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Gulf of Maine Northern Shrimp Stock Assessment

by

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ABSTRACT

Total biomass of the Gulf of Maine northern shrimp stock is currently below-average, and the fishing mortality rate (F) is relatively high. Trends in stock abundance and F were modeled with abundance indices from research vessel surveys and commercial landings (1985-1996) using a modified DeLury technique. Estimates of biomass and F were independently assessed using a non-equilibrium biomass dynamics model of 1968-1996 landings and survey indices. Abundance of recruited shrimp at the end of the 1996 fishing season was the lowest since the early 1980s. Fishing mortality ranged from 0.1 to 0.5 during 1985-1995 and increased to 0.9 in the 1996 fishing season, the highest level since 1975. There is a 90% probability that F_{96} exceeded 0.7, the level associated with a stock collapse in the 1970s. Based on a decade of relatively stable stock levels, an appropriate target may be an F of approximately 0.4, which was the average for 1985-1995. An F of 0.4 corresponds to approximately 40% of maximum egg production per recruit and is slightly below $F_{0.1}$.



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INTRODUCTION

Northern shrimp, *Pandalus borealis*, (also referred to as pink shrimp) are distributed discontinuously throughout boreal waters of the north Atlantic, north Pacific and Arctic Oceans (Shumway et al. 1985). In the Gulf of Maine, northern shrimp are considered to comprise a unit stock. They inhabit soft mud bottom at depths of approximately 10 to 300 m, most commonly in the cold waters of the southwest Gulf of Maine (Haynes and Wigley 1969, Schick 1991). Temperature is an important factor in ontogenetic rates and reproductive success for this stock, because the Gulf of Maine is the southern limit of the species' distribution in the North Atlantic (Shumway et al. 1985).

Northern shrimp are protandrous hermaphrodites. In the Gulf of Maine, they generally spawn as males in their second year, then begin to transform into mature females in their third year. Oviparous females move to coastal waters in late autumn to spawn. Eggs hatch inshore, and juveniles migrate to deeper offshore waters as they begin to mature (Shumway et al. 1985).

A directed otter trawl fishery for northern shrimp began in coastal waters of Maine and Massachusetts during winter months in the 1930s and further developed in the 1940s, but inshore availability of shrimp soon declined (Scattergood 1952). An inshore winter fishery resumed in the late 1950s and steadily expanded to offshore areas throughout the year until the stock collapsed in the late 1970s (Clark and Anthony 1980; Clark 1981, 1982). After a regulated closure of the fishery in 1978, the fishery continued and grew to its current magnitude, which is a relatively valuable industry in New England (1995 landed value was \$13 million; NMFS 1996).

The Gulf of Maine fishery for northern shrimp is managed through interstate agreement among the states of Maine, New Hampshire and Massachusetts. The management framework evolved from 1972 to 1979 under the auspices of the State/Federal Fisheries Management Program. In 1980, this program was restructured in the Northeast Region as the Interstate Fisheries Management Program of the ASMFC (McInnes 1986). Within the interstate structure, the Northern Shrimp Technical Committee (NSTC) provides annual stock assessments and related information to the ASMFC Northern Shrimp Section (a management board). Management has been conducted primarily by controlling the length of fishing seasons (within the time frame of December to June) and gear restrictions. The fishing season currently extends from December of one year to May of the next year. Therefore, fishing seasons are labeled according to the calendar year for January of the fishing season (e.g., the 1996 season includes fishing from December, 1995 to May, 1996).

Stock assessments initially consisted of total landings estimates, indices of abundance from Northeast Fishery Science Center (NEFSC) groundfish surveys, fishing mortality estimates from the application of cohort slicing of length frequencies from the State of Maine survey, and yield per recruit modeling (Clark and Anthony 1980; Clark 1981, 1982). The NSTC developed a port sampling program in the early 1980s to characterize catch at length and developmental stage (sex and maturity), and established a dedicated research trawl survey for the species in the summer of 1983 to monitor relative abundance, biomass, size structure and demographics of the stock.

Subsequent stock assessments provided more detailed description of landings, size composition of catch, patterns in fishing effort, catch per unit effort, relative year class strength and survey indices of total abundance and biomass. Length distributions from the summer shrimp survey have been used for size composition analysis to estimate mortality rates, but did not fit the length-based models well because of variable recruitment and growth (Terceiro and Idoine 1990, Fournier et al. 1991). The present assessment is the first to integrate catch and survey indices of abundance for estimation of stock abundance and mortality rates, and provides estimates of egg production per recruit and revised estimates of yield per recruit.

THE FISHERY

Commercial Landings

Small quantities of northern shrimp have been incidentally caught in New England otter trawl fisheries since 1905 (Scattergood 1952). A directed winter fishery in coastal waters developed in the late 1930s, which landed an annual average of 63 mt from 1938 to 1953, but no shrimp were landed from 1954 to 1957 due to low inshore availability (Wigley 1973; Figure 1). The fishery resumed in 1958, and landings increased steadily to a peak of 12,100 mt during the 1969 season (August 1968 to July 1969) as an offshore, year-round fishery expanded. After 1972, landings declined rapidly, and the fishery was closed in 1978. The fishery reopened in 1979 and seasonal landings increased gradually to 5,300 mt by 1987 and averaged 3,300 mt from 1988 to 1994 (Table 1). Seasonal landings increased to 6,500 mt in 1995 and to 9,200 mt in 1996, which was only exceeded by the five years of landings prior to the late 1970s stock collapse. The preliminary estimate of landings for the 1997 fishing season is approximately 6,700 mt.

Maine landings comprised 75% of season totals during 1984-1996. Massachusetts and New Hampshire landed 17% and 8%, respectively (Table 1). The majority of landings generally occur in January and February (Figure 2).

Information on size and developmental stage of landed shrimp from port sampling (Tables 2 and 3) suggests that landings have been predominated by recruitment of three abundant year classes since 1985 (Figure 3; recruitment patterns are more pronounced in survey catches, described below). Landings more than tripled with recruitment of a strong 1982 year class in 1985 and 1986. Landings declined sharply in 1988 with the passage of this year class through the fishery. A strong 1987 year class began to recruit to the fishery in spring of 1989 and was a major contributor to the 1990-1992 fisheries. The 1992 year class began recruiting to the fishery in 1995. The moderate sized 1993 year class also contributed to relatively large annual landings in 1995 and 1996.

Landings from January to March consist primarily of mature female shrimp (presumably ages 3 and older) and December, April, and May landings have included higher proportions of males (assumed ages 1 and 2; Figure 4). These patterns reflect shifts in distribution of fishing effort in response to seasonal movements of mature females: inshore in early winter and offshore after their eggs hatch.

Catch in numbers was derived by dividing landed weight (Table 1) by mean individual weights (Table 4) by year, state, and month. The general patterns in size composition of landings are reflected in mean weight of individual shrimp landed by year, state, and month: the size of landed shrimp generally increases from December to January, peaks in February, and decreases through the spring. Three percent of total landings for 1984-1996, were from specific year-state-month strata with no port samples, generally from the beginning or the end of a fishing season. Mean weight for these non-sampled landings was estimated by a general linear model of mean weight incorporating year, month and state effects. Some June landings, which had no associated port samples (126 mt, 0.2% of total time series landings), were described using May samples within the same year and state.

Discarded Catch

Sea sampling observations on shrimp otter trawl trips from 1984 to 1996 indicate that weight of discards is less than 1% of total catch in all years (Table 5). Large year classes appear to contribute some discards as age-2 (e.g., the 1992 cohort produced almost 1% discards in 1994). Industry representatives report substantial discards of shrimp in the small-mesh whiting fishery east of Jeffrys Ledge. Sea sampling observations from finfish trawl fisheries in the Gulf of Maine suggest that bycatch of northern shrimp was inconsequential from 1984-1994. However, in 1995 and 1996 the amount of discarded shrimp per trip increased considerably, and the increase was from small-mesh trips sampled in the area of Jeffrys Ledge. Although the observed discards increased, the total was less than 60 kg per observed trip. Unfortunately, no shrimp lengths were measured during sea sampling, and estimates of total number discarded would be difficult. Therefore, discard estimates were not included in the present stock assessment.

Fishery Selectivity

Selectivity of commercial trawl gear was estimated experimentally in July 1995, twenty miles south of Boothbay Harbor (Schick and Brown 1997). Five paired tows were sampled with a trouser trawl over a two-day period. The trouser body consisted of 47.6 mm (1-7/8") diamond polypropylene mesh as did the septum, which divided the trawl in half vertically. The control codend was 12.7 mm (1/2") square polypropylene mesh with a 6.4 mm (1/4") mesh liner. The experimental codend consisted of 47.6 mm (1-7/8") diamond polypropylene mesh.

Three five-kg samples from each codend were bagged, labeled, stored on ice at sea, and then frozen. Mid-dorsal carapace length (CL) was measured for 500 shrimp from each sample. Sample length frequencies were expanded to total catch length frequencies using the ratio of sample weight to catch weight. Observed retention ratios at length were derived by dividing the number at length from the experimental codend (large mesh) by the number at length from the control codend (small mesh). The average of five ratios, one from each tow, was used to fit a selectivity ogive (Nicolajsen 1988):

$$P = 1/(1+e^{-(\alpha CL+b)}) \quad (1)$$

where P is the proportion retained at size. The parameters a and b were estimated using logistic regression. The CL range used in the regression was 13.5-28.5 mm CL.

Nominal Fishing Effort and Catch per Unit Effort

The number of vessels participating in the Gulf of Maine northern shrimp fishery was estimated to range between 300 and 400 in recent years. The distribution of vessel sizes in the shrimp fishery, as indicated by gross registered tonnage, has been relatively stable since 1986: approximately 20% vessels less than 10 gross registered tons, 60% 10-50 tons, and 20% greater than 50 tons. The relative proportion of smaller vessels (<5 tons) in the fishery appears to have been more variable than participation by larger vessels. Most fishing is conducted by otter trawls, although traps are also used off the central coast of Maine. Trapping operations generally account for 4-8% of the Maine's total number of trips. Trap landings have remained below 5% of the annual total reported for the state.

From 1975 to 1994, nominal fishing effort (the number of trips landing shrimp) was estimated from dealers' reported landings and landings per trip information from dockside interviews of vessel captains. For the 1995 and 1996 fishing seasons, the ratio of landings from mandatory Federal vessel trip reports to total dealer weighout landings was used to expand reported trips to total trips. This expansion assumes that unreported trips have the same catch rates as reported trips. Smaller vessels that are not required to file logbooks may have lower catch rates than those reported, and effort may be overestimated for 1995 and 1996. The interview system, used for 1975-1994 effort estimates had a similar bias toward sampling larger boats. Nominal effort increased in the late 1960s to average 16,000 for the 1970-1972 fishing seasons. Effort decreased rapidly in the 1970s, but increased considerably after the 1978 closure was recinded. The number of trips peaked at 12,300 during the 1987 season, decreased to 6,000 trips in 1994, and increased again to 12,000 trips in 1996 (Figure 5).

More detailed effort information has been evaluated over the past 6 years by port sampling interviews in Maine and New Hampshire. The time series of total hours fished reflects the pattern of total trips, suggesting that recent estimates of nominal trips are not substantially overestimated by logbook data in the last two years (Figure 5). The amount of offshore fishing effort has varied seasonally, reflecting movements of mature females (inshore in early winter and offshore following larval hatching).

Effort standardization was not possible, because number of tows and haul duration data from vessel logbooks have not been audited (NEFSC 1996). However, 1984-1993 standardized effort closely reflected nominal effort (Richards 1993).

Catch per unit effort (landings per hour fished) from Maine and New Hampshire port interviews indicates an increasing trend in catch rates since 1993 (Figure 5). The increase in catch rates may reflect increased biomass or denser aggregations of shrimp, which make them more available to the gear. Another possible cause for an increase in catch rate is an increase in vessel fishing power, which can not be assessed independently.

RESEARCH TRAWL SURVEYS

Trends in abundance have been monitored since the late 1960's using data collected by NEFSC spring and autumn bottom trawl surveys and summer surveys by the state of Maine and the NSTC (Figure 6).

Maine Survey

Maine conducted summer surveys in the Gulf of Maine from 1967 to 1983. Fixed stations were sampled with an otter trawl during daylight at locations where shrimp abundance was historically high (Schick et al. 1981; Figure 7). The Maine survey biomass index began declining in 1968, and depicts the stock collapse in the late 1970s (Figure 6; Clark 1981, 1982; Schick et al. 1981).

Groundfish Surveys

NEFSC autumn bottom trawl surveys have been conducted since 1963, and spring bottom trawl surveys have been conducted since 1968. Stations are sampled from Cape Hatteras to Nova Scotia according to a stratified random design (Figure 8; Despres et al. 1988). Although the groundfish surveys catch relatively fewer northern shrimp and have more measurement error, they represent a longer time series. Correspondence among research surveys and fishery indices of abundance suggests that the autumn survey tracks resource conditions more closely than the spring survey (Clark and Anthony 1980; Clark 1981, 1982). The autumn survey indicates a precipitous decline from peak biomass in the 1960's to 3% of peak levels in the late 1970's. The index subsequently increased in the 1980s and, since the mid 1980s, has fluctuated at approximately 40% of the peak levels observed in the 1960s (Figure 6).

NSTC Shrimp Survey

The NSTC shrimp survey has been conducted each summer since 1983 employing a stratified random sampling design and gear specifically designed for Gulf of Maine conditions (Blott et al. 1983, Clark 1989). The summer survey is considered to provide the most reliable information available on abundance, distribution, age and size structure and other biological parameters of the Gulf of Maine northern shrimp resource. Indices of abundance and biomass are based on catches in the strata that have been sampled most intensively and consistently over time (strata 1, 3 and 5-8; Figure 9). Survey catches have been highest in strata 1, 3, 6 and 8, the region from Jeffreys Ledge and Scantum Basin eastward to Penobscot Bay. The 1983 survey did not sample strata 6-8.

The statistical distribution of survey catch per tow (in numbers) was investigated to determine the best estimator of relative abundance. Catches within strata were distributed with significant positive skew, and arithmetic stratum means were correlated to stratum variances. Log transformed catches ($\ln[n+1]$) were more normally distributed. Log transformation is a common practice for estimating relative abundance from trawl surveys, because stratum means and variances are seldom independent, and log transformation generally normalizes observations, renders the variance independent, and reduces anomalous fluctuations (Grosslein 1971).

Geometric means were estimated with more precision (mean CV=2.4%) than arithmetic means (mean CV=13.5%). Therefore, stratified geometric mean catch per tow was used to estimate relative abundance. The nontransformed and transformed indices have different magnitudes and temporal patterns, particularly in recent years (Figure 10). The 1996 arithmetic mean is slightly below the time series mean, but the 1996 geometric mean is the lowest in the time series. Annual variation in the difference between the two series reflects varying degrees of skewness, or patchiness of shrimp aggregations from year to year, which is consistent with observations from the fishery (i.e., the shrimp appear to be more patchily distributed when abundance is low).

Shrimp survey catches by length and developmental stage (Figure 11) reflect the predominance of the strong 1982, 1987 and 1992 cohorts in the stock. Although size at age-1.5 varies from year to year, discrete length modes indicate the relative abundance of age-1.5 shrimp (generally around 12-18.5 mm CL) and age-2.5 shrimp (generally 19-23 mm CL). Length modes for older cohorts overlap extensively.

A "selectivity method" was used to derive indices of recruits and fully-recruited shrimp from survey length frequencies (NEFSC 1995). The number per tow at length was partitioned into three components: fully-recruited, recruits, and pre-recruits (as illustrated in Figure 12). The fishery selectivity curve (Schick and Brown 1997, described above) was used to define fully-recruited shrimp. The products of selectivity at length and survey catch per tow at length were summed to derive total catch per tow of fully-recruited shrimp. The carapace length of each interval was increased by one year of growth according to a vonBertalanffy growth curve:

$$CL_{t+1} = CL_t + (CL_{\infty} - CL_t) (1 - e^{-K}) \quad (2)$$

where $CL_{\infty}=35.2$ and $K=0.36$ (McInnes 1986) to estimate fishery selectivity after a year of growth. The remaining length frequency of recruits and pre-recruits was then multiplied by the end-of-year selectivity at length to obtain an index of recruits. Using the selectivity method, age-classes recruit to the fishery over several years, and recruitment in each year is composed of several cohorts. Therefore, the definition of recruitment used in this assessment is not synonymous with year-class strength (previous northern shrimp assessments defined recruitment as age-2.5 abundance).

Mean weight of recruits and fully recruited shrimp were estimated according to length-weight equations for each developmental stage from Haynes and Wigley (1969) and 1990 northern shrimp survey observations.

ABUNDANCE AND FISHING MORTALITY ESTIMATES

Methods

A modified DeLury model (Collie and Sissenwine 1983, Conser and Idoine 1992) was applied to the Gulf of Maine northern shrimp fishery:

$$N_{t+1} = (N_t + R_t - C_t) e^{-M} \quad (3)$$

where fully-recruited abundance at the end of the year (N_{t+1}) equals fully-recruited abundance at the beginning of the year (N_t), plus recruitment (R_t), minus catch (C_t), all reduced by one year of natural mortality (e^{-M}).

Natural mortality (M) was assumed to be 0.25, as approximated from the intercept of a regression of total mortality on effort (Rinaldo 1973, Shumway et al. 1985). Estimates of Z for age-2+ shrimp from visual inspection of length modes from the Maine summer survey was 0.17 from 1977 to 1978, when the fishery was closed (Clark 1981, 1982), suggesting, for the population as a whole, M is low relative to estimates for other *Pandalus* stocks, which range from 0.2 to 0.8 (ICES 1977, Abramson 1980, Frechette and Labonte 1980).

Catch was assumed to be taken at mid-year, whereby the summer survey marks the beginning of the "survey year" (August 1), and catch was taken on February 1 of the next calendar year (which was based on the time of 50% cumulative seasonal catch for 1985-1996 (Figure 2):

$$N_{t+1} = [(N_t + R_t)e^{-0.5M} - C_t] e^{-0.5M} \quad (4)$$

so that recruited shrimp ($N_t + R_t$) experience a half-year of natural mortality ($e^{-0.5M}$), catch is removed, then the survivors $[(N_t + R_t)e^{-0.5M} - C_t]$ experience another half-year of natural mortality.

Abundance is related to survey indices of relative abundance:

$$n_t' = q_n N_t e^{\eta t} \quad (5)$$

and

$$r_t' = q_r R_t e^{\delta t} \quad (6)$$

where r_t' and n_t' are observed survey indices of recruits and fully-recruited shrimp, q is catchability of the survey gear, and $e^{\eta t}$ and $e^{\delta t}$ are lognormally distributed measurement errors. The process equation is derived by substituting survey indices into equation 4 and including lognormally distributed process error ($e^{\epsilon t}$):

$$n_{t+1} = [(n_t + r_t/s_r)e^{-0.5M} - q_n C_t] e^{-0.5M} e^{\epsilon t} \quad (7)$$

where

$$s_r = q_r / q_n \quad (8)$$

is the relative selectivity of recruits to fully-recruited shrimp. Selectivity studies (Blott et al. 1983) and survey catch at length suggest that age-1.5 sized shrimp are sampled less efficiently than age-2+ shrimp, because total catch per tow is greater at age-2.5 than at age-1.5 for some cohorts (Figure 11). For the shrimp survey, there are two components to s_r : selectivity and availability of age-1.5 shrimp. The 32mm codend mesh in the survey trawl may not retain some

small shrimp, and in some years, age-1.5 males may not completely migrate from inshore areas to the survey strata (Figure 9). Precise estimation of survey selectivity at size was not possible due to high variability in catch at size and few comparative experimental tows (Blott et al. 1983). For the present analysis, s_t was approximated from the relative sampling efficiency of <19mm CL shrimp to that of larger shrimp, and the relative proportions of those sizes comprising total recruits and fully recruited indices.

The parameters n_t , r_t , and q_n were estimated by iteratively minimizing the sum of measurement errors (equations 5 and 6) and process errors (from equation 7) for the entire time series. Total mortality (Z) and fishing mortality (F) were calculated from abundance estimates:

$$Z_{R+N,t} = \text{Ln} [(N_t + R_t) / N_{t+1}] \quad (9)$$

and

$$F_{R+N,t} = Z_{R+N,t} - M \quad (10)$$

The fishing mortality can be partitioned according to the average partial recruitment (p) of recruits over the survey year:

$$F_{N,t} = [F_{R+N,t}(R_t+N_t)] / p R_t \quad (11)$$

and

$$F_{R,t} = p F_{N,t} \quad (12)$$

Average partial recruitment was derived from the schedule of growth to fully-recruited size over the survey year, as approximated by observations of monthly growth of age-1.5 shrimp from a mean carapace length of 14.5mm in July to 21.9mm CL the next July (Haynes and Wigley 1969).

Results

DeLury results are summarized in Table 6 and more detailed model output is reported in Appendix A. Parameters were relatively well-estimated. Coefficients of variation for fully-recruited abundance estimates ranged from 19% to 25%, estimates of recruitment were slightly less precise (CV=23% to 25%), and q_n was estimated with moderate precision (CV=21%). There were no large correlations among the 26 parameter estimates, but q_n was weakly correlated to recruitment in 1996 and 1997 ($r=0.4$). Standardized residuals ranged from -1.1 to 1.0 without significant annual patterns, indicating that the data fit the model well (Figure 13).

