041,154	2,282,134	1.012	0.875	2,684,211	2,380,697	1.309	1.158
1985	2,121,917	2,839,489	0.981	1.033	2,631,460	2,287,295	1.383	1.493
1986	2,417,542	2,574,630	1.162	1.092	2,661,433	1,752,432	1.679	1.476
1987	2,065,914	1,985,073	1.184		2,665,580	2,397,625	1.274	
1988	2,207,052	2,888,862	0.857		2,959,319	2,418,025	1.439	
1989	2,539,647	2,844,001	1.132		3,280,995	2,461,986	1.480	
1990	4,597,347	3,784,129	1.397		2,966,662	1,864,023	1.955	
1991	3,149,908	2,679,858	1.387	1.310	3,313,653	1,790,824	2.158	2.193
1992	2,851,131	2,445,987	1.457	1.407	3,411,009	1,914,481	2.120	2.252
1993	1,423,142	2,235,260	0.759	1.242	2,040,245	1,167,396	2.095	
Mean	2,328,655	2,589,574	1.047	1.064	2,709,298	2,113,969	1.544	1.521

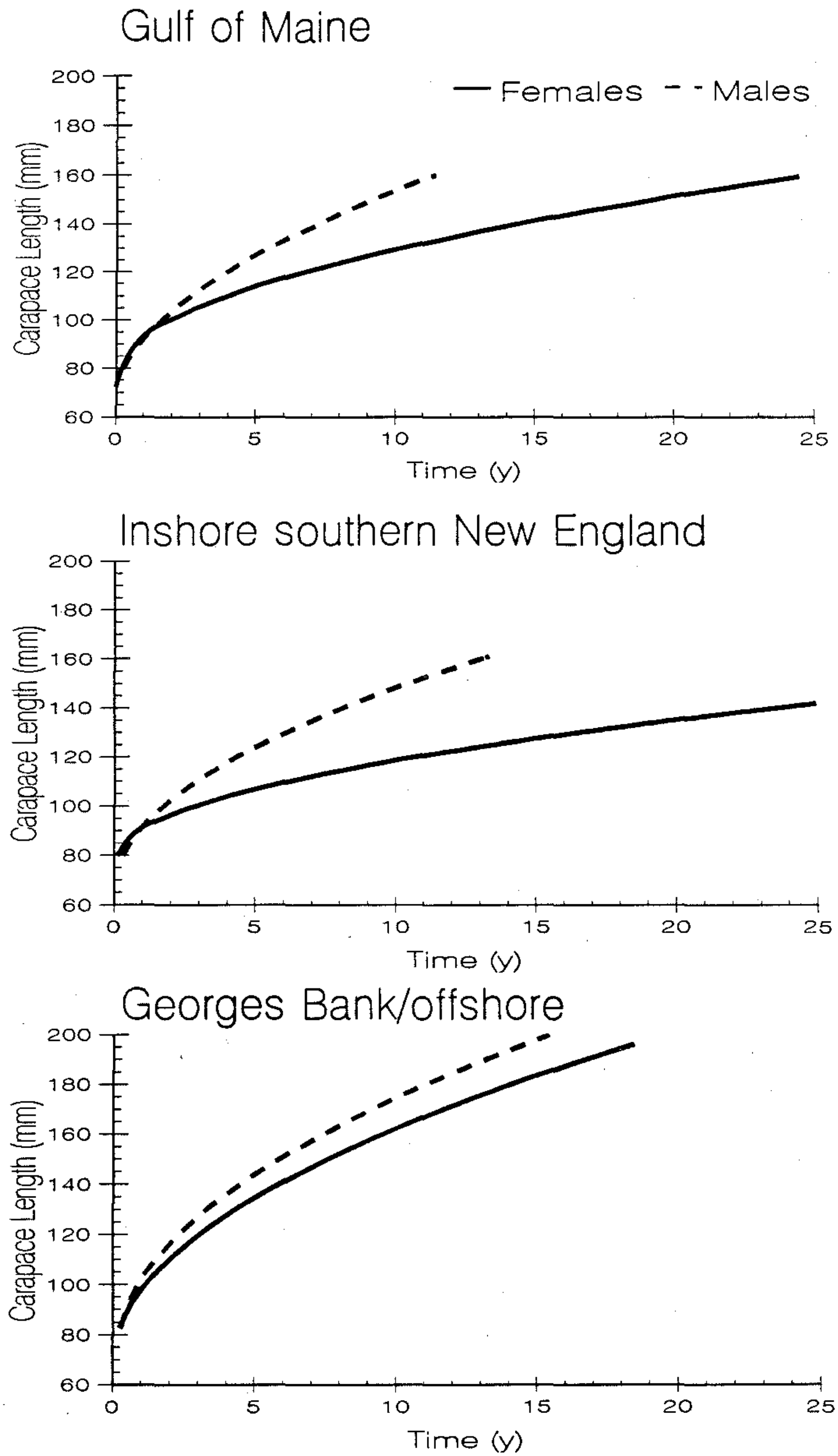


Figure 1. Growth curves used to calculate delta-t for lobster length-cohort analyses.