Recruitment estimates averaged 0.7 billion, peaked at 1.0 billion in 1990, but decreased in recent years to 0.4 billion in 1997. Fully-recruited abundance averaged 0.8 billion, peaked at 1.2 billion in 1991, and decreased to 0.5 billion in 1997, the lowest level in the time series. Comparison of DeLury estimates of fully-recruited abundance to minimum abundance estimates from area-swept expansion suggests that the q estimate is realistic: area-swept estimates were less than DeLury estimates in all years, ranging 0.2 billion-0.5 billion, which implies a survey catchability of approximately 0.5. Total stock biomass estimates averaged 12,500 mt, peaked at over 17,000 mt in 1991, and decreased to 7,300 mt in 1997. The pattern of biomass estimates is similar to

biomass indices from the autumn groundfish survey, and the magnitude of biomass estimates are similar to those estimated for the early 1970s using total catch and survey estimates of F (Anthony and Clark 1980).

Annual estimates of F_{R+N} averaged 0.36 from the 1985 to 1995 fishing seasons, and increased to 0.90 in the 1996 fishing season (Figure 14). The increased F in the 1996 season reflects the pattern in nominal fishing effort (Figure 5). Estimates of mortality in the first and last years are the least reliable in DeLury analysis, because they are linked to one adjacent year rather than two. Averages of terminal mortality estimates (e.g., $F_{95-96}=0.65$ or $F_{94-96}=0.54$) are less sensitive to measurement error in the 1996 survey observation of fully-recruited shrimp. However, averaging F_{96} with previous years may be inappropriate because of the apparently significant increase. Total mortality estimates were within the range of previous estimates using visual inspection of survey length frequencies (previous NSTC reports), Shepherd's Length Composition Analysis (Terceiro and Idoine 1990) and MULTIFAN (Fournier et al. 1991).

Two hundred bootstrap replicates, which were derived by randomly resampling model residuals, suggest that estimates of abundance, biomass and mortality were relatively precise. The median bootstrapped value for F_{96} was 0.93 with an 80% confidence interval of 0.74 to 1.14 (Figure 15). The median F_{95-96} was 0.72 (80% CI=0.59 to 0.84) and the median F_{94-96} was 0.58 (80% CI=0.47 to 0.67). Abundance estimates were not bias-corrected, because estimates of bias were not substantial (<10% in most years).

Sensitivity Analyses

Alternative DeLury analyses were conducted to evaluate sensitivity of results to several assumptions: alternative estimates of M , fishery selectivity, relative survey selectivity of recruits, survey catches, and statistical weighting (Table 7, Figure 16).

The level of M for northern shrimp is uncertain. As described above, there are two sources of information for the Gulf of Maine stock: M was estimated as 0.25 by regressing Z on effort, and as 0.17 from survey catches before and after the fishery closure. These M estimates are below most levels estimated for other stocks of northern shrimp (*Pandalus borealis*). An international working group was unable to precisely determine M , but used 0.5 for an Iceland stock based on catch curves of survey length frequencies, and assumed M for other stocks based on the relative abundance of cod in the area (ICES 1977). An estimate for the Gulf of Alaska stock was 0.35 (Abramson 1980). Frechette and Labonte (1980) reported several estimates of M for the Gulf of Saint Lawrence stock using three years of survey length distributions: 0.4 for age-2+, and 0.2-0.8 for age-3+. A DeLury analysis with $M=0.35$ was conducted to investigate sensitivity of results to M . Greater values for M would exceed some estimates of total mortality. Although the magnitude of Z is affected by the assumed value of M , the temporal pattern does not appear to be sensitive to M (Figure 16), but q and abundance estimates were sensitive. Results from this sensitivity run suggest that substantial catch was produced with negligible F (0.03), because stock abundance and biomass estimates were much greater than those from the base run ($M=0.25$).

Estimates of fishery selectivity from trouser trawl experiments (Schick and Brown 1997, described above) produced a very gradual selectivity curve (Figure 12). Survey and commercial data were used to derive retention ratios at length as an alternative method of approximating vulnerability at size (NEFSC 1995). The ratio of cumulative length frequencies from the 1996 spring NEFSC survey and April 1996 port samples were used to approximate vulnerability at size. The resulting vulnerability curve is steeper than the selectivity curve, and the estimated length at 50% retention is slightly smaller. The "selectivity method" of estimating recruits and fully-recruited shrimp from summer survey catch at length, described above, was revised using the vulnerability curve for an exploratory DeLury analysis. The results from the sensitivity run were similar to the results using the selectivity experiment data (Figure 16), suggesting that these results are not very sensitive to slight changes in L_{50} or substantial changes in the steepness of the assumed selectivity curve.

Previous NSTC stock assessments did not log transform survey catches to derive abundance indices. Sensitivity of log transformation was evaluated by processing untransformed catch at length data to derive alternative indices of recruits and fully-recruited shrimp for an alternative DeLury analysis. Abundance and mortality estimates from this sensitivity run were similar to those using Log transformed survey indices (Figure 16), because the greater magnitude of non-transformed survey indices was compensated by a greater estimate of q .

Sensitivity to the estimates of annually variable s_t was evaluated by setting a time series average ($s_t=0.9$) to all years. Results using $s_t=0.9$ were nearly identical to the base run (Figure 16). Increasing s_t to 1.0 decreased mortality estimates slightly, and decreasing s_t to 0.8 slightly increased mortality estimates (Figure 16).

Terminal estimates from DeLury analysis are typically sensitive to the statistical weighting of process and measurement errors (e.g., NEFSC 1995). The northern shrimp DeLury analyses had equal weighting of error components. There was a slight pattern of positive process residuals in the middle of the time series, and process errors accounted for 45% of total model error. A model run with double weighting of process error was attempted to assess the sensitivity of F_{96} to weighting, decrease to proportion of process error in the solution, and perhaps reduce the residual pattern. The sensitivity run indicated an increase in F_{96} to 0.96 (from 0.90 with equal weighting), 31% process error, and the same pattern of residuals. Therefore, increasing the weight of process error would increase F_{96} , and downweighting process error would not be appropriate, because it is not likely that process errors are greater than survey measurement errors.

Statistical diagnostics of all DeLury runs for sensitivity analyses were similar (Table 7). All sensitivity analyses resulted in an average total mortality of approximately 0.6. Estimated F was greatest in 1996 from all model runs. Therefore, the reported level and temporal pattern of mortality estimates are robust to all assumptions which were evaluated.

Retrospective Analysis

Comparison of results from eight retrospective DeLury analyses to the results reported above was investigated to assess the stability of estimates in the last year of the analysis and the possibility that terminal mortality estimates are systematically inconsistent. The analysis was performed by sequentially truncated by deleting the last year of survey and catch data to create a retrospective series of DeLury estimates (Figure 17). Terminal mortality estimates were quite stable in most years. Retrospective differences in Z were positive for the first two terminal estimates (1988 and 1989), negative for the next three (1990-1992), and positive for the last three (1993-1995).

Confirmatory Analysis

An alternative method of estimating stock size and F was explored to corroborate results from DeLury analysis. A nonequilibrium surplus production model (Prager 1994, 1995) was fit to seasonal catch and survey biomass indices from 1968 to 1996 (summarized in Table 8, more detailed output in Appendix B). The model assumes logistic population growth, in which the change in stock biomass over time (dB_t/dt) is a quadratic function of biomass (B_t):

$$dB_t/dt = rB_t - (r/K)B_t^2 \quad (13)$$

where r is intrinsic rate of population growth, and K is carrying capacity. For a fished stock, the rate of change is also a function of F :

$$dB_t/dt = (r-F_t)B_t - (r/K)B_t^2 \quad (14)$$

For discrete time increments, such as annual fishing seasons, the difference equation is:

$$B_{t+1} = B_t + (r-F_t)B_t - (r/K)B_t^2 \quad (15)$$

Initial biomass (B_1), r , and K were estimated using nonlinear least squares. The fall groundfish survey catch per unit effort (CPUE) contributed to the total sum of squares as a series of observed effort ($E=CPUE/C$); the Maine summer survey and the NSTC shrimp surveys contributed as independent indices of biomass at the start of the fishing season. Note that no assumption about M is needed for the biomass dynamics analysis.

One survey observation (fall 1982) was a statistical outlier, and the pattern of residuals from Maine and NSTC surveys suggest autocorrelation (Figure 18). The majority of variance in the fall and Maine surveys was explained by the model ($R^2=0.6$ and 0.7 , respectively), but much of the variation in the summer shrimp survey was not resolved ($R^2=0.2$). The model did not account for peaks in biomass from strong recruitment.

Estimates of F from the biomass dynamics model generally confirm the pattern and magnitude of estimates from the DeLury model; F_{96} was the highest value since 1975 (Figure 19). Recruitment of the strong 1982, 1987, and 1992 cohorts is not as pronounced in the biomass trajectory from

the production model, because dynamic recruitment is not explicitly estimated, as it is in the DeLury analysis. The biomass dynamics model suggests that a maximum sustainable yield (MSY) of 5,000 mt can be produced when stock biomass is approximately 31,000 mt (B_{MSY}) and F is approximately 0.2 (F_{MSY} ; Figure 20). However, B_{MSY} was only exceeded by the first three years in the analysis, which are not reliable (Prager 1994, 1995).

Survey residuals were randomly resampled 200 times to estimate precision and model bias. Bootstrap results suggest that r , MSY and F_{MSY} were relatively well estimated (relative interquartile ranges were <17%, and bias was <3%). Estimates of K , B_{MSY} , and q 's were moderately precise (relative IQs were 23-25%, bias was <2%), and B_1 was not as precisely estimated (relative IQ=45%). Fishing mortality in 1996 was estimated with less precision than DeLury analysis (relative IQs were 24% from DeLury analysis and 59% from the production model). Similarly, B_{96} was estimated with less precision than DeLury analysis (relative IQs were 24% from DeLury analysis and 76% from the production model).

Three alternative production model runs were investigated. The first sensitivity run removed the summer shrimp survey, which did not fit the model well, to provide a more independent confirmation of the DeLury analysis; the revised analysis had very similar parameter estimates and trajectories of F and biomass. Another run removed both the summer shrimp and Maine surveys; the model did not converge well, but did produce similar parameter estimates and slightly lower biomass trajectories. The third alternative run included the preliminary estimate of 1997 landings (6,500 mt); parameter estimates and trajectories did not change from the base run, and F_{97} increased to 2.5. The original run, with three series of survey indices and 1968-1996 landings, was accepted as the best configuration.

BIOLOGICAL REFERENCE POINTS

Yield per recruit (Thompson and Bell 1934) and percent maximum spawning potential (Gabriel et al. 1989) were estimated for the Gulf of Maine northern shrimp fishery (Table 9, Figure 21). Yield and egg production were derived as a function of abundance at the time of spawning (i.e., abundance at the start of the year, approximately February 1) to reflect size and weight at age during spawning and the fishery. The model assumes annual growth and ontogenetic transition occur before oviposition and the onset of the fishing season. As described above, M was assumed to be 0.25 (Rinaldo 1973). Length at age was estimated using the vonBertalanffy growth parameters $L_{\infty}=35.2$ mm and $K=0.36$ (McInnes 1986). Proportion female at the time of hatch was the average of 1984-1996 observed sex ratios at length from the summer survey, applied to a carapace length which was increased by a half-year of growth using equation (2). Selectivity at size was estimated using the selectivity curve from Schick and Brown (1997), described above. Mean weight at length for males and females was estimated using relationships developed by Haynes and Wigley (1969). Estimates of fecundity at oblique CL were from a linear relationship developed by Apollonio et al. (1984).

Yield per recruit was maximized at $F=0.77$ (F_{max}) (Table 9). The increase in yield per unit F decreased to one tenth the initial increase at $F=0.46$ ($F_{0.1}$). Maximum spawning potential (i.e., with no F) was 2,395 eggs per recruit. Spawning potential was reduced by half at $F=0.25$ ($F_{50\%}$).

Information from the stock collapse in the 1970s may provide guidance on the level of sustainable F for Gulf of Maine northern shrimp. Biomass indices from the Maine survey and the biomass dynamics model suggest that biomass was declining as early as 1968. Log catch ratios of assumed age-2+ shrimp from survey length frequencies suggested that F was 0.7 to 0.8 from 1968 to 1970, and continued annual harvests of over 5,000 mt drove F to an annual average of 1.6 from 1971 to 1975 (Clark and Anthony 1980). Estimates of F from the first several years of the production model (e.g., 1968-1972) are imprecise and are not considered reliable (Prager 1994, 1995), but F estimates for 1973-1975 ranged from 0.6 to 1.1 (Figure 19). According to the present egg production per recruit analysis and historical F estimates, the stock was not replacing itself when spawning potential was reduced to less than 18% of maximum, and the stock collapsed when egg production was reduced further. Therefore, $F_{20\%}$ may be an appropriate overfishing threshold, which would result in target F s well below 0.6.

Reproductive success for Gulf of Maine northern shrimp is influenced by population fecundity and spring seawater temperature (Richards et al. 1996, Richards and Clark 1996). Landings are also correlated to lagged population fecundity (Stickney 1980, Richards et al. 1996). Although temperature conditions affect survival and growth during early life history, the shrimp survey index of age-1.5 shrimp biomass is significantly correlated to the biomass index of females from two years previous ($r=0.6$; Figure 22). A survey index of egg production, derived as the sum of catch per tow of females at length multiplied by fecundity at length (Apollonio et al. 1984), had a similar relationship to recruitment. The two dominant cohorts in the time series were produced when spawning stock biomass was among the highest levels in the time series. When spawning stock indices were greater than 6 kg/tow, two of four dominant cohorts were produced. These relationships suggest that poor recruitment is more likely at low levels of spawning stock biomass and egg production, and adequate egg production per recruit should be conserved. The 1996 spawning stock index was 3 kg/tow; all cohorts produced by spawning indices of 3kg/tow or less were below average.

Survey indices of egg production, recruitment, and spawning biomass (Figure 22), and historical estimates of spawners and recruits (Richards et al. 1996, Richards and Clark 1996) suggested that at median survival rates, greater than 50% of maximum spawning potential was needed to replace the stock. Provisional F_{med} estimates (Sissenwine and Shepherd 1987, Gabriel et al. 1989) averaged 0.20 (0.10 based on eggs/recruit, 0.16 based on spawning biomass/recruit, and 0.35 based on the extended series of spawners/recruit), which is similar to F_{MSY} . However, survival ratios and estimates of F_{med} may be underestimated, because partial selectivity of recruits to the survey was not accounted for.

DISCUSSION

It appears that the high F in 1996 was the result of a large removal from a low stock size and an increase in catchability. This interpretation is based on patterns in catch, effort, and survey indices. Landings and effort increased sharply in 1995 and continued to increase in 1996 (Figures 1 and 5), but F increased moderately in 1995 and substantially in 1996 (Figure 14). Survey indices of abundance increased in 1995 then declined in 1996 (Figure 13). Catch per unit effort has steadily increased since 1993 (Figure 5).

Updating the analysis with 1997 catch and survey information may change the estimates of abundance and F in 1996. However, given the magnitude of past measurement errors in survey indices and the large catch in 1996, it is unlikely that revised estimates of F_{96} will be substantially lower.

Recent temperatures in the Gulf of Maine, as illustrated by Boothbay Harbor observations, were well above average in 1996. Correlation analyses indicate that, although spawning stock is the principal determinant of year class strength, larval survival is reduced at high temperatures (Richards et al. 1996, Richards and Clark 1996). It was also reported that catchability decreased in 1997 due to high winter temperatures. At high temperatures and low stock sizes, the probability of a strong year class may be poor in the near future. Under conditions of high temperature, the risk of stock collapse at high F is greater.

Yield per recruit reference points (F_{max} , $F_{0.1}$) may be too high to use as overfishing thresholds, and spawner-recruit information is too preliminary to use for determining the level of F which will provide adequate stock replacement. The 1985-1995 mean F (0.36) produced relatively stable stock sizes. An F of 0.36, which corresponds to 38% of maximum egg production per recruit and is slightly below $F_{0.1}$, may be an appropriate interim management target pending more definitive analyses

ACKNOWLEDGMENTS

The Northern Shrimp Technical Committee thanks all those people that have contributed to this assessment through their time and efforts as past Technical Committee members, scientific and vessel crew on the shrimp survey, port samplers, sample processors, data entry personnel, and data processors. Anne Richards and Paul Rago initiated the development of the present yield and egg production per recruit analyses. Han-Lin Lai provided guidance on DeLury methods and reviewed the draft report. Steve Murawski reviewed the final document.

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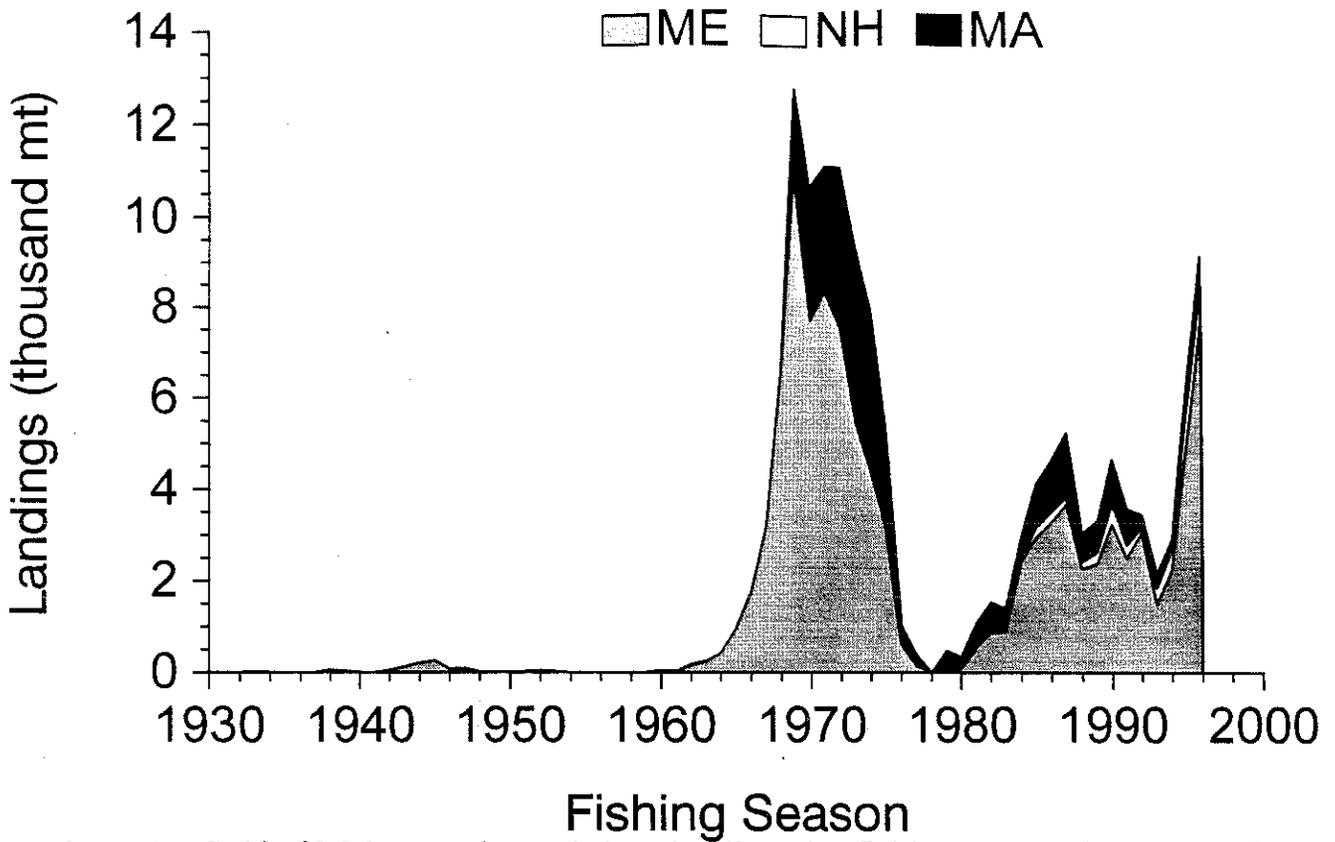


Figure 1. Gulf of Maine northern shrimp landings by fishing season (August to July).

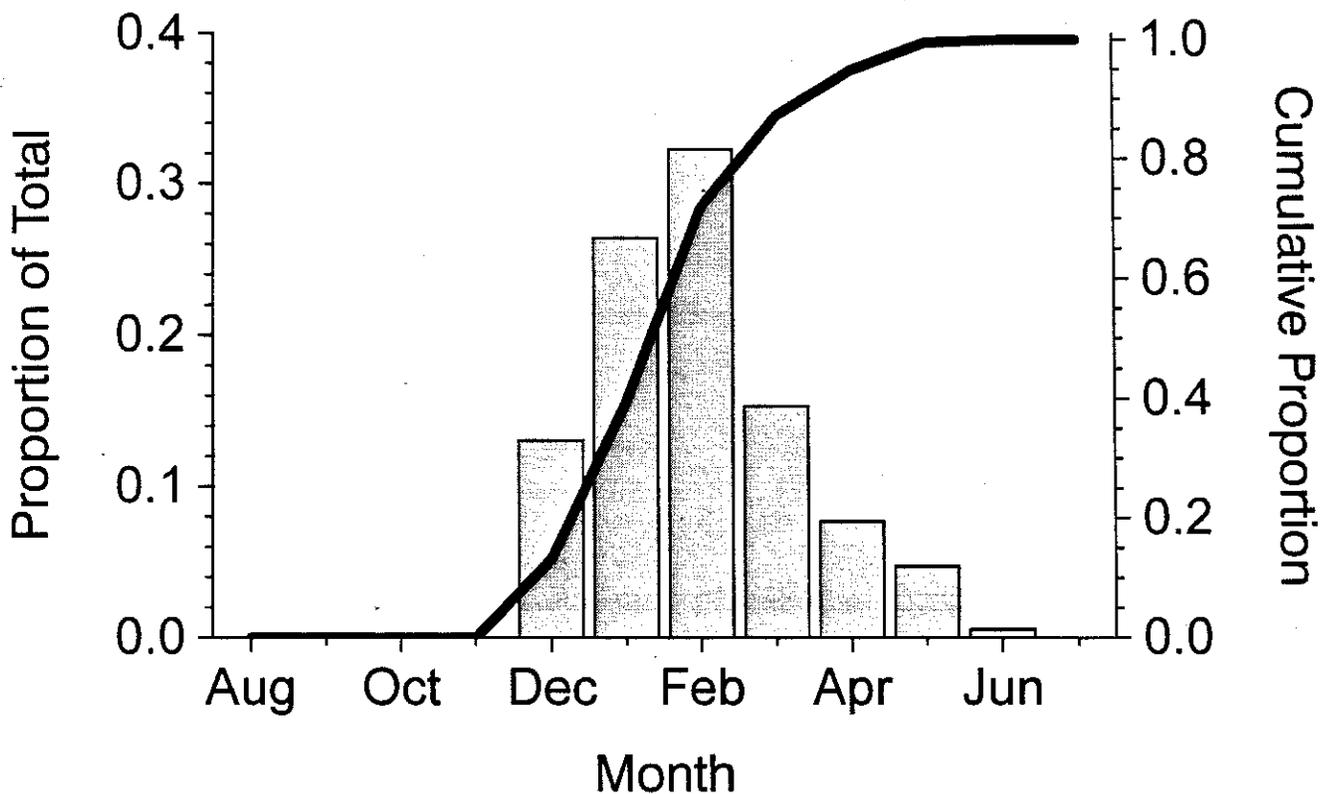


Figure 2. Distribution of monthly landings of Gulf of Maine northern shrimp, 1984-1996.

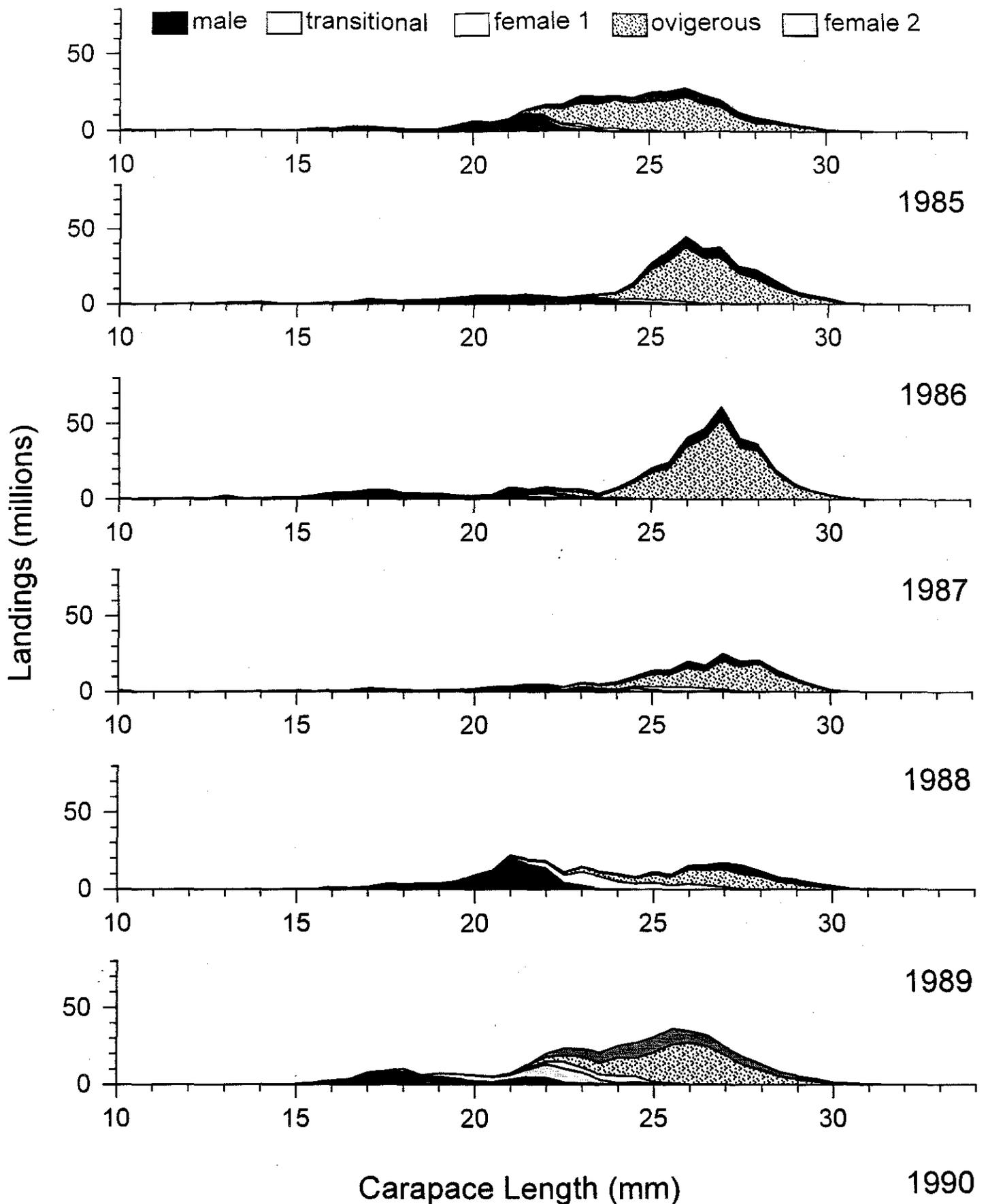


Figure 3. Gulf of Maine northern shrimp landings by length, developmental stage, and fishing season.

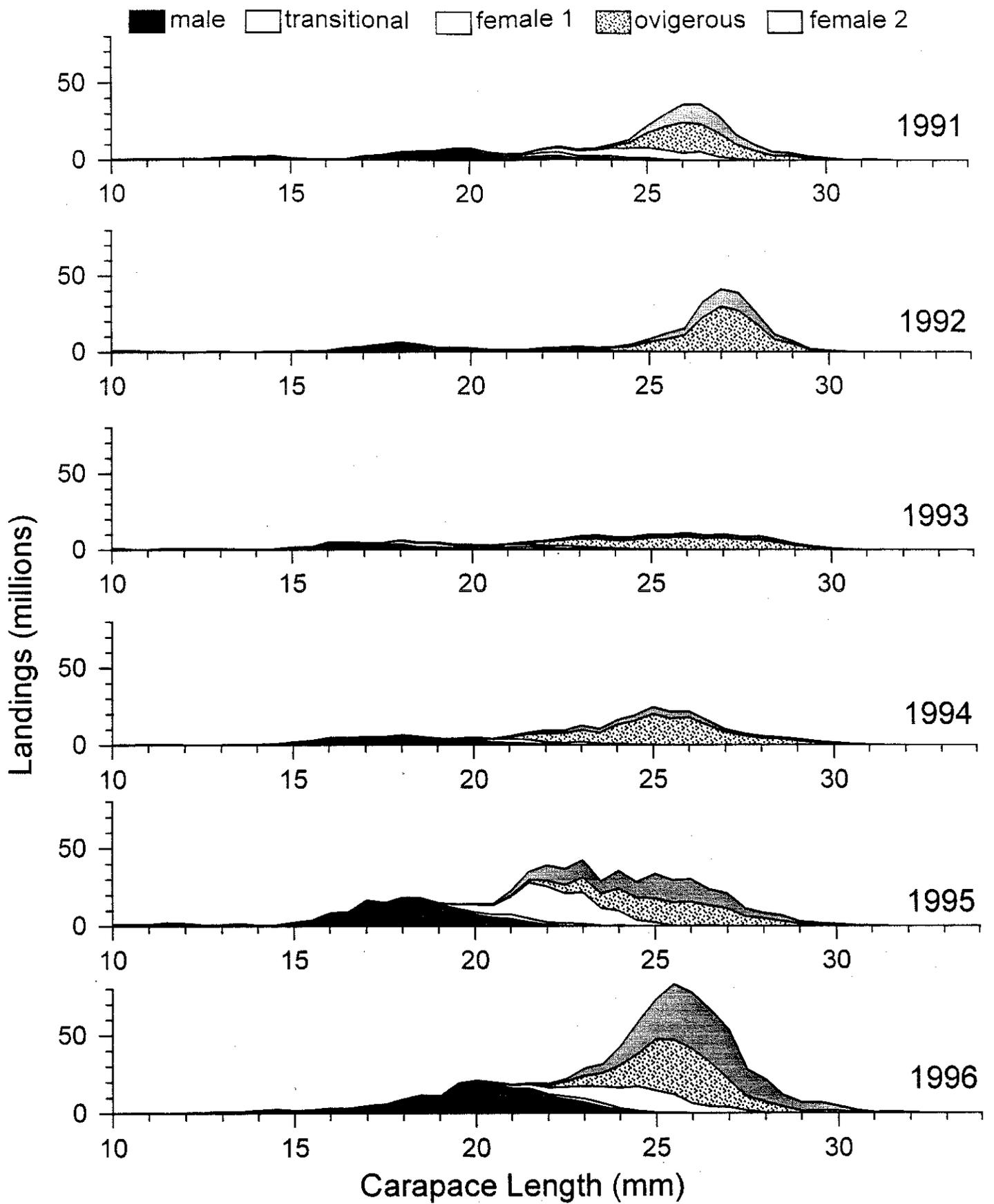


Figure 3. continued.

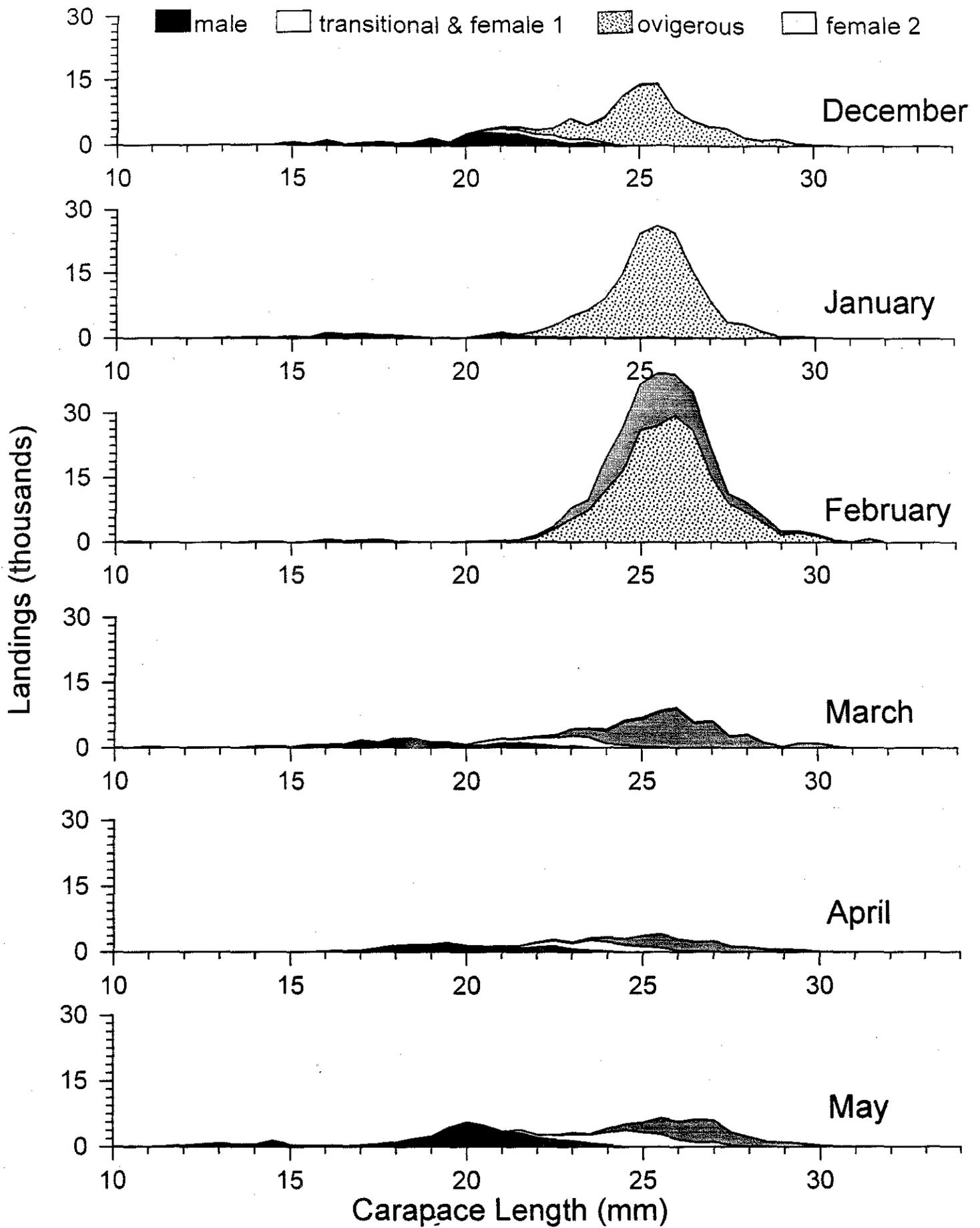


Figure 4. Gulf of Maine northern shrimp 1996 landings by length, developmental stage, and month.

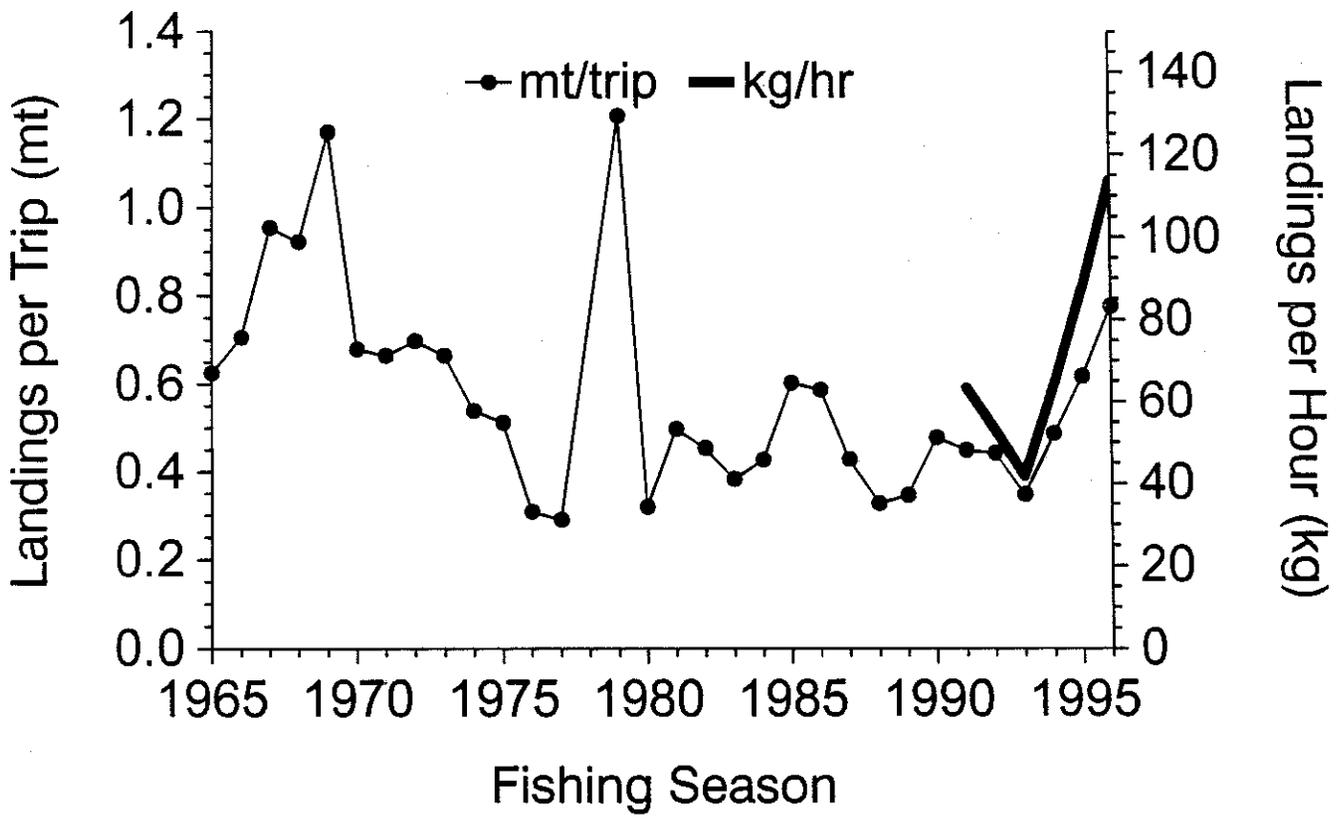
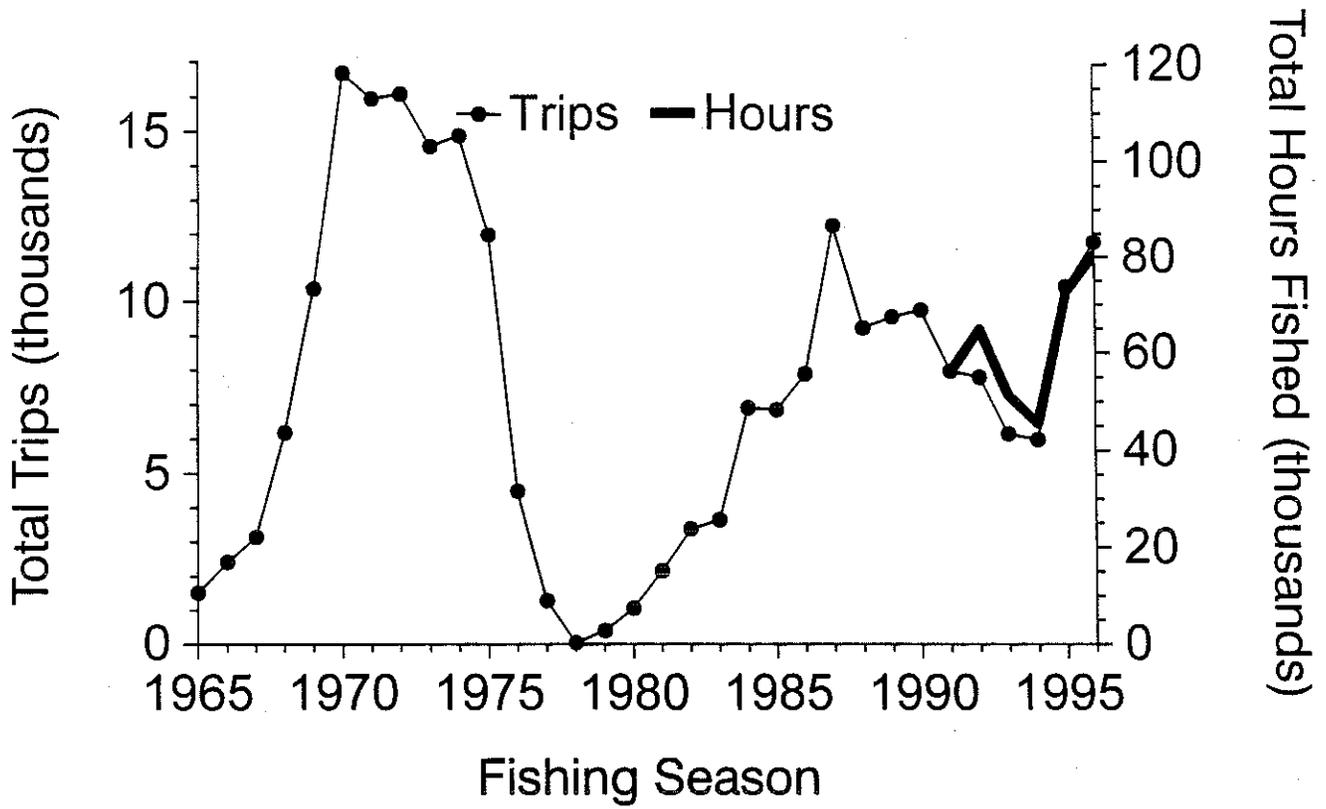


Figure 5. Nominal fishing effort (above; 1965-1996 trips from NMFS data, 1991-1996 hours data-from state interview data) and catch per unit effort (below) in the Gulf of Maine northern shrimp fishery.