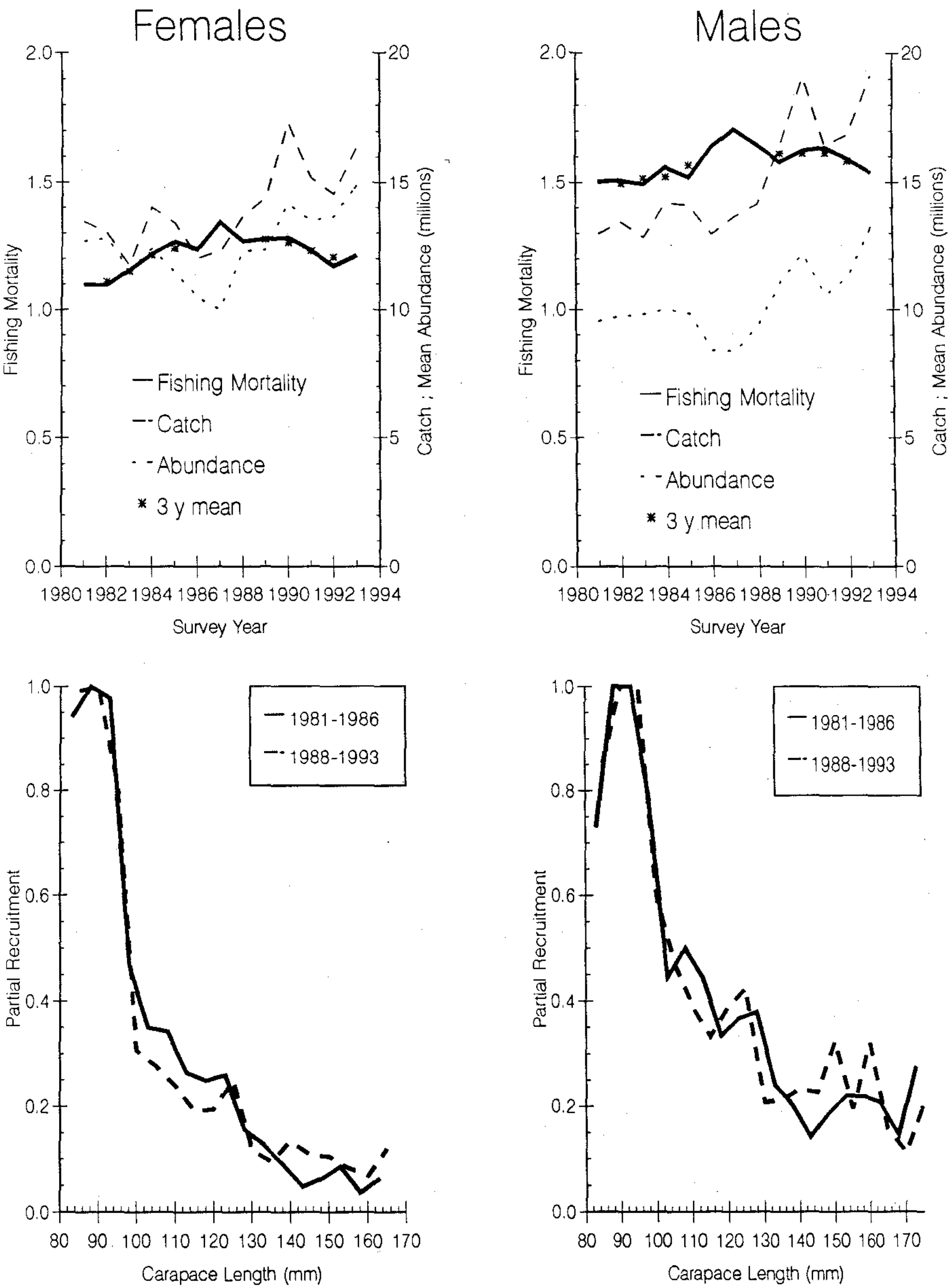


Figure 2. Length-cohort analyses of female (left) and male (right) lobster in the Gulf of Maine.

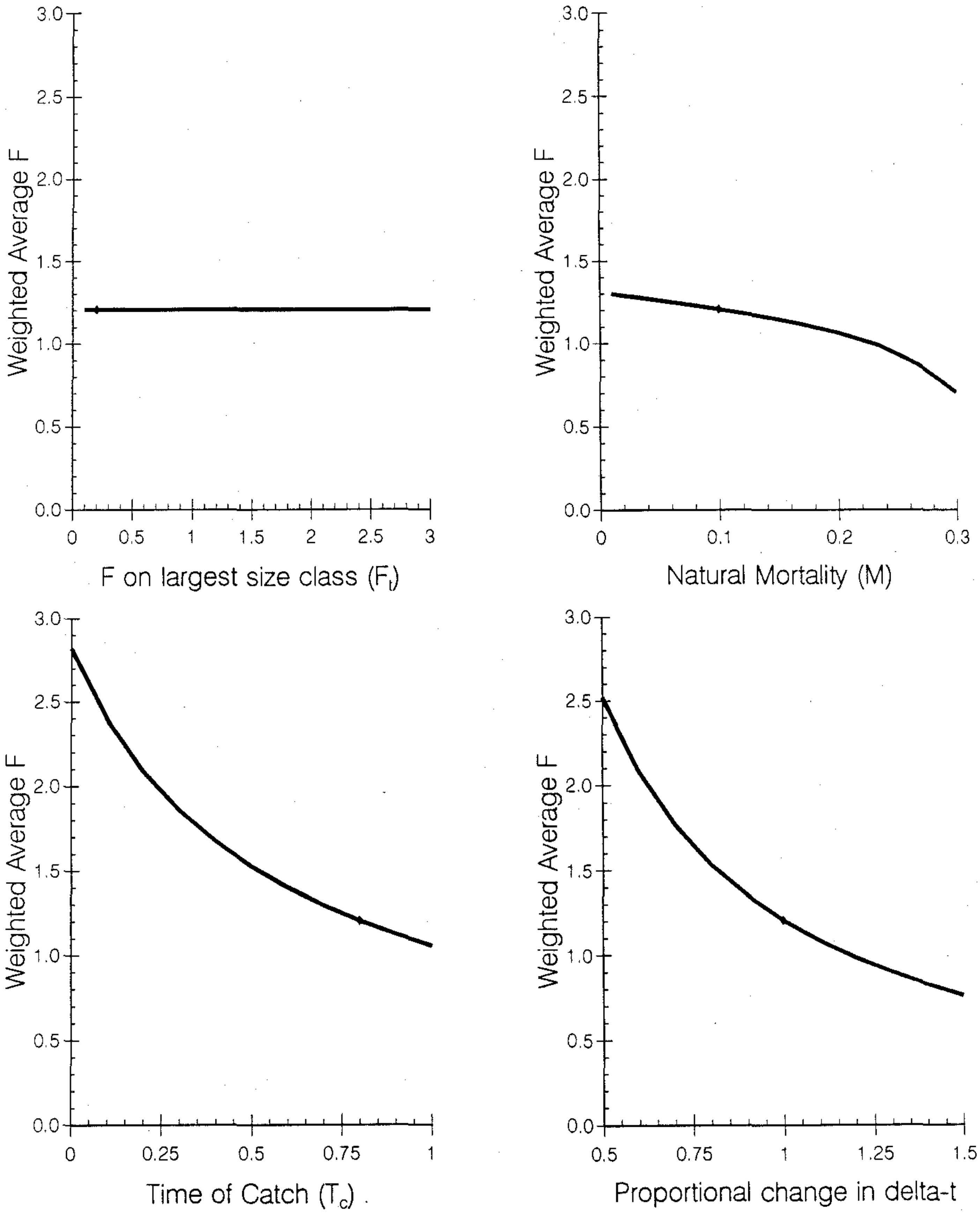


Figure 3. Sensitivity of lobster F estimates to length-cohort analysis input parameters.