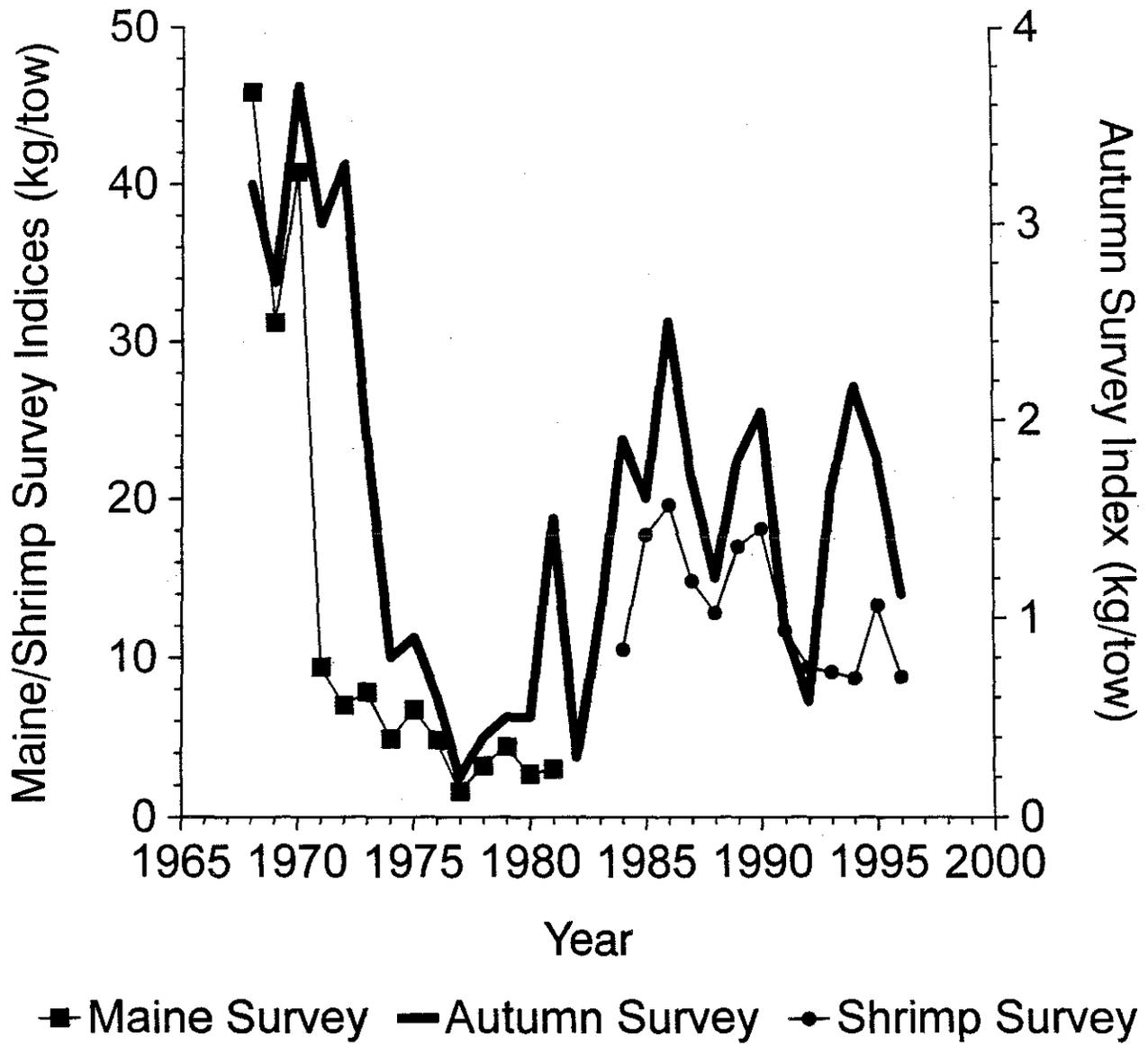


Figure 6. Research trawl survey indices of Gulf of Maine northern shrimp biomass.



Figure 7. State of Maine summer survey fixed station locations.

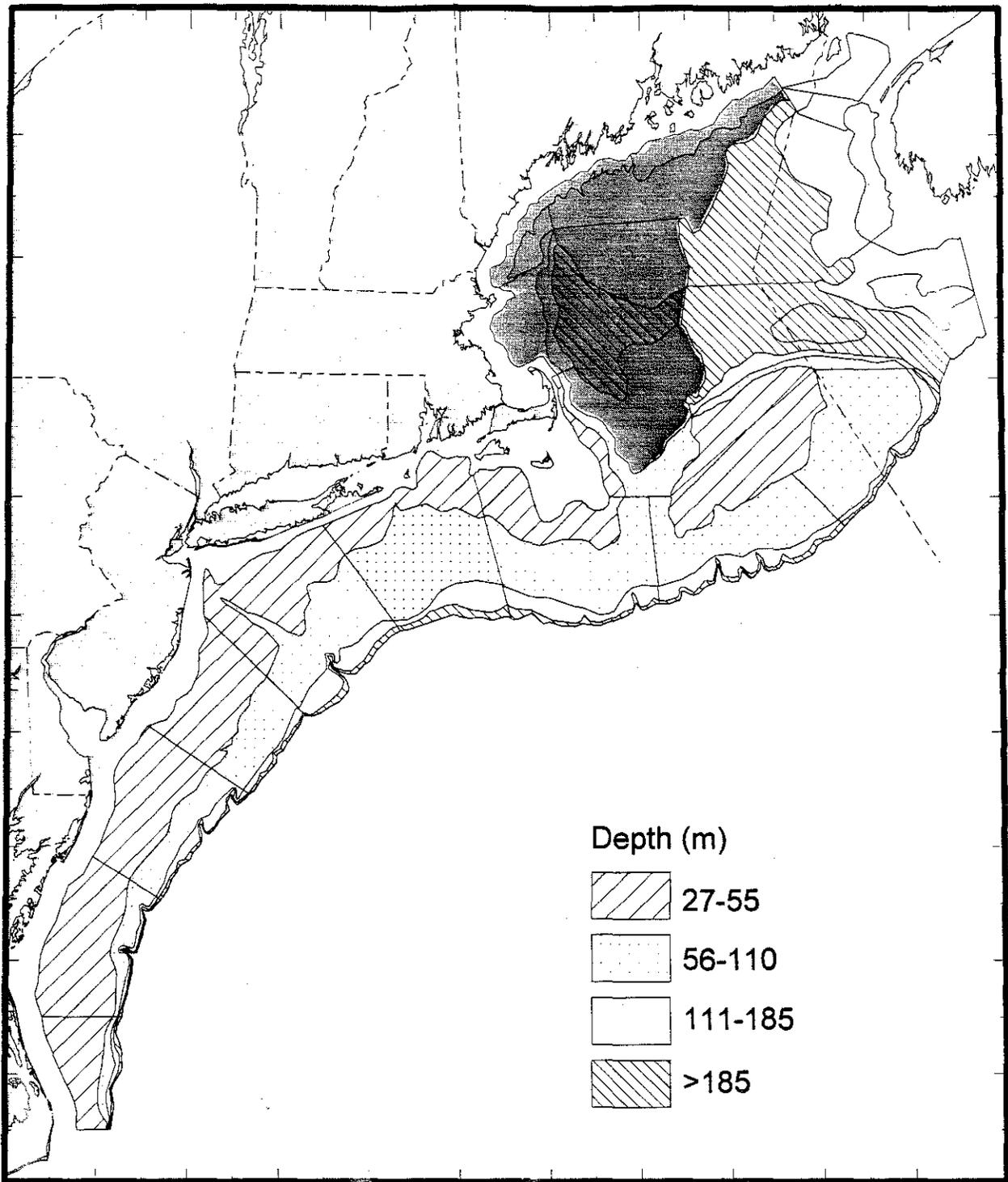


Figure 8. NEFSC groundfish survey strata. Catches from shaded strata are included in the assessment.

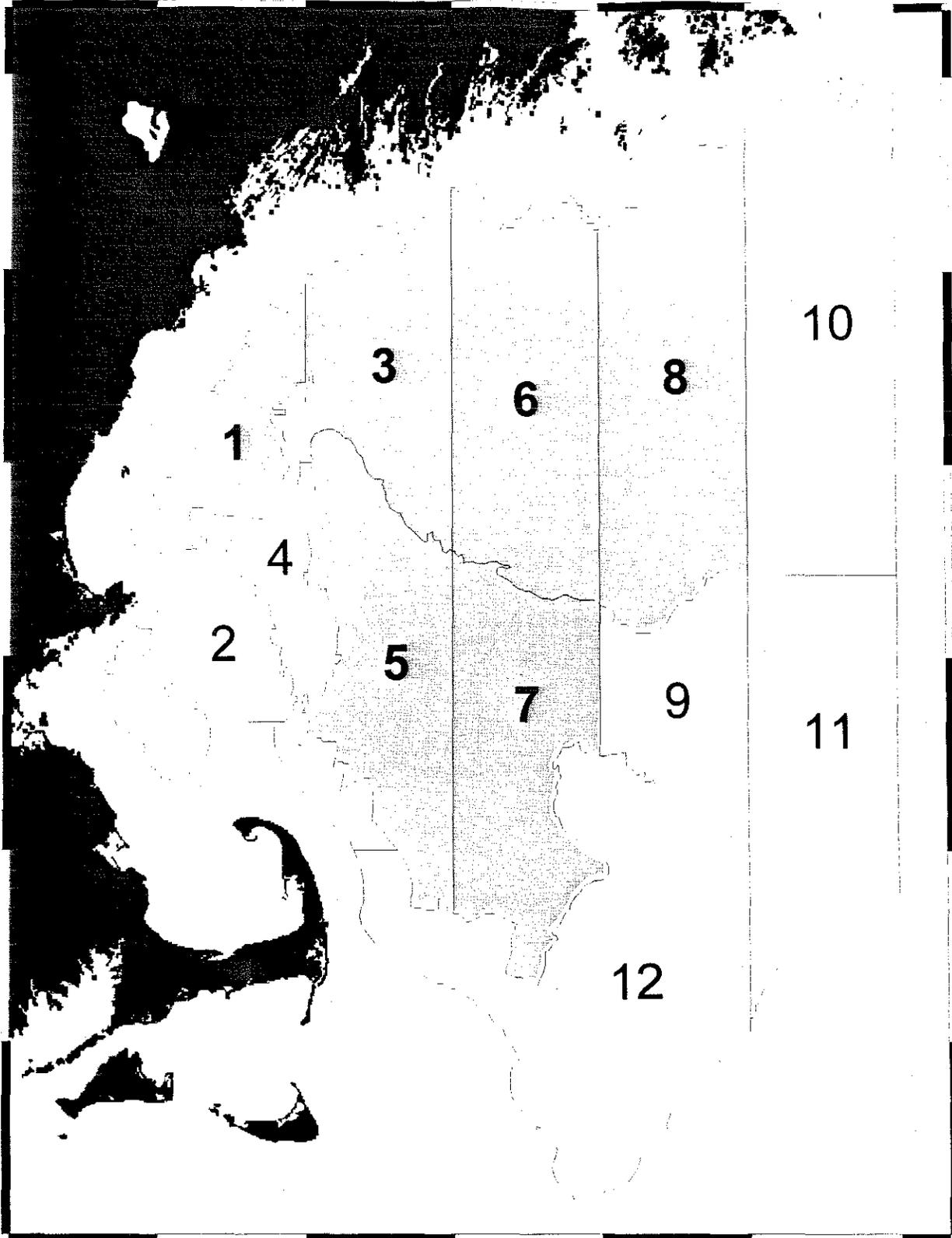


Figure 9. Gulf of Maine northern shrimp summer survey strata. Catches from shaded strata are included in the assessment.

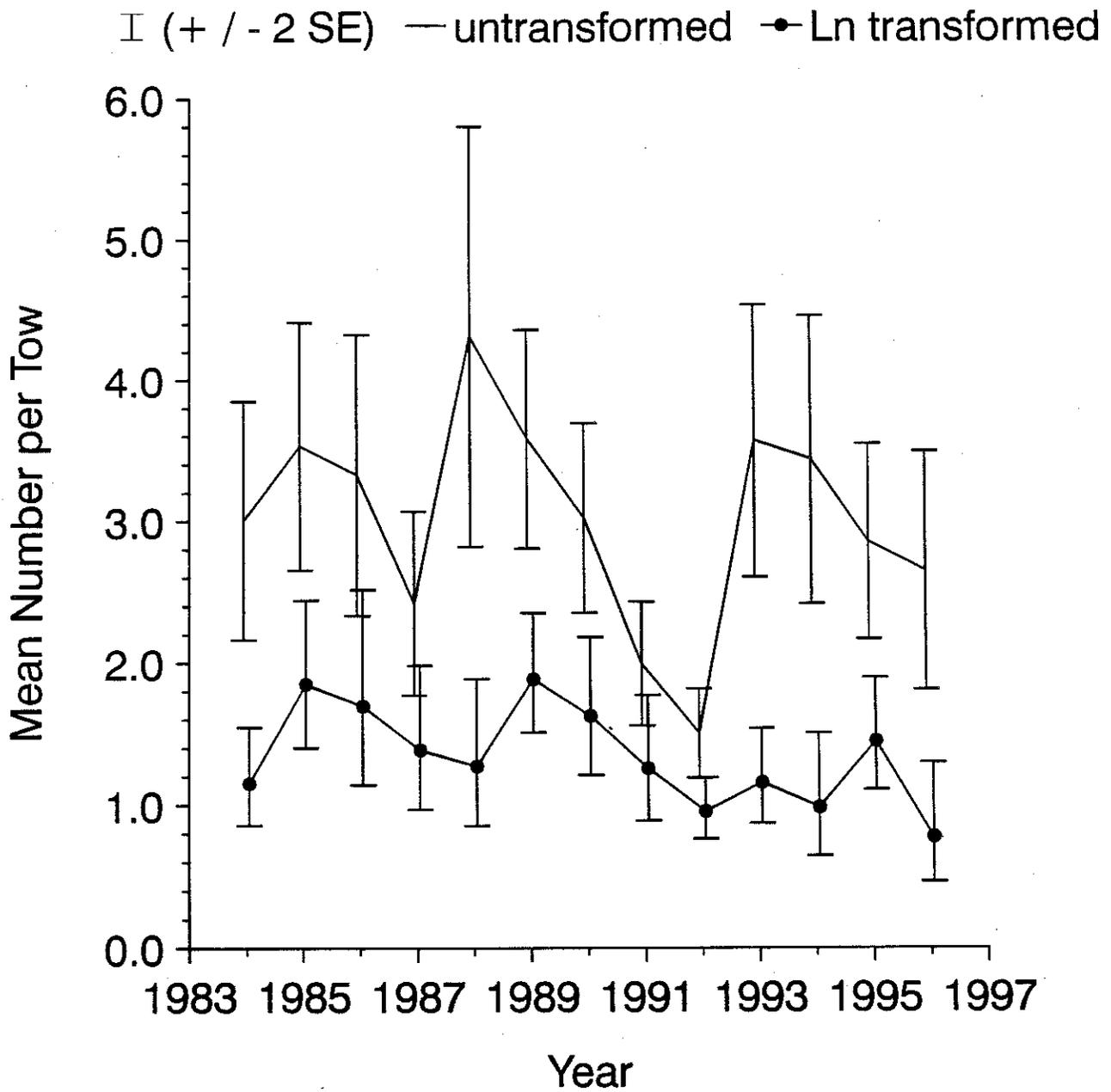


Figure 10. Gulf of Maine northern shrimp summer survey indices of abundance.

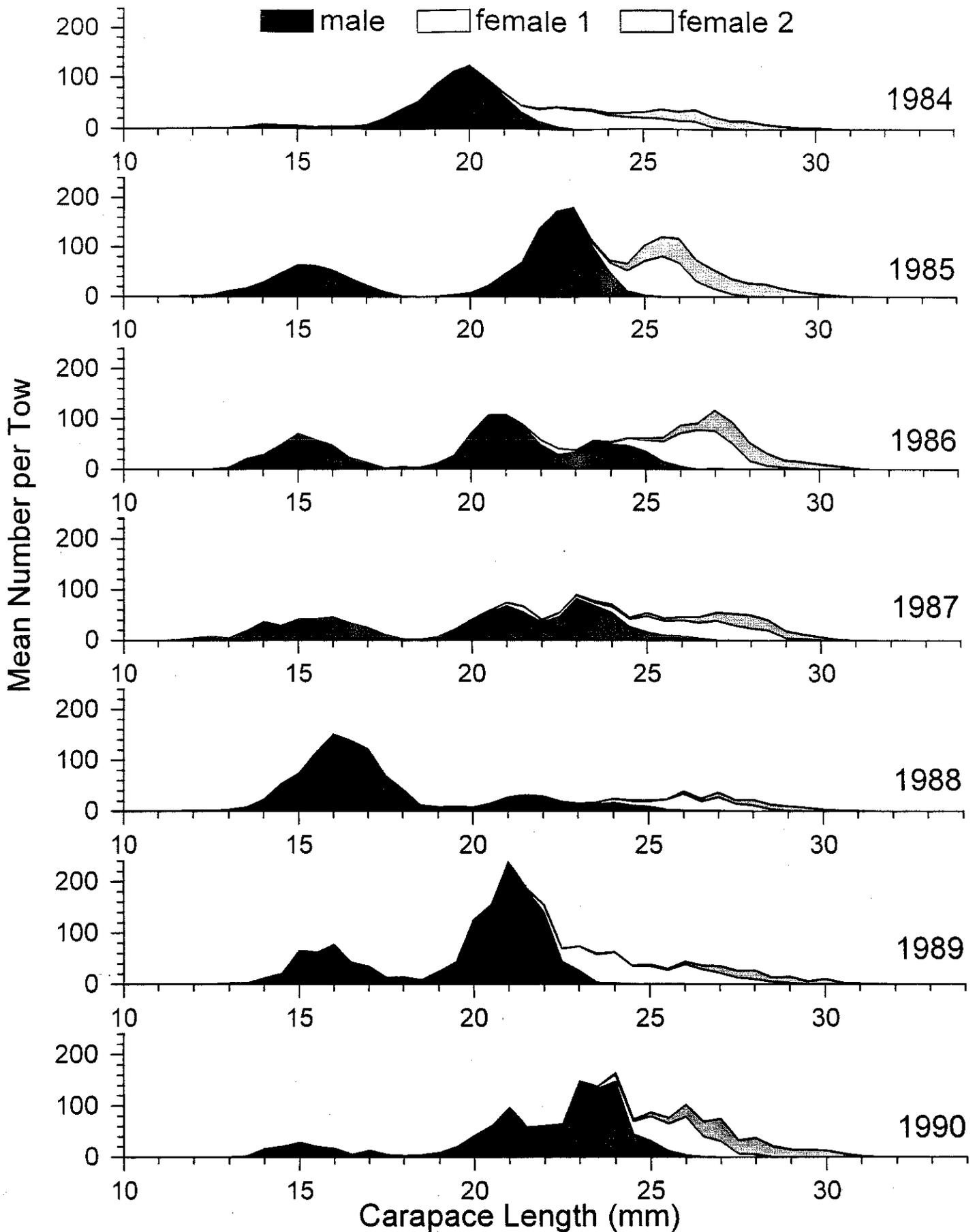


Figure 11. Gulf of Maine northern shrimp summer survey mean catch per tow by length and developmental stage.

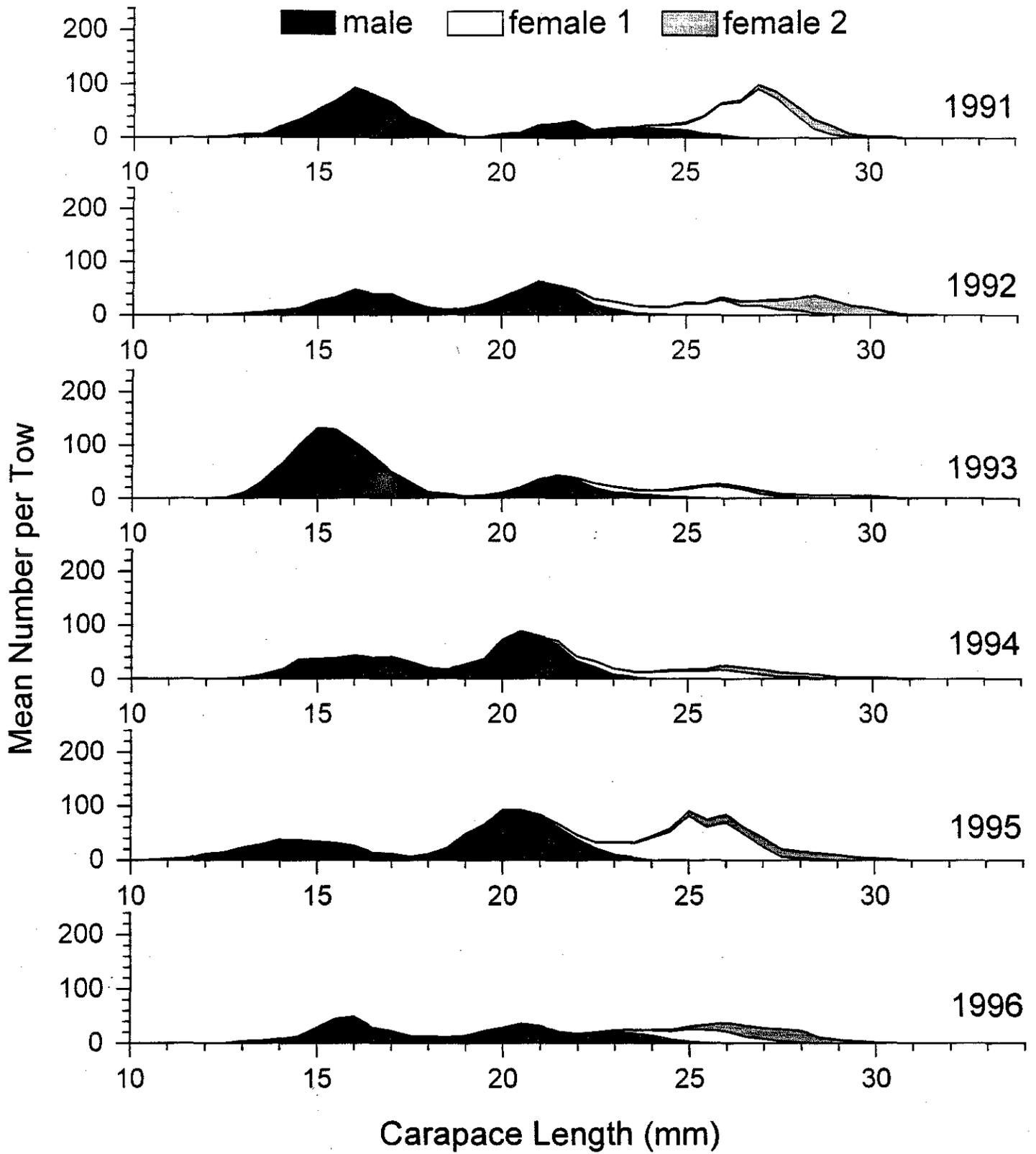
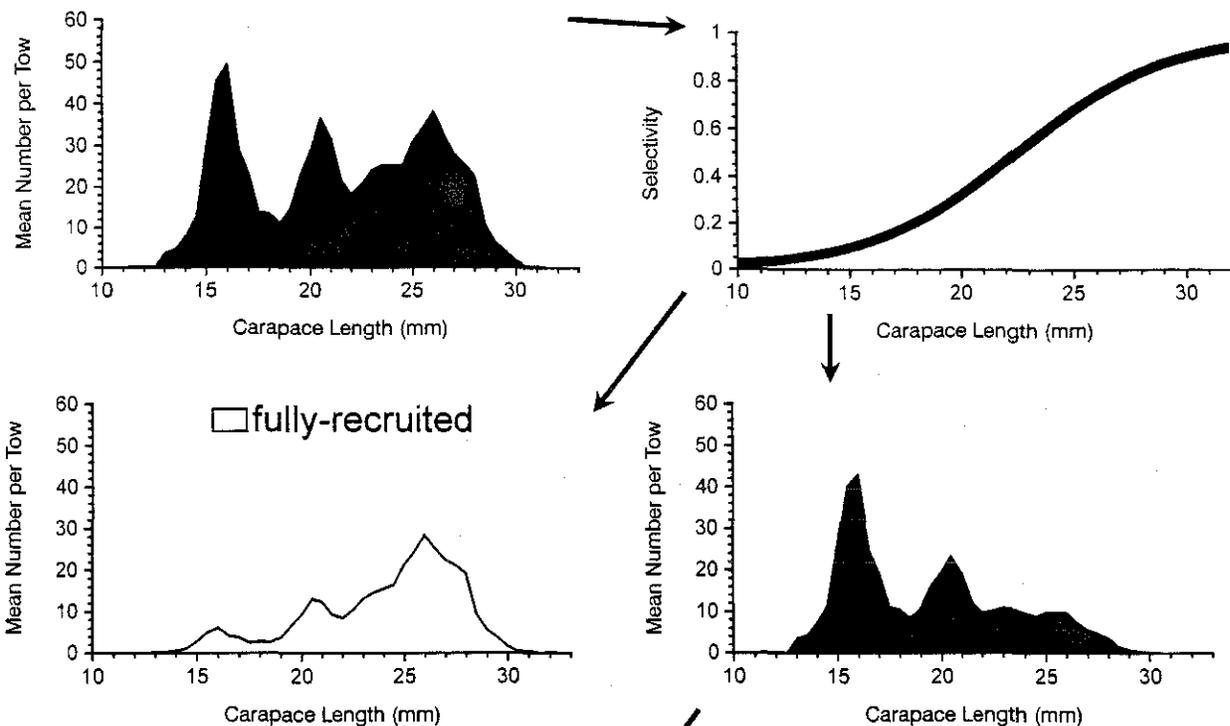


Figure 11 (continued).

1. survey catch at length is multiplied by selectivity at length to derive catch of fully-recruited shrimp at length.



2. Selectivity is increased according to one year of growth using a vonBertalanffy equation.

3. the remaining catch at length is multiplied by the adjusted selectivity at length to derive catch of recruits at length.

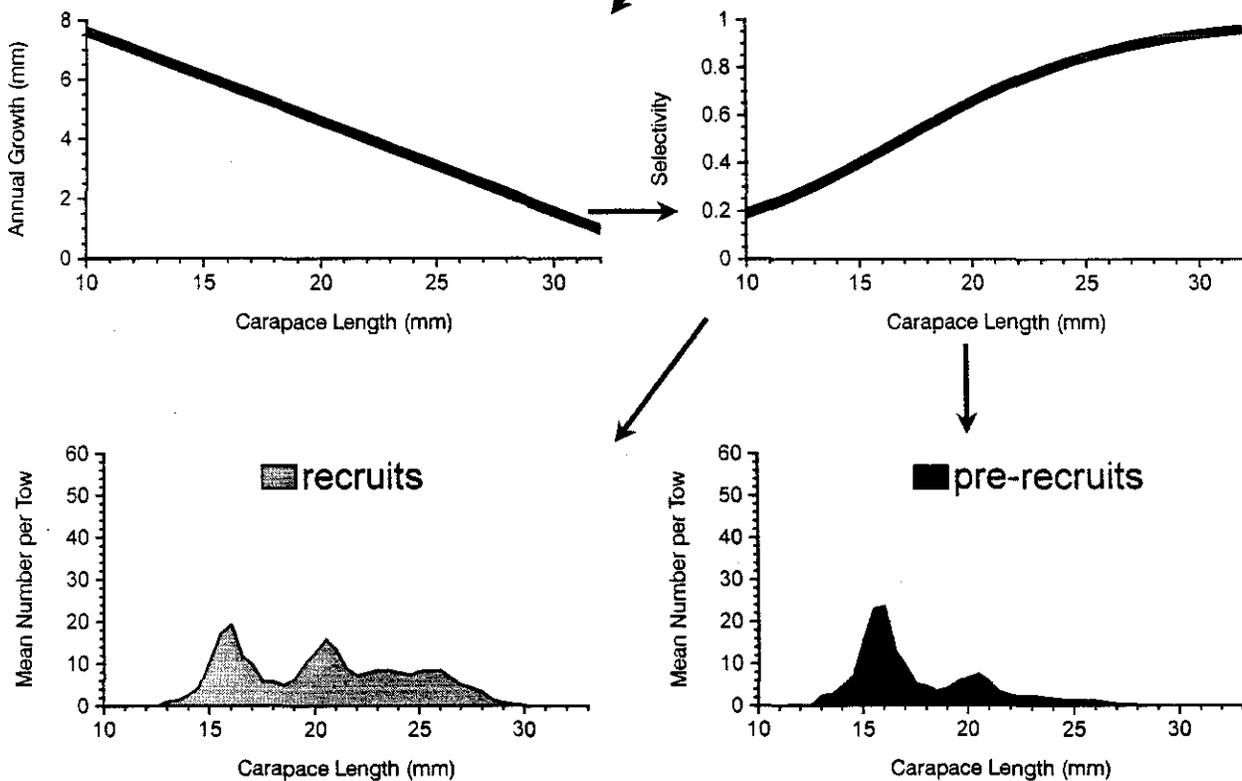


Figure 12. The "selectivity" method of deriving indices of abundance for fully-recruited and recruit Gulf of Maine northern shrimp from summer survey length frequencies (example used is 1996).

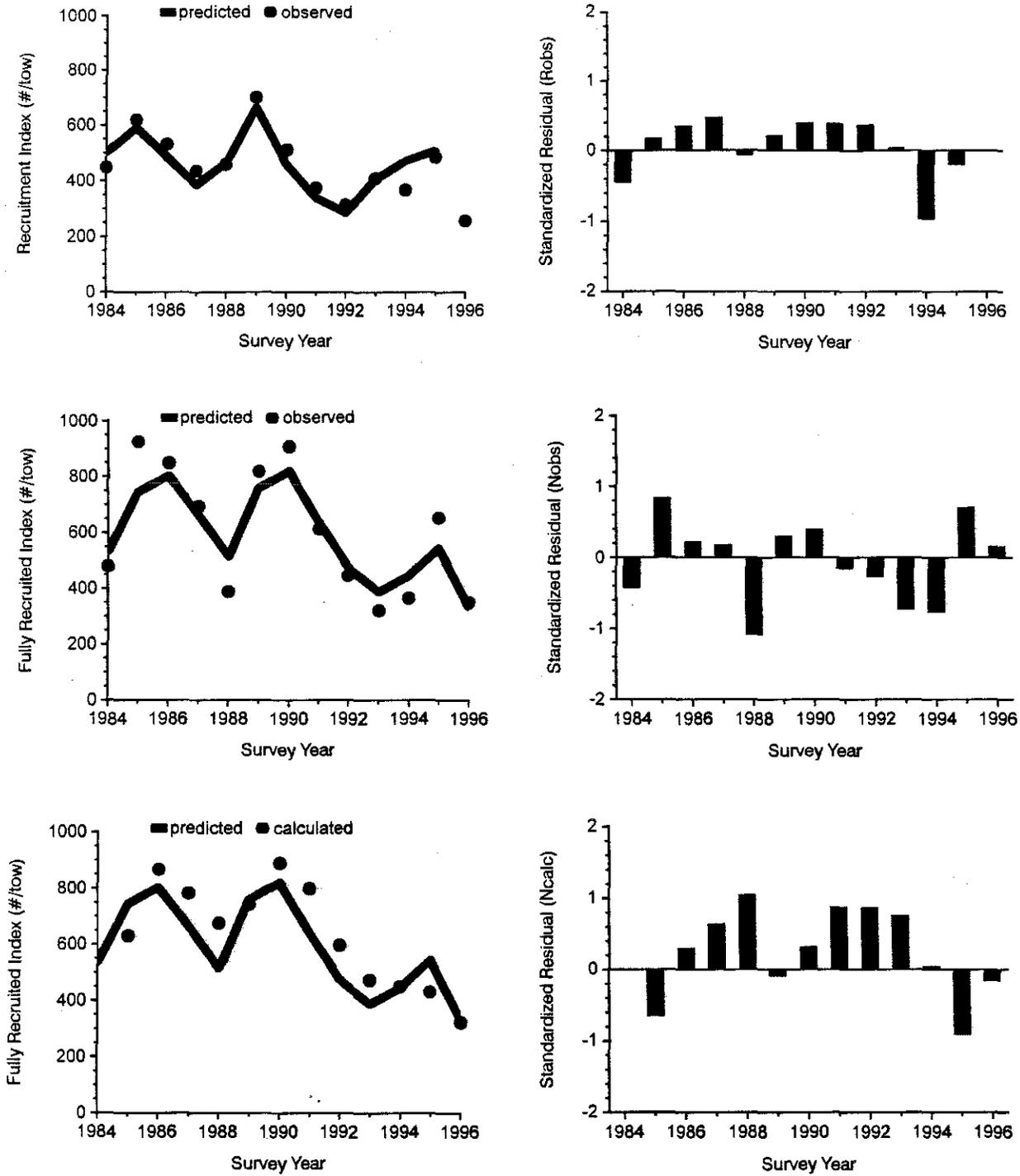


Figure 13. Summary of results from DeLury analysis of Gulf of Maine northern shrimp.

Instantaneous Fishing Mortality

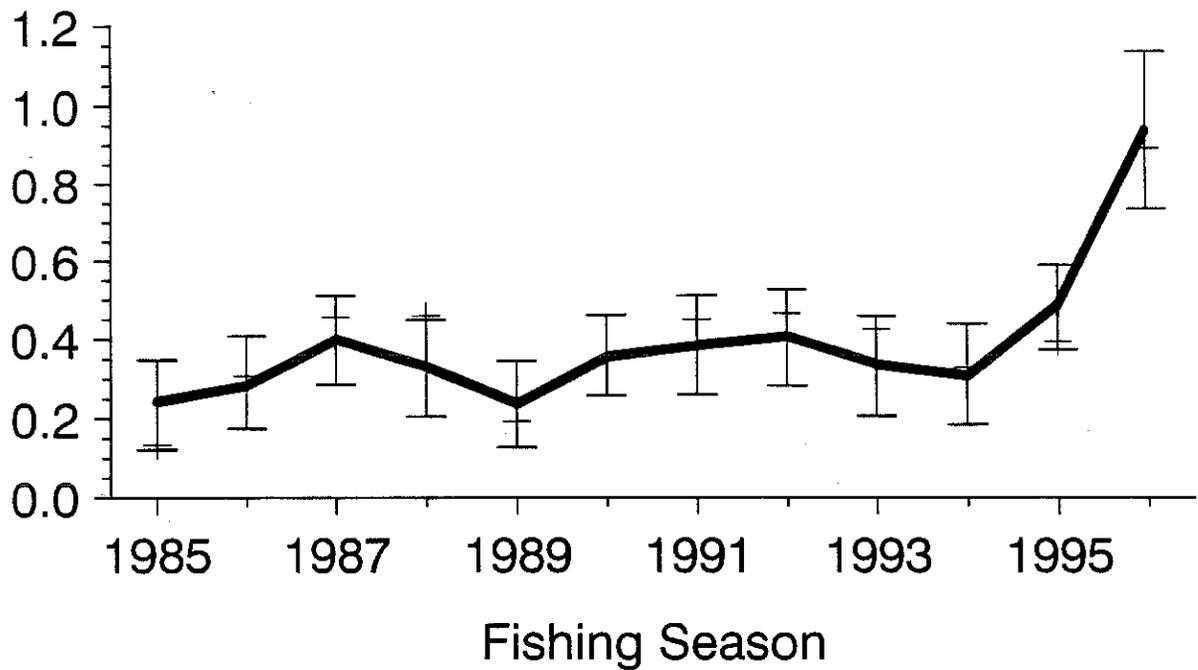


Figure 14. Fishing mortality estimates for Gulf of Maine northern shrimp catch, least-squares estimates, bootstrapped mean, and 80% confidence limits.

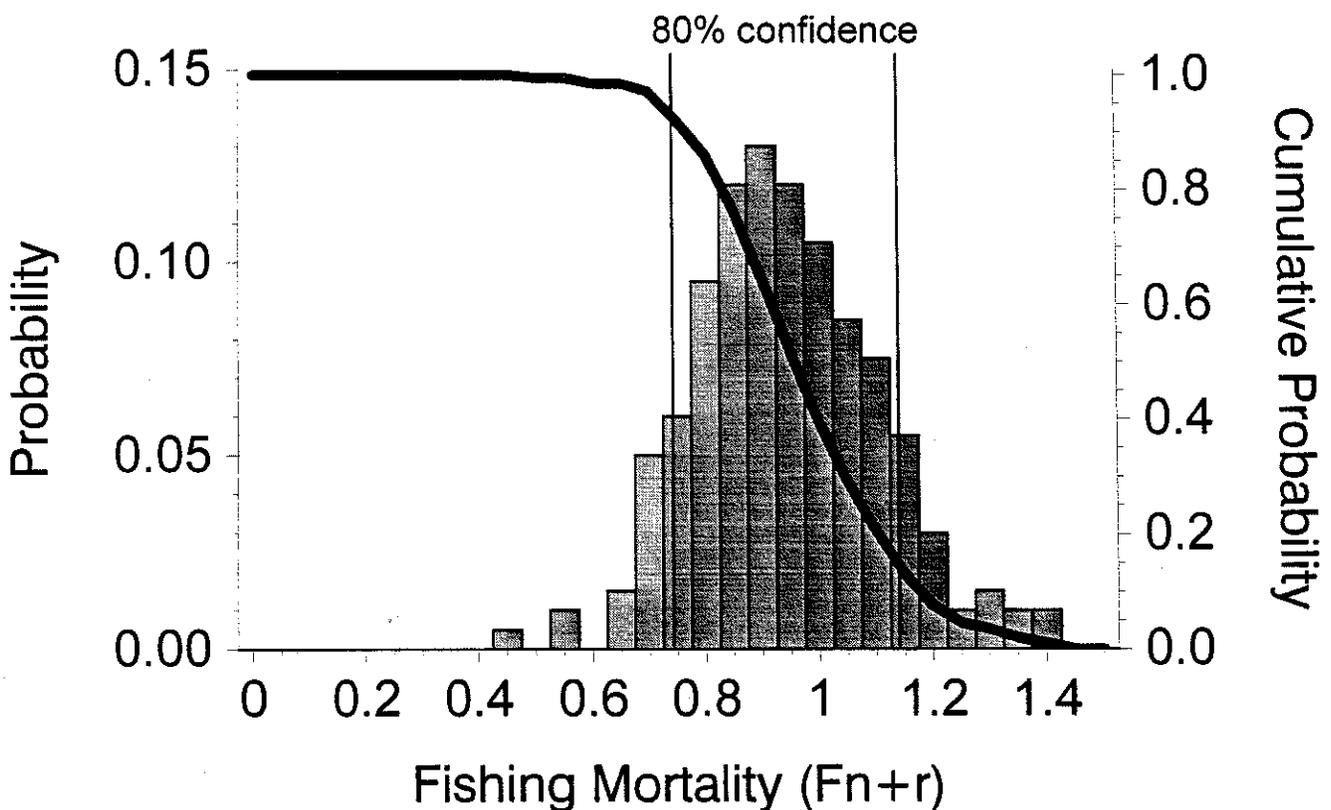


Figure 15. Bootstrapped DeLury estimates of fishing mortality for the 1996 fishing season (i.e. 1995 survey year) for Gulf of Maine northern shrimp.

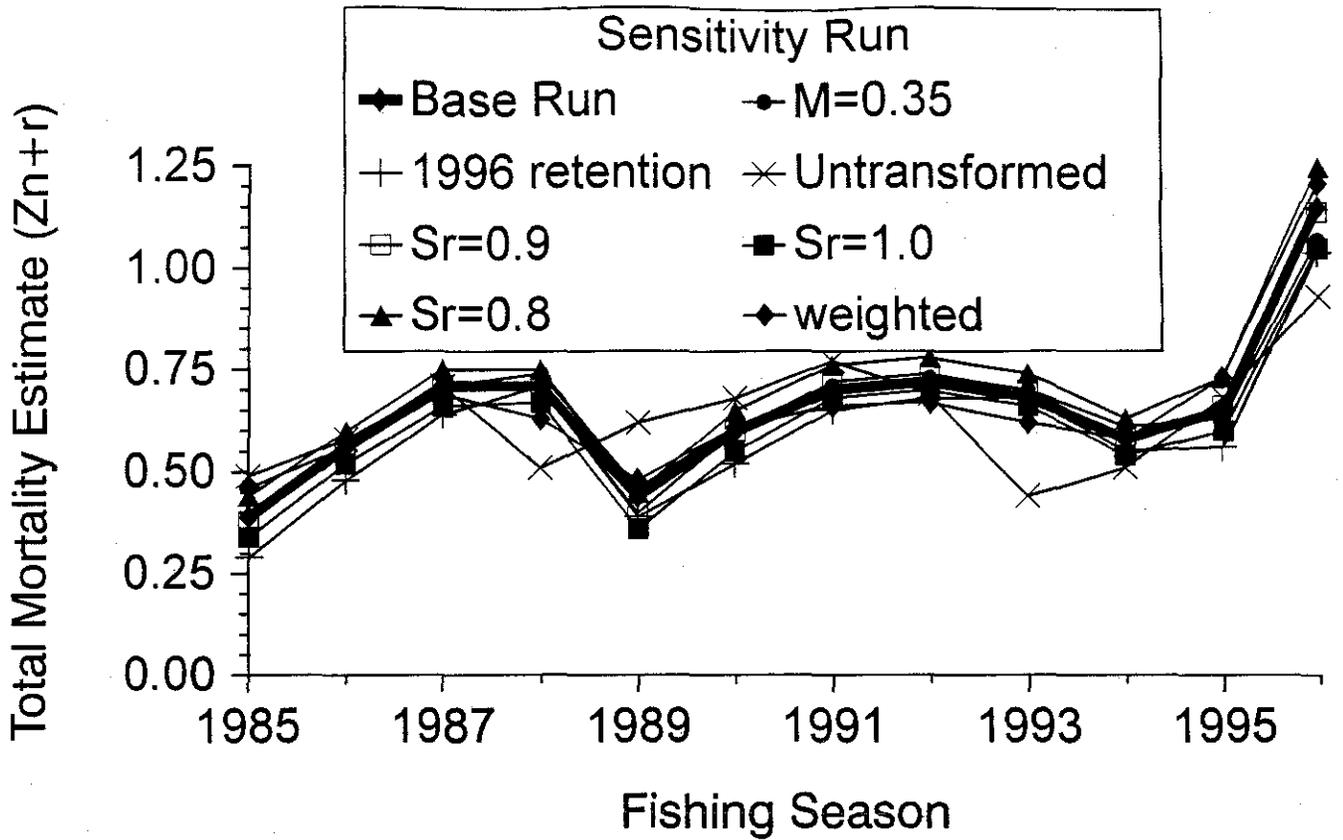


Figure 16. Total mortality estimates from sensitivity analysis of Gulf of Maine northern shrimp.