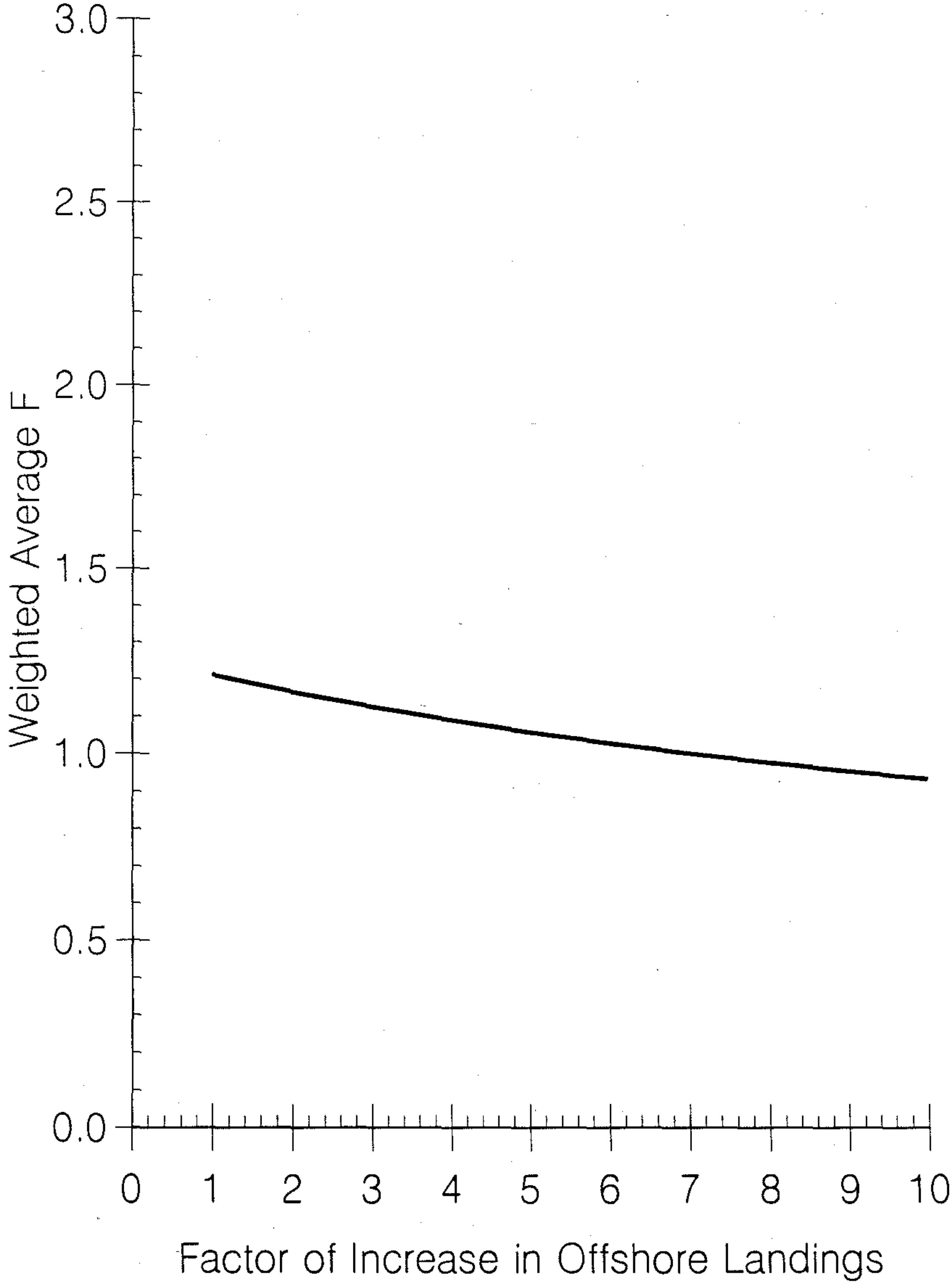


Figure 4. Sensitivity of length-cohort analyses in the Gulf of Maine to underestimating offshore catch.

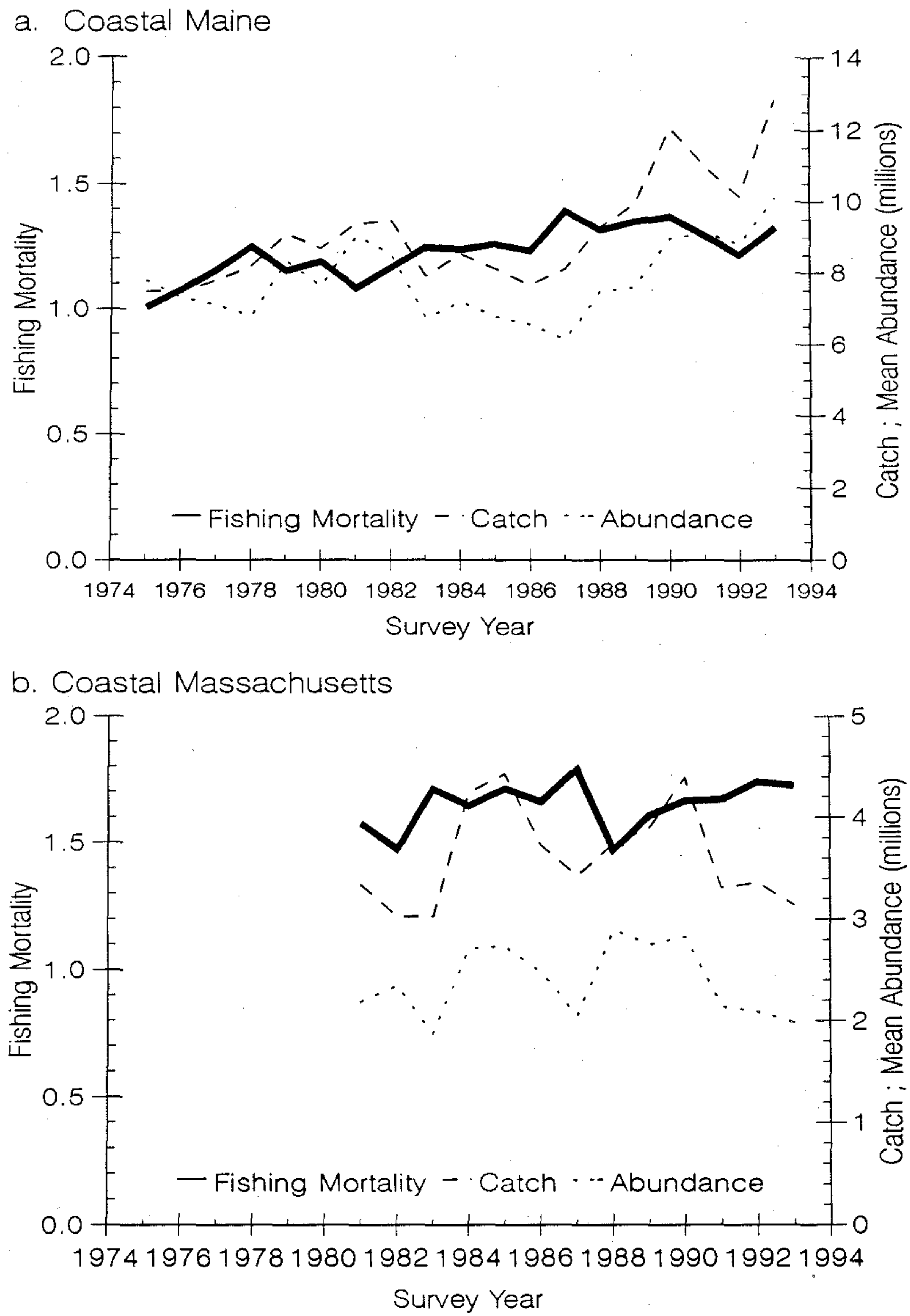


Figure 5. Length-cohort analyses of inshore areas of the Gulf of Maine: (a) coastal Maine (areas 511-513) and (b) coastal Massachusetts (area 514).

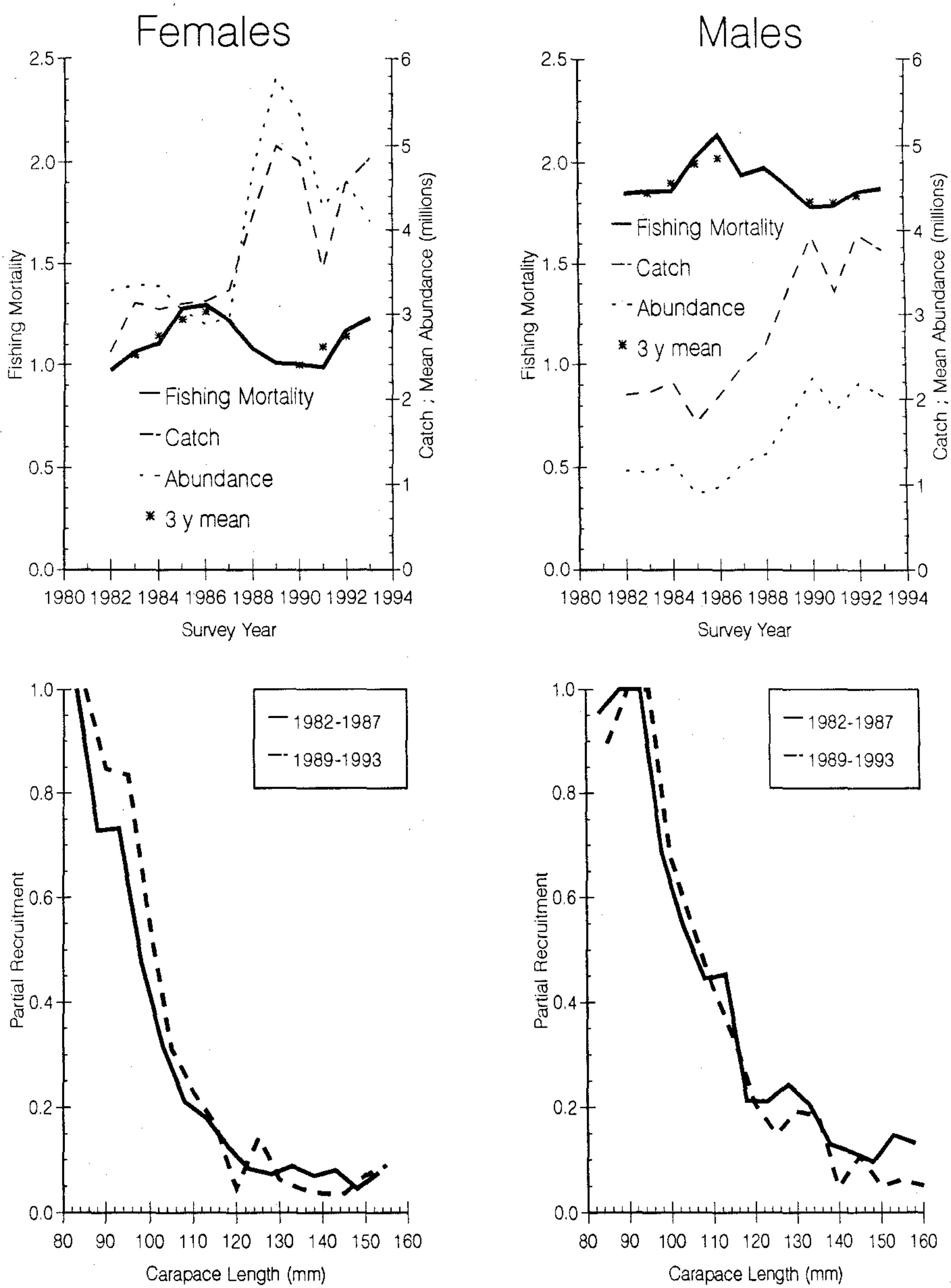
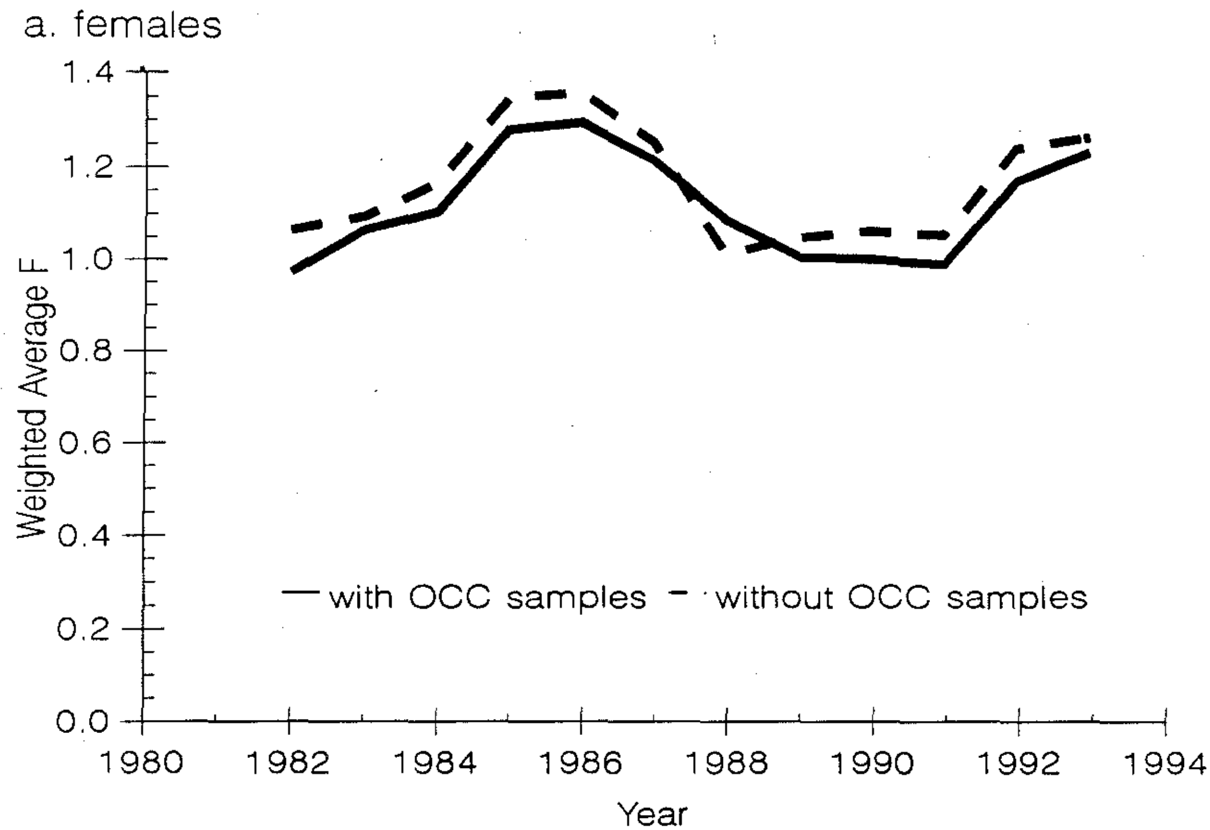