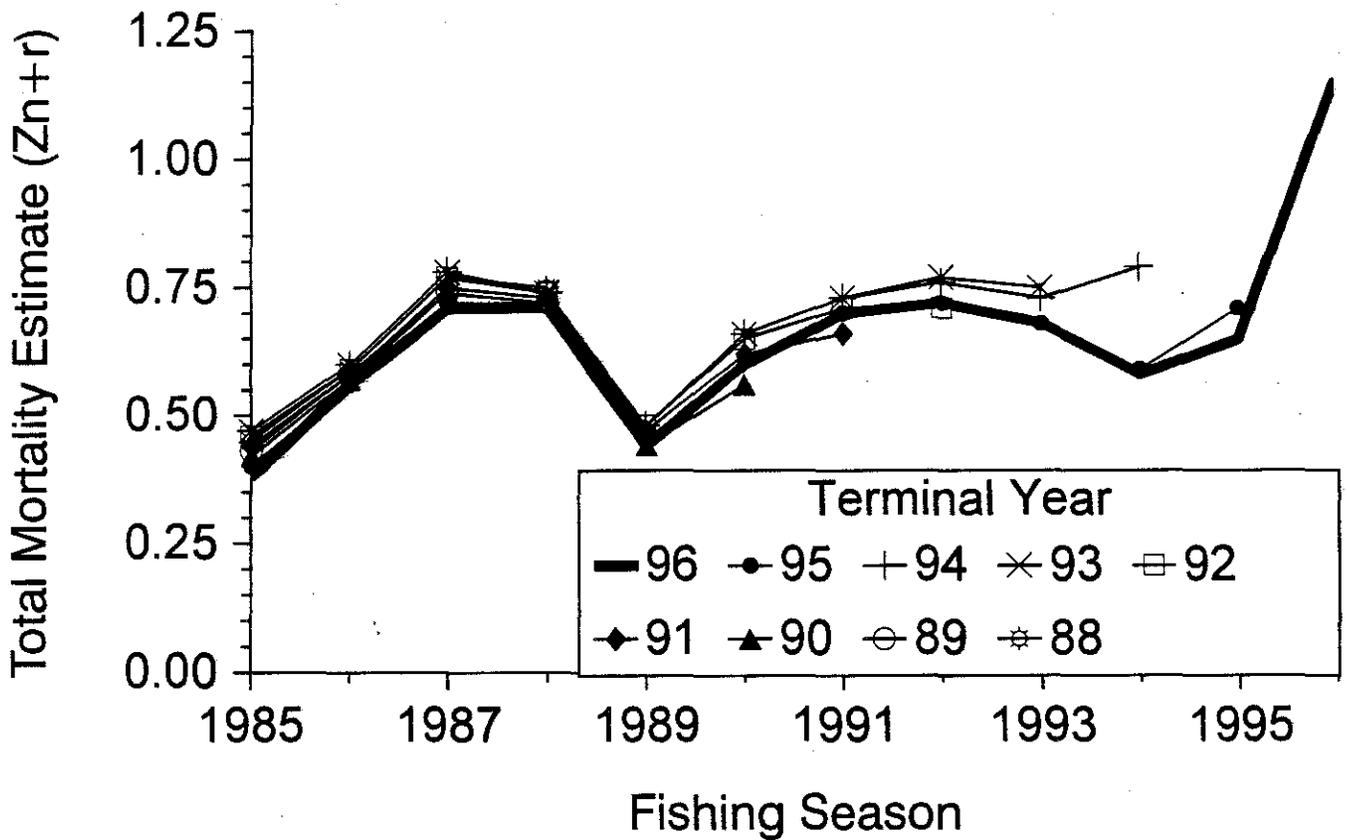


Figure 17. Retrospective DeLury estimates of total mortality for Gulf of Maine northern shrimp.

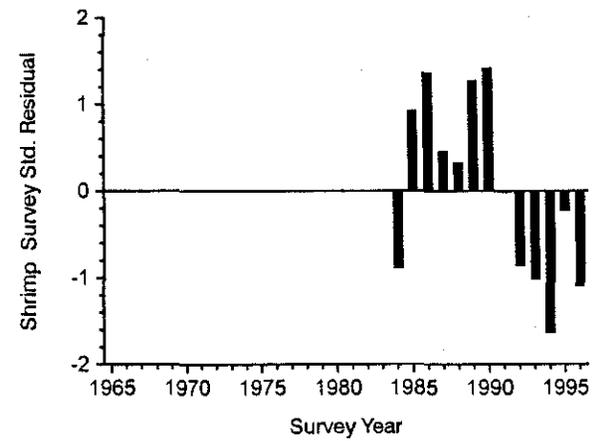
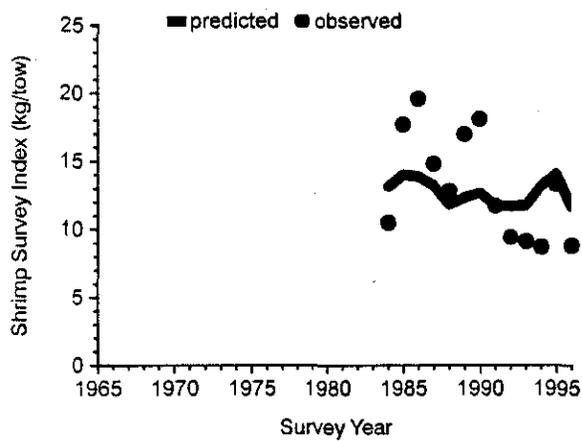
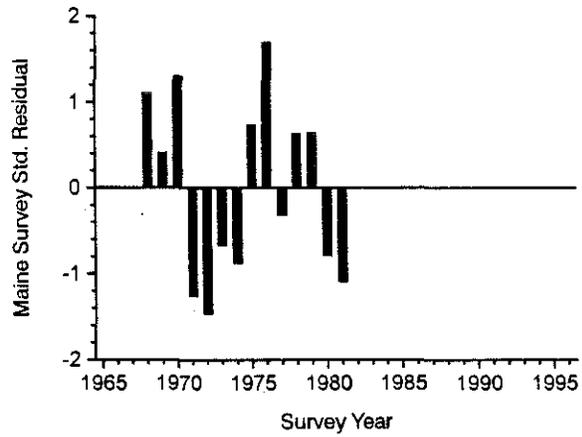
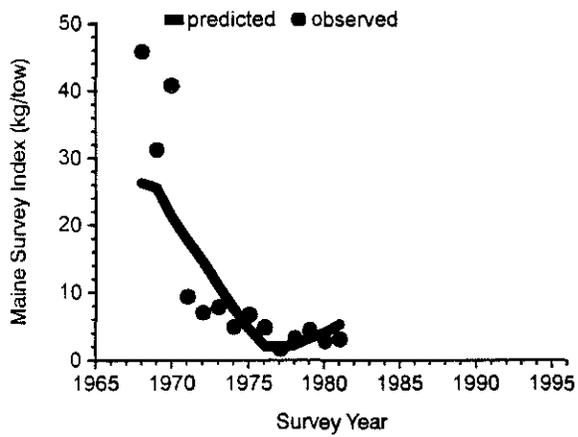
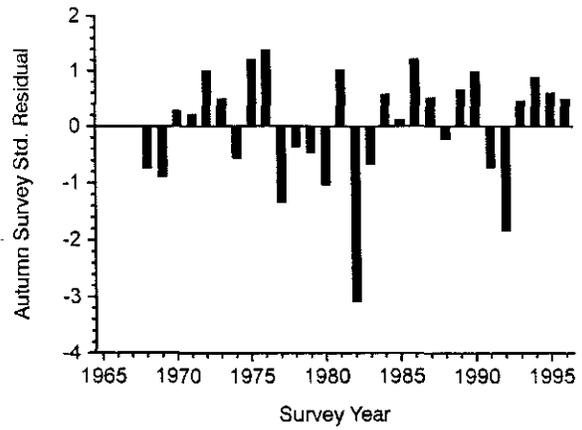
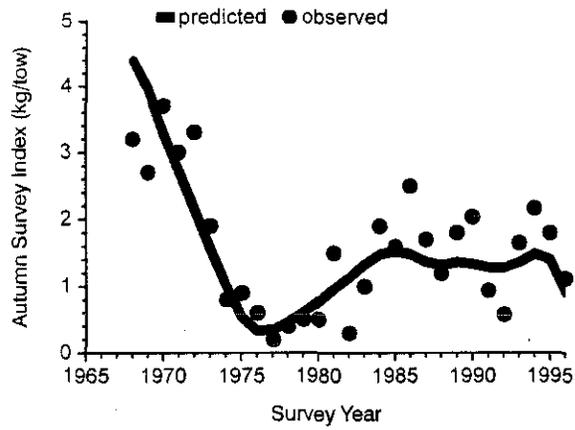


Figure 18. Summary of results from ASPIC analysis of Gulf of Maine northern shrimp biomass dynamics.

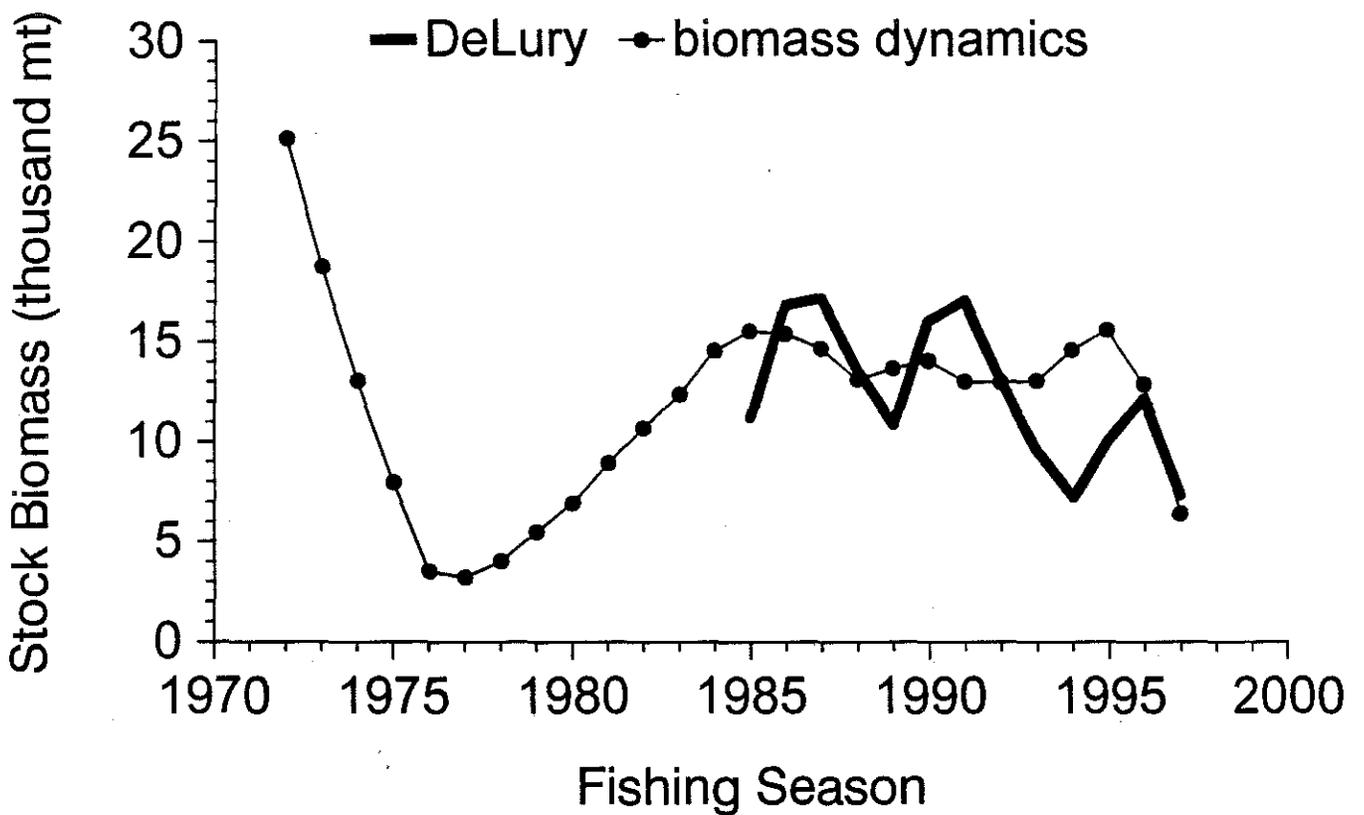
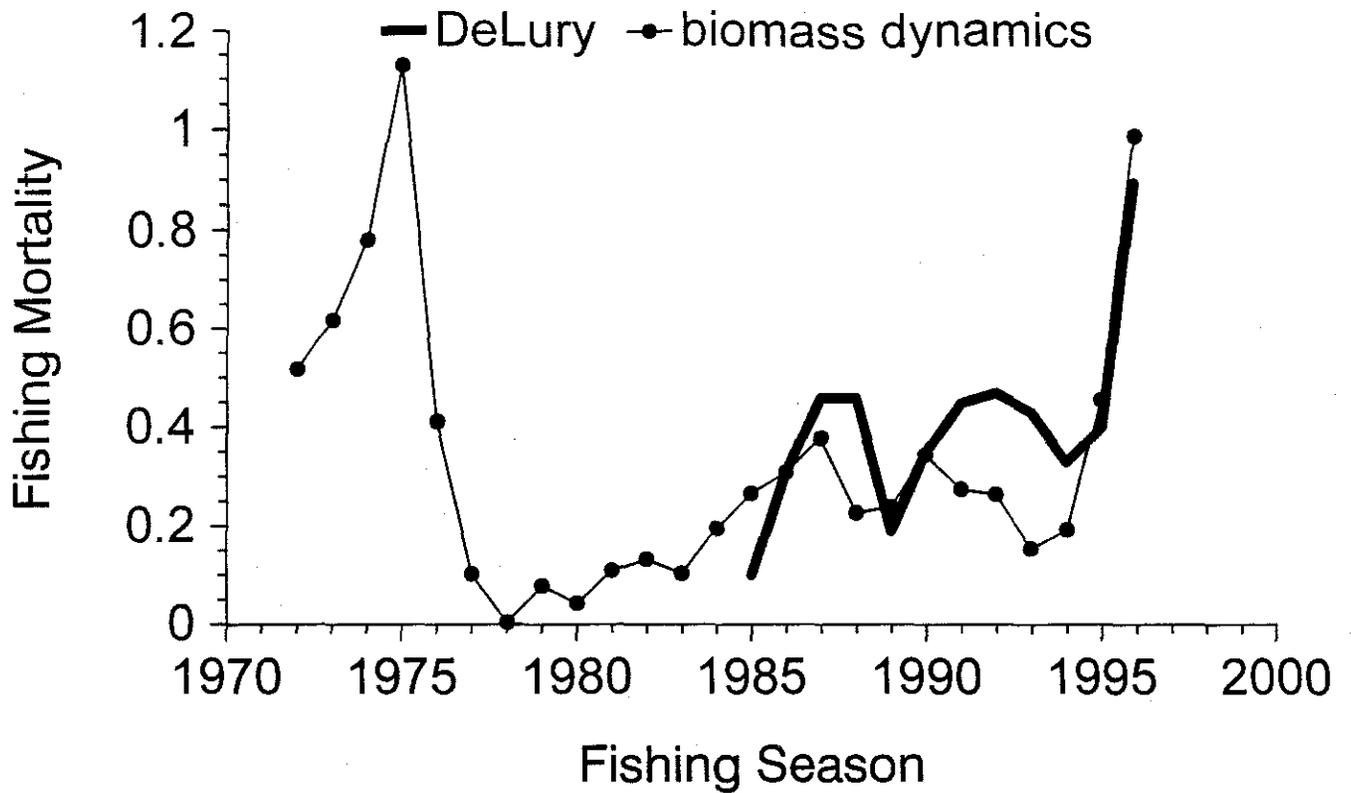


Figure 19. Estimates of fishing mortality (above) and stock biomass (below) for Gulf of Maine northern shrimp from DeLury analysis and biomass dynamics modeling.

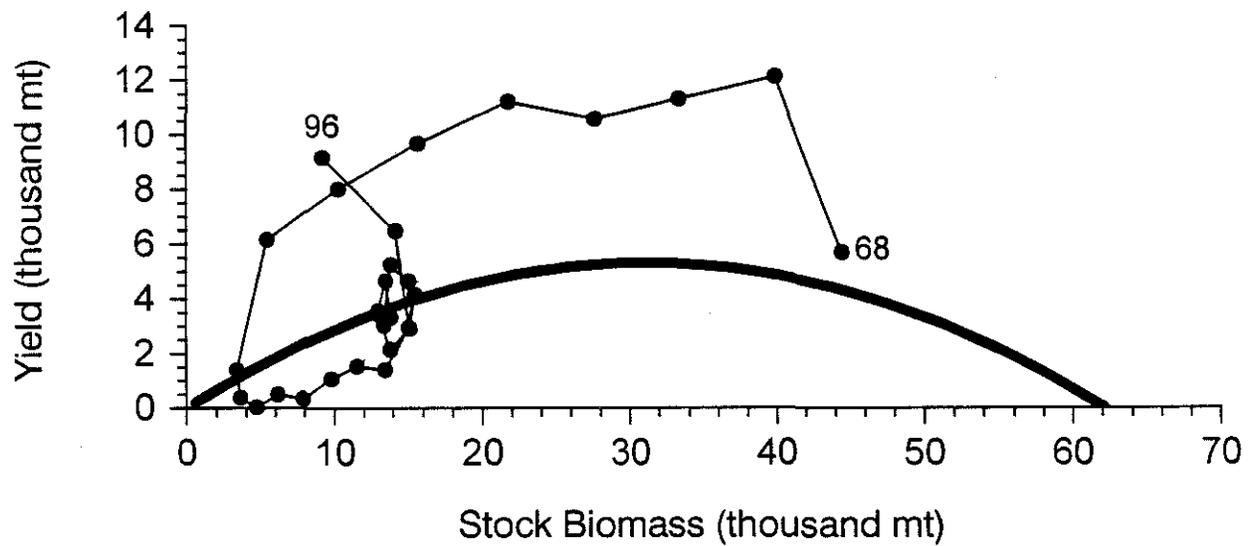
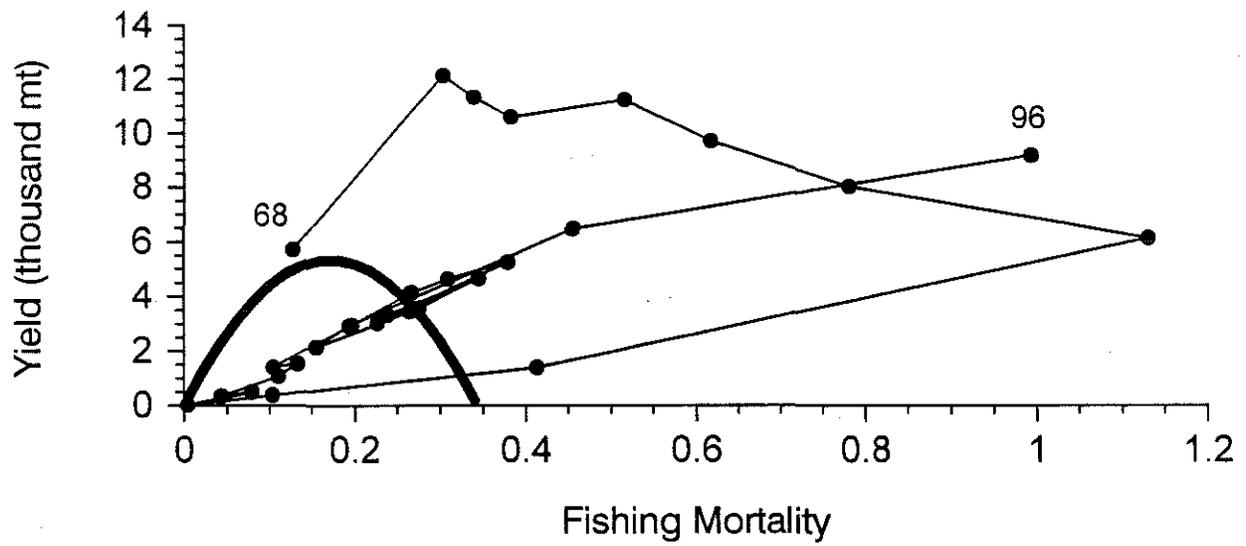
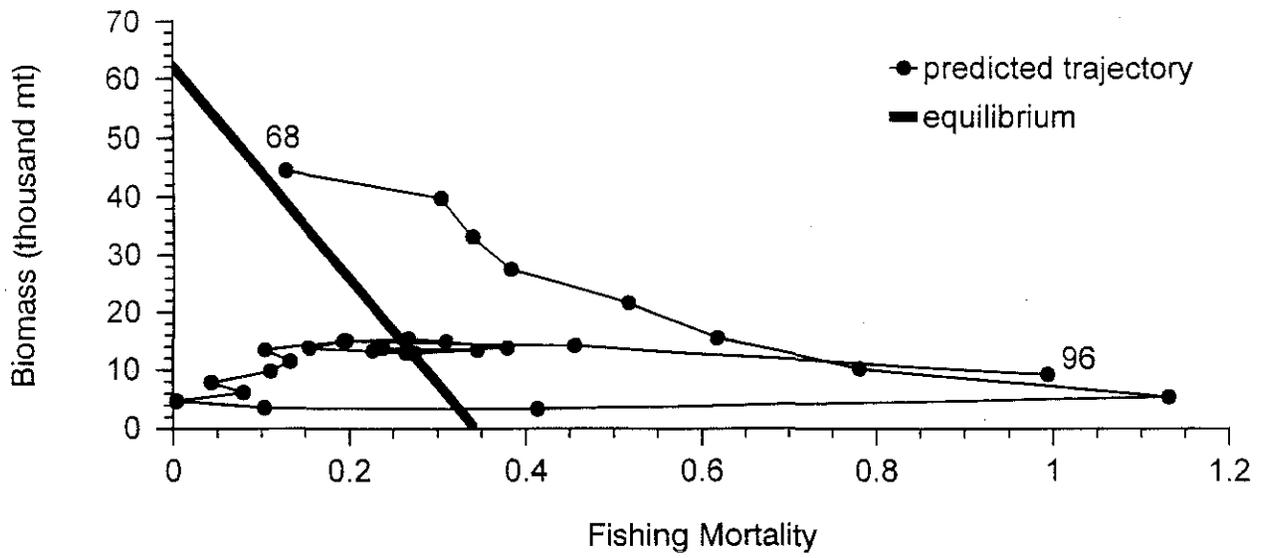


Figure 20. Biomass dynamics of Gulf of Maine northern shrimp.