Figure 6. Length-cohort analyses of female (left) and male (right) lobster in inshore southern New England.



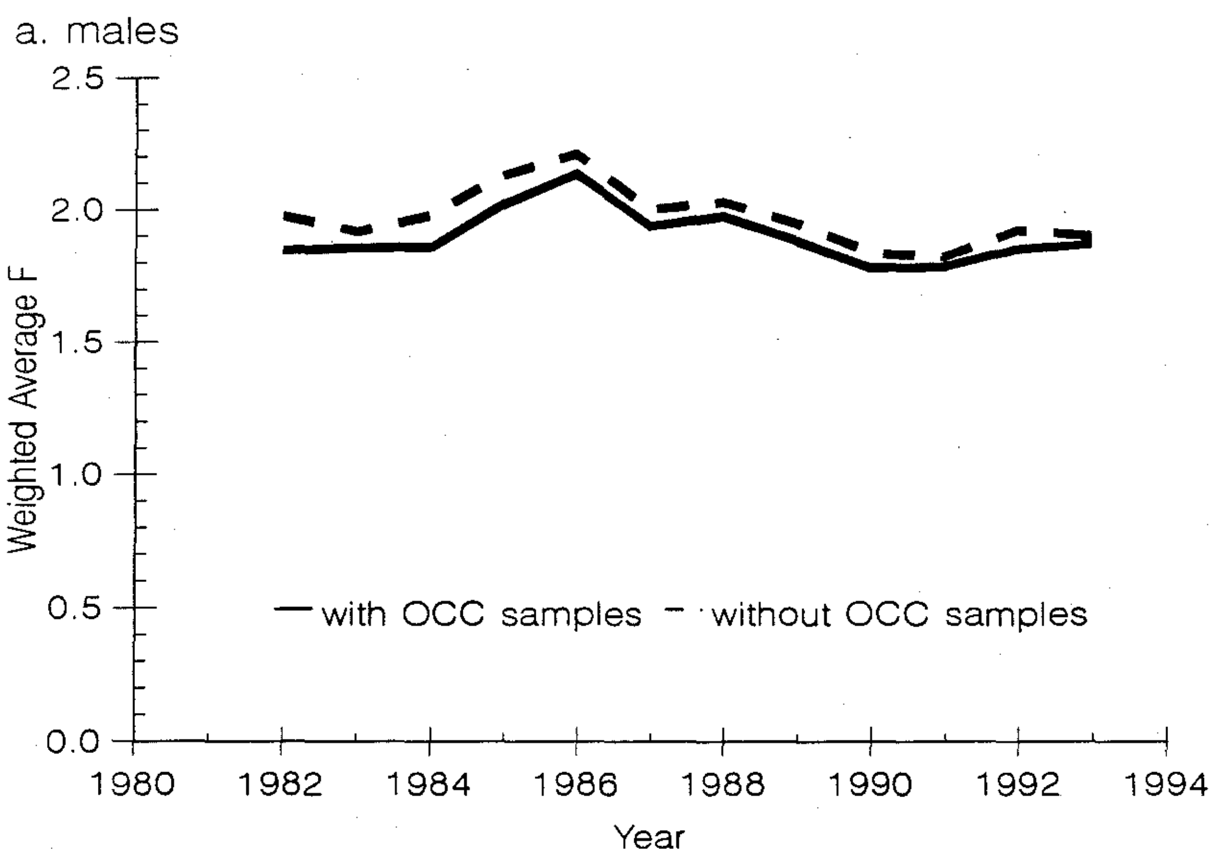
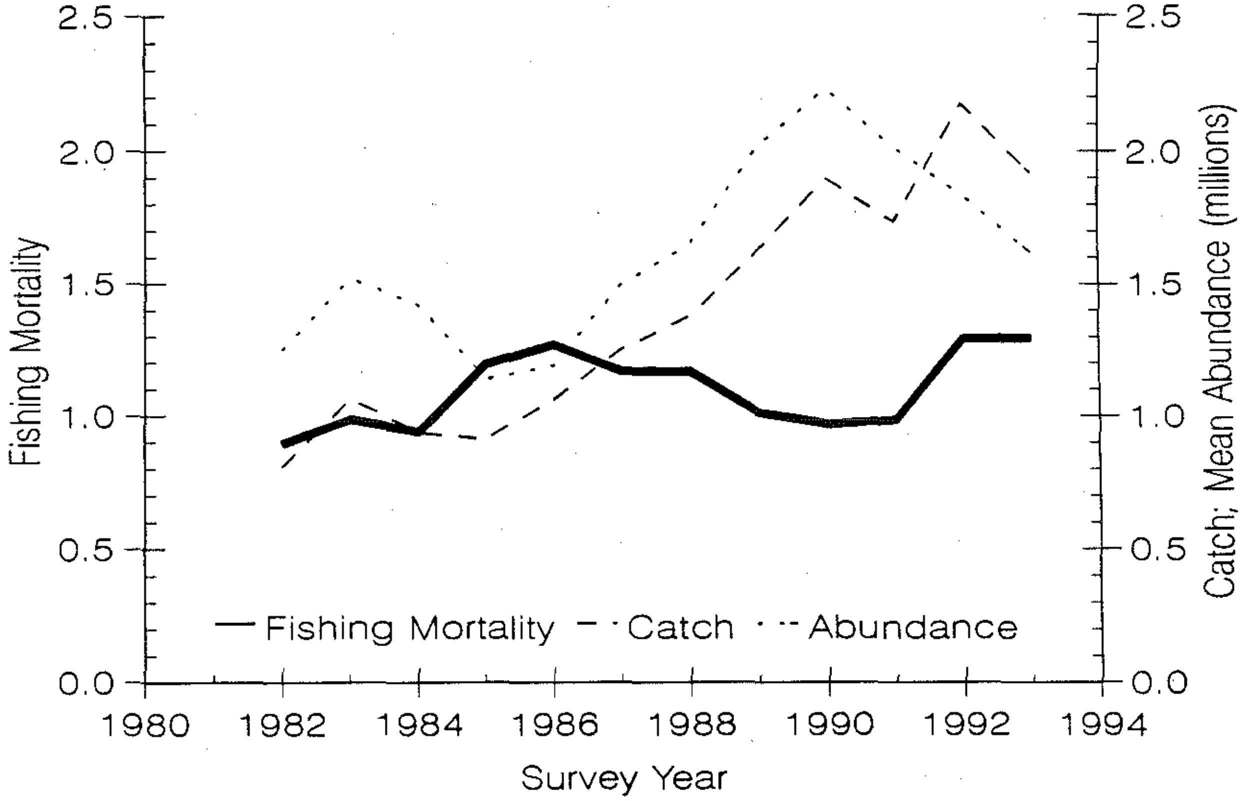


Figure 7. Sensitivity of inshore southern New England lobster F estimates to use of outer Cape Cod biological samples: (a) females and (b) males.

b. males



b. males

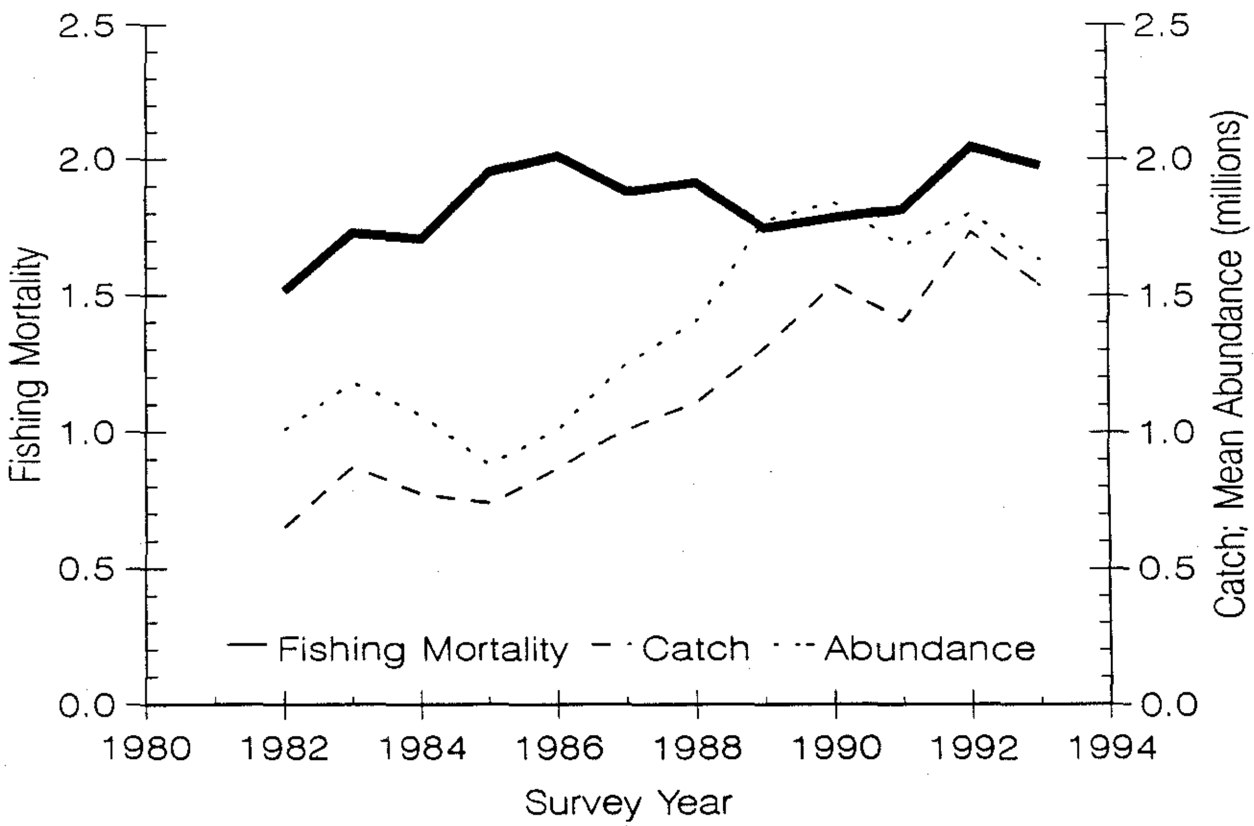


Figure 8. Length-cohort analyses of central-western Long Island Sound: (a) females and (b) males.