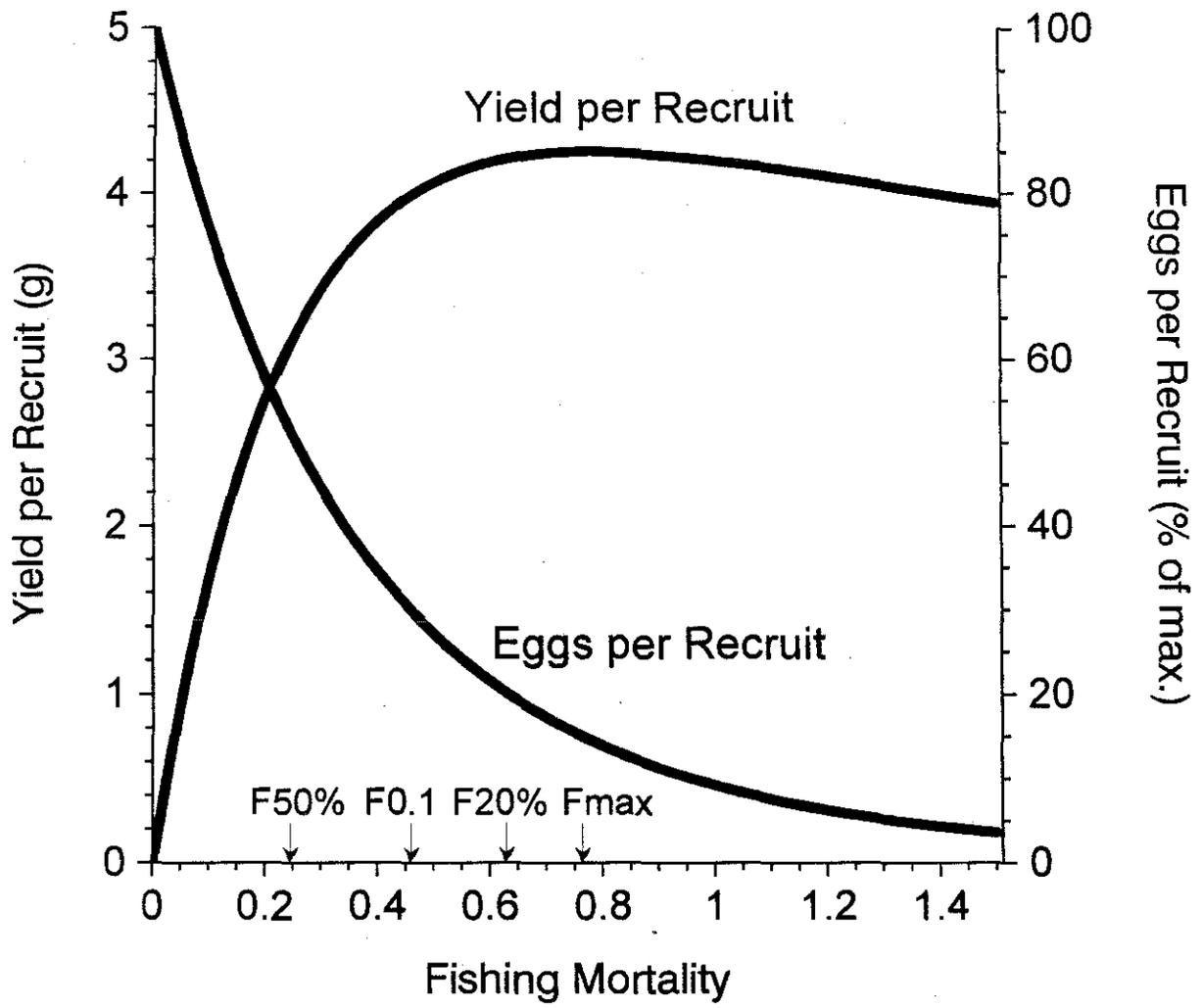


Figure 21. Yield and egg production per recruit for Gulf of Maine northern shrimp.

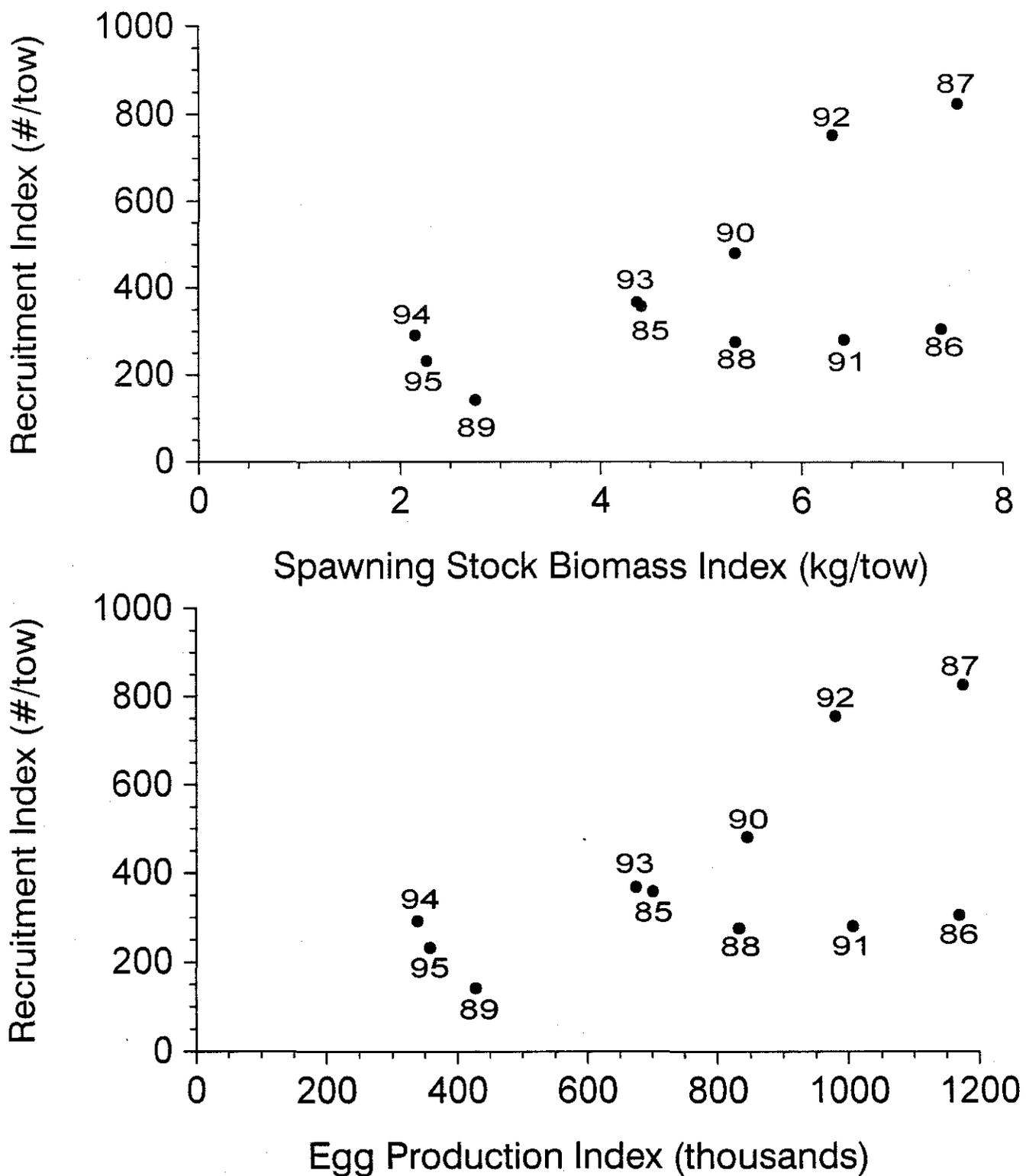


Figure 22. Relationships between summer survey indices of Gulf of Maine northern shrimp female biomass the summer before spawning and survey egg production index to age-1.5 abundance two years later. Data labels indicate year of spawn.

APPENDIX A: MODIFIED DELURY ANALYSIS

DELURY v2.0 Oct94 Run Number 104 1997 1 28 9 22 34
Northern Shrimp

The NEFSC summer shrimp survey was used to measure abundance of recruits and fully-recruited shrimp at the beginning of the fishery season (generally December to April or May). A selectivity ogive derived by Schick & Brown (1997) and a growth curve from McInnes (1986) was used to derive indices of recruits and fully-recruited from survey length frequencies.

INPUT PARAMETERS AND OPTIONS SELECTED

Input data and options read from file: R104.DAT
Data used in fitting the model:

The survey provides indices of abundance for recruit and fully-recruited numbers at a point 0% into the survey year.
The catch is taken at a point 50% into the survey year.

Natural mortality is 0.25

SURVEY YEAR	-- INDICES OF ABUNDANCE --		TOTAL CATCH (millions)
	RECRUITS	FULLY-RECRUITED	
1984	447.6000	479.1000	352.793000
1985	619.5000	925.4000	361.171000
1986	533.4000	848.7000	425.294000
1987	436.3000	693.6000	228.434000
1988	459.9000	387.9000	283.647000
1989	700.7000	817.5000	442.429000
1990	511.6000	907.7000	320.290000
1991	374.1000	611.9000	262.434000
1992	313.6000	444.4000	194.788000
1993	410.0000	320.6000	270.406000
1994	368.7000	364.4000	604.137000
1995	485.9000	653.1000	799.368000
1996	257.7000	348.6000	

Geometric mean number per tow in assessment strata (1, 3, 5-8).

Note that the recruit abundance index for the last year is NOT used in the least squares estimation. It is, however, used in conjunction with the least squares estimate of q_n and the selectivity of the recruits to calculate recruit population size in 1996 (see RESULTS section).

MEAN WEIGHT (kg) AT THE TIME OF THE SURVEY

SURVEY YEAR	RECRUITS	FULLY- RECRUITED
1984	0.006	0.008
1985	0.008	0.009
1986	0.007	0.010
1987	0.007	0.010
1988	0.005	0.009
1989	0.007	0.009
1990	0.008	0.010
1991	0.007	0.011
1992	0.007	0.010
1993	0.005	0.008
1994	0.006	0.008
1995	0.007	0.010
1996	0.007	0.010

SELECTIVITY OF RECRUITS TO THE SURVEY GEAR

Selectivity of the recruits (relative to the fully-recruited animals) to the survey gear is set at:

1984	0.9000
1985	0.9000
1986	0.9000
1987	1.0000
1988	0.7000
1989	0.9000
1990	1.0000
1991	1.0000
1992	1.0000
1993	1.0000
1994	0.8000
1995	1.0000
1996	0.9000

PARTIAL RECRUITMENT (OF RECRUITS) TO THE COMMERCIAL FISHERY

A survey year (SY) is the period between successive annual surveys. Partial recruitment (PR) of the recruits to the commercial fishery is a function of month during the survey year. As animals grow in size, partial recruitment increases, eventually reaching 1.0 at the end of each survey year. The PR function may vary over SYs due to changes in regulations and/or unusually small (or large) mean size of the recruits. The following table gives the input PR functions for each survey year. The rows of the table represent the percent of the SY completed, e.g. 0 represents the beginning of the SY and 100 (**) represents the end of the SY. The annual average partial recruitment (shown after this table) results from integrating the annual PR functions with respect to time during the SY.

PARTIAL RECRUITMENT DURING EACH SURVEY YEAR

	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996
0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
25	0.36	0.36	0.36	0.36	0.36	0.36	0.36	0.36	0.36	0.36	0.36	0.36	0.36
33	0.49	0.49	0.49	0.49	0.49	0.49	0.49	0.49	0.49	0.49	0.49	0.49	0.49
50	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55
58	0.61	0.61	0.61	0.61	0.61	0.61	0.61	0.61	0.61	0.61	0.61	0.61	0.61
**	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00

AVERAGE PARTIAL RECRUITMENT OF RECRUITS TO THE COMMERCIAL FISHERY

Survey Year	Average Partial Recruitment
1984	0.552
1985	0.552
1986	0.552
1987	0.552
1988	0.552
1989	0.552
1990	0.552
1991	0.552
1992	0.552
1993	0.552
1994	0.552
1995	0.552
1996	0.552

OTHER INPUT DATA AND OPTIONS

Measurement error in the abundance indices for both the recruits and the fully-recruited is assumed to be lognormally distributed. Process error is assumed to follow a lognormal distribution.

The input objective function weights are normalized (so that they will sum to 1.0) prior to their use in the estimation. Both the original input weights and the normalized weights are given below. The square root of the normalized weights is printed in the residual tables near the end of the RESULTS section (under the heading "WEIGHT").

YEAR	-- ORIGINAL INPUT WEIGHTS --			---- NORMALIZED WEIGHTS ----		
	Measurement Error n Index	r Index	Process Error	Measurement Error n Index	r Index	Process Error
1984	1.0000	1.0000	-999.0000	0.0270	0.0270	-999.0000
1985	1.0000	1.0000	1.0000	0.0270	0.0270	0.0270
1986	1.0000	1.0000	1.0000	0.0270	0.0270	0.0270
1987	1.0000	1.0000	1.0000	0.0270	0.0270	0.0270
1988	1.0000	1.0000	1.0000	0.0270	0.0270	0.0270
1989	1.0000	1.0000	1.0000	0.0270	0.0270	0.0270
1990	1.0000	1.0000	1.0000	0.0270	0.0270	0.0270
1991	1.0000	1.0000	1.0000	0.0270	0.0270	0.0270
1992	1.0000	1.0000	1.0000	0.0270	0.0270	0.0270
1993	1.0000	1.0000	1.0000	0.0270	0.0270	0.0270
1994	1.0000	1.0000	1.0000	0.0270	0.0270	0.0270
1995	1.0000	1.0000	1.0000	0.0270	0.0270	0.0270
1996	1.0000	-999.0000	1.0000	0.0270	-999.0000	0.0270

-999 indicates that no weighting is used for that year-error type combination

Initial estimates of parameters for the Marquardt algorithm and lower and upper bounds on the parameter estimates:

	Parameter	Initial Est	Lower Bnd	Upper Bnd
1	n 2+ 1984	4.7910000E2	1.0000000E-10	1.0000000E6
2	n 2+ 1985	9.2540000E2	1.0000000E-10	1.0000000E6
3	n 2+ 1986	8.4870000E2	1.0000000E-10	1.0000000E6
4	n 2+ 1987	6.9360000E2	1.0000000E-10	1.0000000E6
5	n 2+ 1988	3.8790000E2	1.0000000E-10	1.0000000E6
6	n 2+ 1989	8.1750000E2	1.0000000E-10	1.0000000E6
7	n 2+ 1990	9.0770000E2	1.0000000E-10	1.0000000E6
8	n 2+ 1991	6.1190000E2	1.0000000E-10	1.0000000E6
9	n 2+ 1992	4.4440000E2	1.0000000E-10	1.0000000E6
10	n 2+ 1993	3.2060000E2	1.0000000E-10	1.0000000E6
11	n 2+ 1994	3.6440000E2	1.0000000E-10	1.0000000E6
12	n 2+ 1995	6.5310000E2	1.0000000E-10	1.0000000E6
13	n 2+ 1996	3.4860000E2	1.0000000E-10	1.0000000E6
14	r 1 1984	4.4760000E2	1.0000000E-10	1.0000000E6
15	r 1 1985	6.1950000E2	1.0000000E-10	1.0000000E6
16	r 1 1986	5.3340000E2	1.0000000E-10	1.0000000E6
17	r 1 1987	4.3630000E2	1.0000000E-10	1.0000000E6
18	r 1 1988	4.5990000E2	1.0000000E-10	1.0000000E6
19	r 1 1989	7.0070000E2	1.0000000E-10	1.0000000E6
20	r 1 1990	5.1160000E2	1.0000000E-10	1.0000000E6
21	r 1 1991	3.7410000E2	1.0000000E-10	1.0000000E6
22	r 1 1992	3.1360000E2	1.0000000E-10	1.0000000E6
23	r 1 1993	4.1000000E2	1.0000000E-10	1.0000000E6
24	r 1 1994	3.6870000E2	1.0000000E-10	1.0000000E6
25	r 1 1995	4.8590000E2	1.0000000E-10	1.0000000E6
26	Surv q_n	1.0000000E-3	1.0000000E-10	1.0000000E3

BEGIN MARQUARDT ALGORITHM

 LAMBDA 1.00000E-2
 RSS 8.87361E-2
 NPFI 8.87361E-2
 par
 4.79100E2 9.25400E2 8.48700E2 6.93600E2 3.87900E2 8.
 17500E2 9.07700E2 6.11900E2 4.44400E2 3.20600E2 3
 .64400E2 6.53100E2 3.48600E2 4.47600E2 6.19500E2
 5.33400E2 4.36300E2 4.59900E2 7.00700E2 5.11600E2
 3.74100E2 3.13600E2 4.10000E2 3.68700E2 4.85900E2
 1.00000E-3

LAMBDA 1.00000E-3
 RSS 6.41800E-2
 NPFI 6.41800E-2
 par
 5.28746E2 7.00982E2 8.18679E2 6.83835E2 5.02620E2 7.
 46799E2 8.37549E2 6.61317E2 4.86569E2 3.80317E2 4
 .16014E2 4.53579E2 3.58103E2 4.95742E2 6.04650E2
 4.99310E2 3.89859E2 4.76452E2 6.81047E2 4.72699E2
 3.44477E2 2.88575E2 4.06955E2 4.28617E2 4.80224E2
 8.79368E-1

LAMBDA 1.00000E-4
 RSS 2.44478E-2
 NPFI 2.44478E-2
 par
 5.43296E2 7.44068E2 7.97322E2 6.52641E2 5.08961E2 7.
 54609E2 8.11555E2 6.28335E2 4.70175E2 3.84975E2 4
 .45171E2 5.26186E2 3.50931E2 5.10223E2 5.94152E2
 4.90055E2 3.88328E2 4.72216E2 6.69304E2 4.63189E2
 3.40648E2 2.87800E2 4.14640E2 4.83716E2 4.74288E2
 7.73743E-1

LAMBDA 1.00000E-5
 RSS 2.03280E-2
 NPFI 2.03280E-2
 par
 5.36195E2 7.44448E2 8.01315E2 6.61633E2 5.13421E2 7.
 57491E2 8.18213E2 6.34646E2 4.74801E2 3.86968E2 4
 .45679E2 5.45161E2 3.39044E2 5.03390E2 5.91720E2
 4.87055E2 3.85302E2 4.67287E2 6.64307E2 4.60704E2
 3.37817E2 2.85261E2 4.07955E2 4.80187E2 5.06160E2
 7.15223E-1