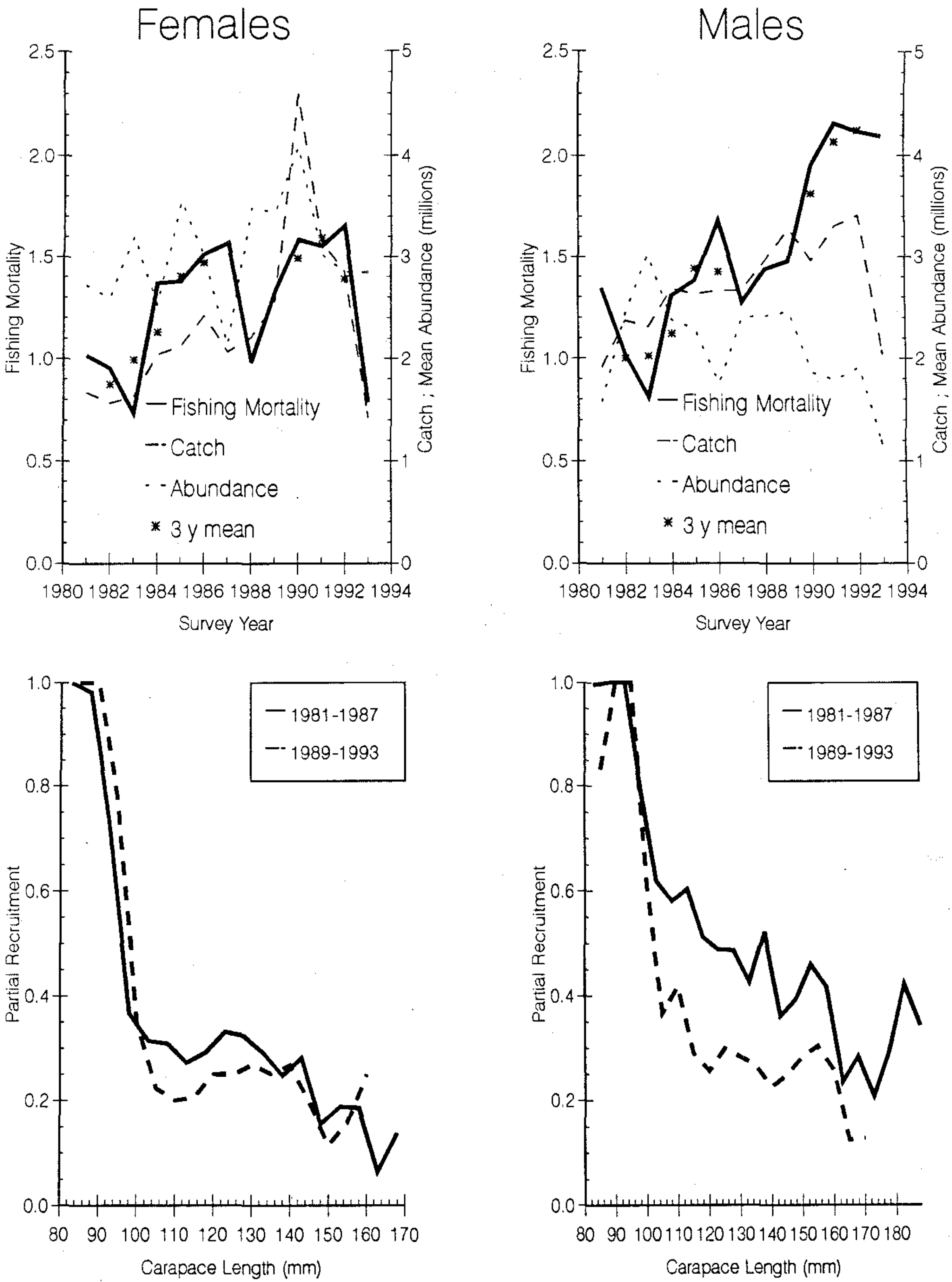


Figure 9. Length-cohort analyses of female (left) and male (right) lobster from Georges Bank/offshore.

APPENDIX

LENGTH-COHORT ANALYSES OF U.S. AMERICAN LOBSTER STOCKS. MODEL OUTPUT FOR 1993

Table A1. Length-cohort analysis of Gulf of Maine female lobster 1993.

LENGTH-BASED COHORT ANALYSIS 05/15/96 08:49 PM Ft = 0.2
American lobster M = 0.1
Gulf of Maine females, 1993 survey year Tc = 0.8

Length (mm)	Catch (numbers)	Delta-t (y)	Stock Numbers	Mean Number	F/Z	Z	F
168 -172	90	3.411	134				
163 -167	45	3.234	244	645	0.410	0.169	0.069
158 -162	134	3.056	502	1,242	0.519	0.208	0.108
153 -157	313	2.879	1,064	2,487	0.558	0.226	0.126
148 -152	1,036	2.701	2,680	5,798	0.641	0.279	0.179
143 -147	1,445	2.524	5,217	10,926	0.569	0.232	0.132
138 -142	1,990	2.346	8,997	17,901	0.526	0.211	0.111
133 -137	3,274	2.169	15,070	27,995	0.539	0.217	0.117
128 -132	6,318	1.992	25,801	44,132	0.589	0.243	0.143
123 -127	18,430	1.814	52,240	80,099	0.697	0.330	0.230
118 -122	35,992	1.637	102,560	143,276	0.715	0.351	0.251
113 -117	66,103	1.459	192,956	242,940	0.731	0.372	0.272
108 -112	102,388	1.282	332,795	374,509	0.732	0.373	0.273
103 -107	167,662	1.104	554,784	543,269	0.755	0.409	0.309
98 -102	219,744	0.927	845,331	708,033	0.756	0.410	0.310
93 - 97	1,874,839	0.750	2,901,941	1,817,715	0.912	1.131	1.031
88 - 92	6,090,966	0.572	9,448,936	4,560,284	0.930	1.436	1.336
83 - 87	7,722,206	0.395	17,799,762	6,286,205	0.925	1.328	1.228
Total	16,312,972			14,867,455	Wtd.Ave.F		1.210

Table A2. Length-cohort analysis of Gulf of Maine male lobster 1993.

LENGTH-BASED COHORT ANALYSIS 05/29/96 02:40 PM Ft = 0.4
American lobster M = 0.1
Gulf of Maine males, 1993 Tc = 0.8

Length (mm)	Catch (numbers)	Delta-t (y)	Stock Numbers	Mean Number	F/Z	Z	F
178 -198	201		251				
173 -177	90	3.673	483	1,421	0.386	0.163	0.063
168 -172	45	1.307	600	724	0.382	0.162	0.062
163 -167	380	1.249	1,100	1,198	0.760	0.418	0.318
158 -162	739	1.191	2,052	2,130	0.776	0.447	0.347
153 -157	1,007	1.132	3,401	3,415	0.747	0.395	0.295
148 -152	1,679	1.074	5,615	5,361	0.758	0.413	0.313
143 -147	2,552	1.015	8,983	8,161	0.758	0.413	0.313
138 -142	3,514	0.957	13,679	11,818	0.748	0.397	0.297
133 -137	4,566	0.899	19,871	16,264	0.737	0.381	0.281
128 -132	8,363	0.840	30,558	23,231	0.783	0.460	0.360
123 -127	32,457	0.782	67,594	45,795	0.876	0.809	0.709
118 -122	15,836	0.723	89,444	60,140	0.725	0.363	0.263
113 -117	65,758	0.665	164,945	97,424	0.871	0.775	0.675
108 -112	109,043	0.607	289,723	157,355	0.874	0.793	0.693
103 -107	188,688	0.548	503,192	247,814	0.884	0.861	0.761
98 -102	605,533	0.490	1,158,173	494,482	0.925	1.325	1.225
93 - 97	4,406,414	0.431	5,770,321	2,057,334	0.955	2.242	2.142
88 - 92	6,448,727	0.373	12,633,539	4,144,917	0.940	1.656	1.556
83 - 87	7,232,542	0.314	20,453,939	5,878,572	0.925	1.330	1.230
Total	19,128,133			13,257,556	Wtd.Ave.F		1.537

Table A3. Length-cohort analysis of inshore southern New England female lobster 1993.

LENGTH-BASED COHORT ANALYSIS 06/03/96 01:32 PM
American lobster
inshore southern New England females, 1993

Ft = 0.2
M = 0.1
Tc = 0.8

Length (mm)	Catch (numbers)	Delta-t (y)	Stock Numbers	Mean Number	F/Z	Z	F
153 -157	29	4.979	44				
148 -152	110	4.661	230	760	0.592	0.245	0.145
143 -147	49	4.343	425	1,457	0.253	0.134	0.034
138 -142	49	4.024	704	2,295	0.177	0.122	0.022
133 -137	28	3.706	1,057	3,254	0.078	0.109	0.009
128 -132	229	3.388	1,784	4,977	0.315	0.146	0.046
123 -127	359	3.070	2,884	7,410	0.327	0.148	0.048
118 -122	1,090	2.752	5,156	11,819	0.480	0.192	0.092
113 -117	960	2.433	7,742	16,268	0.371	0.159	0.059
108 -112	3,023	2.115	13,146	23,812	0.559	0.227	0.127
103 -107	6,579	1.797	23,331	36,054	0.646	0.282	0.182
98 -102	19,662	1.479	49,181	61,882	0.761	0.418	0.318
93 - 97	183,609	1.161	256,710	239,200	0.885	0.868	0.768
88 - 92	1,580,371	0.843	1,969,848	1,327,670	0.923	1.290	1.190
83 - 87	3,058,096	0.524	5,265,024	2,370,802	0.928	1.390	1.290
Total	4,854,244			4,107,658	Wtd.Ave.F		1.231

Table A4. Length-cohort analysis of inshore southern New England male lobster 1993.

LENGTH-BASED COHORT ANALYSIS 06/03/96 02:03 PM
American lobster
inshore southern New England males, 1993

Ft = 1.5
M = 0.1
Tc = 0.8

Length (mm)	Catch (numbers)	Delta-t (y)	Stock Numbers	Mean Number	F/Z	Z	F
138 -142	35	1.128	38				
133 -137	113	1.054	165	142	0.889	0.899	0.799
128 -132	160	0.981	355	301	0.841	0.631	0.531
123 -127	256	0.908	663	530	0.828	0.583	0.483
118 -122	684	0.834	1,452	1,049	0.867	0.752	0.652
113 -117	1,107	0.761	2,744	1,842	0.857	0.701	0.601
108 -112	1,774	0.687	4,813	2,955	0.857	0.700	0.600
103 -107	9,005	0.614	14,576	7,580	0.922	1.288	1.188
98 -102	49,092	0.540	66,646	29,785	0.943	1.748	1.648
93 - 97	503,677	0.467	592,685	223,611	0.957	2.352	2.252
88 - 92	1,251,884	0.394	1,908,412	638,423	0.951	2.061	1.961
83 - 87	1,948,881	0.320	3,969,955	1,126,630	0.945	1.830	1.730
Total	3,766,668			2,032,846	Wtd.Ave.F		1.873

Table A5. Length-cohort analysis of Georges Bank/offshore female lobster 1993.

LENGTH-BASED COHORT ANALYSIS 06/05/96 01:48 PM

American lobster

Georges Bank/offshore females, 1993

Ft = 0.4
M = 0.1
Tc = 0.8

Length (mm)	Catch (numbers)	Delta-t (y)	Stock Numbers	Mean Number	F/Z	Z	F
173 -177	189	1.226	237				
168 -172	0	1.170	266	294	0.000	0.100	0.000
163 -167	189	1.114	505	490	0.794	0.486	0.386
158 -162	947	1.059	1,592	1,401	0.871	0.776	0.676
153 -157	2,150	1.003	4,089	3,475	0.861	0.719	0.619
148 -152	3,780	0.947	8,573	7,039	0.843	0.637	0.537
143 -147	6,529	0.892	16,385	12,823	0.836	0.609	0.509
138 -142	15,640	0.836	34,535	25,102	0.862	0.723	0.623
133 -137	22,389	0.780	61,168	42,445	0.841	0.627	0.527
128 -132	37,136	0.725	105,117	68,126	0.845	0.645	0.545
123 -127	50,263	0.669	165,414	100,341	0.834	0.601	0.501
118 -122	73,639	0.613	253,215	141,626	0.839	0.620	0.520
113 -117	72,343	0.557	343,376	178,169	0.802	0.506	0.406
108 -112	79,266	0.502	443,558	209,171	0.791	0.479	0.379
103 -107	90,165	0.446	557,236	235,120	0.793	0.483	0.383
98 -102	80,779	0.390	662,764	247,494	0.765	0.426	0.326
93 - 97	192,649	0.335	883,203	277,898	0.874	0.793	0.693
88 - 92	375,632	0.279	1,292,309	334,736	0.918	1.222	1.122
83 - 87	319,455	0.223	1,646,715	349,510	0.901	1.014	0.914
Total	1,423,142			2,235,260	Wtd.Ave.F		0.759

Table A6. Length-cohort analysis of Georges Bank/offshore male lobster 1993.

LENGTH-BASED COHORT ANALYSIS 05/30/96 03:10 PM Ft = 0.7
American lobster M = 0.1
Georges Bank/offshore males, 1993 Tc = 0.8

Length (mm)	Catch (numbers)	Delta-t (y)	Stock Numbers	Mean Number	F/Z	Z	F
183 -187	379	1.033	433				
178 -182	0	0.990	478	451	0.000	0.100	0.000
173 -177	43	0.948	572	509	0.459	0.185	0.085
168 -172	0	0.905	626	542	0.000	0.100	0.000
163 -167	0	0.862	683	564	0.000	0.100	0.000
158 -162	626	0.819	1,409	1,007	0.861	0.721	0.621
153 -157	815	0.776	2,390	1,660	0.831	0.591	0.491
148 -152	2,646	0.734	5,378	3,419	0.886	0.874	0.774
143 -147	2,062	0.691	7,942	5,018	0.804	0.511	0.411
138 -142	4,577	0.648	13,295	7,753	0.855	0.690	0.590
133 -137	8,027	0.605	22,549	12,277	0.867	0.754	0.654
128 -132	11,054	0.562	35,416	18,133	0.859	0.710	0.610
123 -127	13,917	0.520	51,813	24,797	0.849	0.661	0.561
118 -122	17,872	0.477	72,910	32,253	0.847	0.654	0.554
113 -117	25,264	0.434	102,302	41,267	0.860	0.712	0.612
108 -112	32,696	0.391	140,119	51,209	0.865	0.738	0.638
103 -107	43,214	0.348	189,522	61,892	0.875	0.798	0.698
98 -102	71,981	0.306	269,165	76,627	0.904	1.039	0.939
93 - 97	467,318	0.263	753,579	170,961	0.965	2.833	2.733
88 - 92	732,813	0.220	1,516,165	297,732	0.961	2.561	2.461
83 - 87	604,941	0.177	2,156,847	357,406	0.944	1.793	1.693
Total	2,040,246			1,165,474	Wtd.Ave.F		2.095