LAMBDA 1.00000E-5
 RSS 2.02776E-2
 NPFI 2.02776E-2
 par
 5.34996E2 7.44542E2 8.02827E2 6.63376E2 5.14493E2 7.
 58449E2 8.20353E2 6.36488E2 4.75981E2 3.87337E2 4
 .44642E2 5.44801E2 3.34938E2 5.02198E2 5.92156E2
 4.87991E2 3.86398E2 4.66807E2 6.64934E2 4.61753E2
 3.38623E2 2.85702E2 4.06942E2 4.75038E2 5.10776E2
 7.09194E-1

LAMBDA 1.00000E-5
 RSS 2.02775E-2
 NPFI 2.02775E-2
 par
 5.34857E2 7.44618E2 8.03092E2 6.63715E2 5.14654E2 7.
 58607E2 8.20703E2 6.36793E2 4.76188E2 3.87458E2 4
 .44855E2 5.44376E2 3.35003E2 5.02054E2 5.92158E2
 4.88051E2 3.86426E2 4.66721E2 6.64953E2 4.61825E2
 3.38670E2 2.85725E2 4.06893E2 4.74219E2 5.10365E2
 7.08080E-1

RELATIVE CHANGE IN RESIDUAL SUM OF SQUARES LESS THAN 0.00001

CORRELATION BETWEEN PARAMETERS ESTIMATED

■	1	2	3	4	5	6	7	8	9	10	11	12
1	1.00	0.28	0.07	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.01
2	0.28	1.00	0.26	0.08	0.03	0.01	0.00	0.00	0.00	0.00	0.00	0.00
3	0.07	0.26	1.00	0.30	0.10	0.02	0.01	0.00	0.00	0.00	0.00	0.00
4	0.01	0.08	0.30	1.00	0.32	0.06	0.02	0.01	0.01	0.00	-0.01	-0.01
5	0.00	0.03	0.10	0.32	1.00	0.20	0.05	0.02	0.01	0.00	0.00	-0.01
6	0.00	0.01	0.02	0.06	0.20	1.00	0.24	0.07	0.02	0.01	0.00	0.00
7	0.00	0.00	0.01	0.02	0.05	0.24	1.00	0.31	0.10	0.03	0.00	0.00
8	0.00	0.00	0.00	0.01	0.02	0.07	0.31	1.00	0.32	0.10	0.02	0.00
9	0.00	0.00	0.00	0.01	0.01	0.02	0.10	0.32	1.00	0.31	0.07	0.01
10	0.00	0.00	0.00	0.00	0.00	0.01	0.03	0.10	0.31	1.00	0.23	0.04
11	0.01	0.00	0.00	-0.01	0.00	0.00	0.00	0.02	0.07	0.23	1.00	0.20
12	0.01	0.00	0.00	-0.01	-0.01	0.00	0.00	0.00	0.01	0.04	0.20	1.00
13	-0.03	0.01	0.01	0.03	0.03	0.01	0.01	0.01	0.02	0.02	0.04	0.25
14	-0.19	0.30	0.07	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.01
15	-0.03	-0.16	0.28	0.07	0.02	0.00	0.00	0.00	0.00	0.00	0.01	0.01
16	0.00	-0.04	-0.16	0.24	0.07	0.01	0.00	0.00	0.00	0.00	0.01	0.01
17	0.00	-0.01	-0.04	-0.13	0.22	0.04	0.01	0.00	0.00	0.00	0.00	0.01
18	0.01	-0.01	-0.02	-0.05	-0.14	0.34	0.08	0.02	0.00	0.00	0.01	0.01
19	0.01	0.00	-0.01	-0.02	-0.04	-0.16	0.30	0.09	0.02	0.01	0.01	0.01
20	0.01	0.00	0.00	-0.01	-0.01	-0.04	-0.14	0.21	0.06	0.02	0.01	0.01
21	0.01	0.00	0.00	-0.01	-0.01	-0.01	-0.05	-0.14	0.20	0.06	0.02	0.01
22	0.01	0.00	0.00	-0.01	-0.01	-0.01	-0.02	-0.05	-0.14	0.23	0.06	0.02
23	0.02	-0.01	0.00	-0.02	-0.01	-0.01	-0.01	-0.02	-0.06	-0.17	0.33	0.08
24	0.04	-0.02	-0.01	-0.04	-0.03	-0.01	-0.02	-0.02	-0.04	-0.07	-0.23	0.39
25	0.04	-0.02	-0.01	-0.04	-0.03	-0.01	-0.02	-0.02	-0.02	-0.03	-0.05	-0.32
26	0.09	-0.04	-0.03	-0.39	-0.08	-0.03	-0.04	-0.03	-0.05	-0.02	0.06	0.11

■	13	14	15	16	17	18	19	20	21	22	23	24
1	-0.03	-0.19	-0.03	0.00	0.00	0.01	0.01	0.01	0.01	0.01	0.02	0.04
2	0.01	0.30	-0.16	-0.04	-0.01	-0.31	0.00	0.00	0.00	0.00	-0.01	-0.02
3	0.01	0.07	0.28	-0.16	-0.04	-0.02	-0.01	0.00	0.00	0.00	0.00	-0.01
4	0.03	0.01	0.07	0.24	-0.13	-0.05	-0.02	-0.01	-0.01	-0.01	-0.02	-0.04
5	0.03	0.00	0.02	0.07	0.22	-0.14	-0.04	-0.01	-0.01	-0.01	-0.01	-0.03
6	0.01	0.00	0.00	0.01	0.04	0.34	-0.16	-0.04	-0.01	-0.01	-0.01	-0.01
7	0.01	0.00	0.00	0.00	0.01	0.08	0.30	-0.14	-0.05	-0.02	-0.01	-0.02
8	0.01	0.00	0.00	0.00	0.00	0.02	0.09	0.21	-0.14	-0.05	-0.02	-0.02
9	0.02	0.00	0.00	0.00	0.00	0.00	0.02	0.06	0.20	-0.14	-0.06	-0.04
10	0.02	0.00	0.00	0.00	0.00	0.00	0.01	0.02	0.06	0.23	-0.17	-0.07
11	0.04	0.01	0.01	0.01	0.00	0.01	0.01	0.01	0.02	0.06	0.33	-0.23
12	0.25	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.02	0.08	0.39
13	1.00	-0.03	-0.03	-0.03	-0.02	-0.03	-0.04	-0.03	-0.03	-0.03	-0.04	-0.04
14	-0.03	1.00	-0.04	0.00	0.00	0.01	0.01	0.01	0.01	0.01	0.02	0.04
15	-0.03	-0.04	1.00	-0.04	0.00	0.01	0.01	0.01	0.01	0.01	0.02	0.04
16	-0.03	0.00	-0.04	1.00	-0.03	0.00	0.01	0.01	0.01	0.01	0.02	0.04
17	-0.02	0.00	0.00	-0.03	1.00	-0.02	0.00	0.00	0.00	0.01	0.01	0.03
18	-0.03	0.01	0.01	0.00	-0.02	1.00	-0.04	0.00	0.00	0.01	0.02	0.04
19	-0.04	0.01	0.01	0.01	0.00	-0.04	1.00	-0.03	0.00	0.01	0.02	0.05
20	-0.03	0.01	0.01	0.01	0.00	0.00	-0.03	1.00	-0.02	0.00	0.01	0.03
21	-0.03	0.01	0.01	0.01	0.00	0.00	0.00	-0.02	1.00	-0.02	0.00	0.03
22	-0.03	0.01	0.01	0.01	0.01	0.01	0.01	0.00	-0.02	1.00	-0.02	0.02
23	-0.04	0.02	0.02	0.02	0.01	0.02	0.02	0.01	0.00	-0.02	1.00	-0.01
24	-0.04	0.04	0.04	0.04	0.03	0.04	0.05	0.03	0.03	0.02	-0.01	1.00
25	0.15	0.04	0.04	0.04	0.03	0.04	0.05	0.03	0.03	0.03	0.05	0.05
26	-0.34	0.10	0.10	0.10	0.06	0.10	0.11	0.08	0.08	0.09	0.18	0.42

■	25	26
1	0.04	0.09
2	-0.02	-0.04
3	-0.01	-0.03
4	-0.04	-0.09
5	-0.03	-0.08
6	-0.01	-0.03
7	-0.02	-0.04
8	-0.02	-0.03
9	-0.02	-0.05
10	-0.03	-0.02
11	-0.05	0.06
12	-0.32	0.11
13	0.15	-0.34
14	0.04	0.10
15	0.04	0.10
16	0.04	0.10
17	0.03	0.06
18	0.04	0.10
19	0.05	0.11
20	0.03	0.08
21	0.03	0.08
22	0.03	0.09
23	0.05	0.18
24	0.05	0.42
25	1.00	0.43
26	0.43	1.00

SURVEY YEAR	STOCK SIZE ESTIMATES (millions at time of survey)		MORTALITY RATES (between surveys)		
			Z	F	F
			on sizes 1+	on size 1	on sizes 2+
	RECRUITS	FULLY-RECRUITED			
1984	787.817	755.363	0.38	0.10	0.17
1985	929.208	1051.603	0.56	0.21	0.39
1986	765.845	1134.184	0.71	0.31	0.56
1987	545.737	937.345	0.71	0.31	0.55
1988	941.622	726.830	0.44	0.14	0.26
1989	1043.437	1071.358	0.60	0.25	0.45
1990	652.222	1159.054	0.70	0.30	0.54
1991	478.293	899.324	0.72	0.31	0.55
1992	403.521	672.507	0.68	0.28	0.51
1993	574.643	547.195	0.58	0.24	0.43
1994	837.157	628.256	0.65	0.29	0.53
1995	720.773	768.806	1.15	0.63	1.15
1996	404.380	473.115			

RECRUITS = SIZECLASS 1 FULLY-RECRUITED = SIZECLASS 2+

Note that the recruit population estimate for the last year (1996) is NOT a least squares estimate. It is calculated from the observed survey index, the least squares estimate of q, and the s_r.

SURVEY YEAR	---- BIOMASS ESTIMATES (at time of the survey) ---- (1000 mt)				CATCH BIOMASS DURING YEAR (1000 mt)
	RECRUITS	FULLY- RECRUITED	TOTAL BIOMASS	EXPLOITED BIOMASS	
1984	5.041	6.169	11.210	8.951	4.132
1985	6.973	9.879	16.852	13.727	4.635
1986	5.499	11.682	17.181	14.717	5.266
1987	3.954	9.608	13.562	11.790	3.036
1988	4.594	6.243	10.837	8.778	3.315
1989	6.923	9.107	16.030	12.927	4.665
1990	5.378	11.706	17.084	14.674	3.571
1991	3.212	9.839	13.050	11.611	3.443
1992	2.653	6.893	9.546	8.357	2.142
1993	2.670	4.526	7.196	6.000	2.915
1994	4.874	5.206	10.080	7.896	6.378
1995	4.878	7.311	12.189	10.003	9.166
1996	2.657	4.644	7.301	6.110	

SURVEY YEAR	----- 1000 Metric Tons -----			SURPLUS PRODUCTION	PROD-BIOMASS RATIO
	EXPLOITED BIOMASS	DELTA B	CATCH		
1984	8.951	4.776	4.132	8.908	0.9951
1985	13.727	0.990	4.635	5.625	0.4098
1986	14.717	-2.927	5.266	2.339	0.1590
1987	11.790	-3.012	3.036	0.024	0.0020
1988	8.778	4.149	3.315	7.465	0.8503
1989	12.927	1.747	4.665	6.412	0.4960
1990	14.674	-3.063	3.571	0.508	0.0346
1991	11.611	-3.254	3.443	0.189	0.0163
1992	8.357	-2.358	2.142	-0.215	-0.0258
1993	6.000	1.897	2.915	4.811	0.8020
1994	7.896	2.107	6.378	8.485	1.0745
1995	10.003	-3.893	9.166	5.273	0.5272
1996	6.110				

The SURPLUS PRODUCTION table, above, assumes that DELTA B over the course of a survey year can be approximated by differencing the successive EXPLOITED BIOMASS estimates at time of the survey. More specifically, this assumes that the change in EXPLOITED BIOMASS between Jan 1 and the time of the survey is constant in successive years. Note also that the PRODUCTION-BIOMASS RATIO is with respect to exploited biomass at time of the survey.

SUMMARY OF RESIDUALS FROM THE FITTED MODEL

MEASUREMENT ERROR -- Fully-recruited index with lognormal errors

ERROR TERM	OBSERVED	PREDICTED	WEIGHT	RESIDUAL	STD RES	%SS
n 2+ 1984	479.1000	534.8571	0.1644	-0.0181	-0.4215	1.6
n 2+ 1985	925.4000	744.6185	0.1644	0.0357	0.8323	6.3
n 2+ 1986	848.7000	803.0924	0.1644	0.0091	0.2115	0.4
n 2+ 1987	693.6000	663.7147	0.1644	0.0072	0.1686	0.3
n 2+ 1988	387.9000	514.6536	0.1644	-0.0465	-1.0826	10.7
n 2+ 1989	817.5000	758.6070	0.1644	0.0123	0.2863	0.7
n 2+ 1990	907.7000	820.7025	0.1644	0.0166	0.3858	1.4
n 2+ 1991	611.9000	636.7932	0.1644	-0.0066	-0.1527	0.2
n 2+ 1992	444.4000	476.1884	0.1644	-0.0114	-0.2645	0.6
n 2+ 1993	320.6000	387.4579	0.1644	-0.0311	-0.7253	4.8
n 2+ 1994	364.4000	444.8551	0.1644	-0.0328	-0.7639	5.3
n 2+ 1995	653.1000	544.3759	0.1644	0.0299	0.6972	4.4
n 2+ 1996	348.6000	335.0028	0.1644	0.0065	0.1523	0.2
SUM				-0.0290	-0.6765	36.9

MEASUREMENT ERROR -- Recruit index with lognormal errors

ERROR TERM	OBSERVED	PREDICTED	WEIGHT	RESIDUAL	STD RES	%SS
r 1 1984	447.6000	502.0536	0.1644	-0.0189	-0.4396	1.8
r 1 1985	619.5000	592.1581	0.1644	0.0074	0.1728	0.3
r 1 1986	533.4000	488.0511	0.1644	0.0146	0.3402	1.1
r 1 1987	436.3000	386.4256	0.1644	0.0200	0.4648	2.0
r 1 1988	459.9000	466.7206	0.1644	-0.0024	-0.0564	0.0
r 1 1989	700.7000	664.9529	0.1644	0.0086	0.2005	0.4
r 1 1990	511.6000	461.8250	0.1644	0.0168	0.3919	1.4
r 1 1991	374.1000	338.6699	0.1644	0.0164	0.3810	1.3
r 1 1992	313.6000	285.7254	0.1644	0.0153	0.3564	1.2
r 1 1993	410.0000	406.8929	0.1644	0.0013	0.0291	0.0
r 1 1994	368.7000	474.2190	0.1644	-0.0414	-0.9637	8.4
r 1 1995	485.9000	510.3645	0.1644	-0.0081	-0.1881	0.3
SUM				0.0296	0.6891	18.1

PROCESS ERROR -- DeLury equation with lognormal errors

ERROR TERM	CALCULATED	PREDICTED	WEIGHT	RESIDUAL	STD RES	%SS
n 2+ 1985	630.5386	744.6185	0.1644	-0.0273	-0.6368	3.7
n 2+ 1986	866.6362	803.0924	0.1644	0.0125	0.2916	0.8
n 2+ 1987	782.0193	663.7147	0.1644	0.0270	0.6281	3.6
n 2+ 1988	675.1067	514.6536	0.1644	0.0446	1.0391	9.8
n 2+ 1989	742.8283	758.6070	0.1644	-0.0035	-0.0805	0.1
n 2+ 1990	889.7460	820.7025	0.1644	0.0133	0.3093	0.9
n 2+ 1991	798.6912	636.7932	0.1644	0.0372	0.8674	6.8
n 2+ 1992	595.7021	476.1884	0.1644	0.0368	0.8574	6.7
n 2+ 1993	471.6603	387.4579	0.1644	0.0323	0.7530	5.2
n 2+ 1994	449.6702	444.8551	0.1644	0.0018	0.0412	0.0
n 2+ 1995	430.5941	544.3759	0.1644	-0.0385	-0.8978	7.3
n 2+ 1996	321.9251	335.0028	0.1644	-0.0065	-0.1525	0.2
SUM				0.1296	3.0195	45.0

37 residual error terms
 26 parameters estimated
 11 degrees of freedom

Time stamp at end of run 1997 1 28 9 22 38

BOOTSTRAP TYPE : LOB
 BOOTSTRAP CLASS: parametric conditional
 SEED FOR THE RANDOM NUMBER GENERATOR: 74747

MAIN LOOP LIMIT IN MARQUARDT ALGORITHM: 50
 NUMBER OF BOOTSTRAP REPLICATIONS ATTEMPTED: 200
 NUMBER FOR WHICH NLLS CONVERGED: 200
 Results from the converged replications are used for computing the statistics that follow. Other replications are ignored.

This bootstrap run finished running at timestamp: 1997 1 28 9 23 57 780
 This bootstrap run was started at timestamp: 1997 1 28 9 22 41 380

BOOTSTRAP OUTPUT VARIABLE: n_hat
 Predicted indices of abundance for the fully-recruited animals for years
 1984 1985 1986 1987 1988 1989 1990 1991 1992 1993 1994 1995 1996

PARAMETER	NLLS ESTIMATE	BOOTSTRAP MEAN	BOOTSTRAP STD ERROR	C.V. FOR NLLS SOLN
n 2+ 1984	5.349E2	5.546E2	8.041E1	0.15
n 2+ 1985	7.446E2	7.081E2	1.009E2	0.14
n 2+ 1986	8.031E2	8.087E2	1.063E2	0.13
n 2+ 1987	6.637E2	7.030E2	8.241E1	0.12
n 2+ 1988	5.147E2	6.063E2	7.847E1	0.15
n 2+ 1989	7.586E2	7.892E2	9.749E1	0.13
n 2+ 1990	8.207E2	8.318E2	1.022E2	0.12
n 2+ 1991	6.368E2	6.791E2	8.025E1	0.13
n 2+ 1992	4.762E2	5.226E2	6.857E1	0.14
n 2+ 1993	3.875E2	4.475E2	6.114E1	0.16
n 2+ 1994	4.449E2	4.996E2	7.318E1	0.16
n 2+ 1995	5.444E2	5.640E2	7.589E1	0.14
n 2+ 1996	3.350E2	3.436E2	6.820E1	0.20

PARAMETER	PERCENTILES						MAX
	MIN	10	25	MEDIAN	75	90	
n 2+ 1984	3.872E2	4.612E2	5.008E2	5.407E2	6.072E2	6.606E2	8.240E2
n 2+ 1985	4.628E2	5.821E2	6.325E2	7.098E2	7.748E2	8.396E2	1.062E3
n 2+ 1986	4.717E2	6.731E2	7.484E2	8.108E2	8.752E2	9.368E2	1.137E3
n 2+ 1987	4.950E2	5.984E2	6.418E2	6.986E2	7.605E2	8.179E2	8.996E2
n 2+ 1988	3.948E2	5.173E2	5.529E2	6.007E2	6.552E2	7.094E2	8.139E2
n 2+ 1989	5.867E2	6.649E2	7.223E2	7.854E2	8.485E2	9.202E2	1.050E3
n 2+ 1990	5.969E2	7.085E2	7.551E2	8.234E2	8.978E2	9.574E2	1.123E3
n 2+ 1991	4.794E2	5.810E2	6.213E2	6.706E2	7.372E2	7.860E2	9.121E2
n 2+ 1992	3.511E2	4.314E2	4.830E2	5.218E2	5.692E2	6.032E2	7.513E2
n 2+ 1993	2.909E2	3.757E2	4.086E2	4.455E2	4.849E2	5.215E2	6.408E2
n 2+ 1994	3.192E2	4.042E2	4.442E2	5.035E2	5.486E2	5.942E2	6.840E2
n 2+ 1995	3.645E2	4.758E2	5.090E2	5.566E2	5.994E2	6.700E2	7.829E2
n 2+ 1996	1.984E2	2.643E2	2.970E2	3.347E2	3.860E2	4.370E2	6.544E2

PARAMETER	BIAS ESTIMATE	BIAS STD ERROR	PERCENT BIAS	NLLS EST CORRECTED FOR BIAS	C.V FOR CORRECTED ESTIMATE
n 2+ 1984	1.973E1	5.686E0	3.69	5.151E2	0.16
n 2+ 1985	-3.654E1	7.137E0	-4.91	7.812E2	0.13
n 2+ 1986	5.571E0	7.518E0	0.69	7.975E2	0.13
n 2+ 1987	3.929E1	5.827E0	5.92	6.244E2	0.13
n 2+ 1988	9.170E1	5.549E0	17.82	4.230E2	0.19
n 2+ 1989	3.059E1	6.894E0	4.03	7.280E2	0.13
n 2+ 1990	1.106E1	7.225E0	1.35	8.096E2	0.13
n 2+ 1991	4.230E1	5.675E0	6.64	5.945E2	0.13
n 2+ 1992	4.639E1	4.849E0	9.74	4.298E2	0.16
n 2+ 1993	6.007E1	4.323E0	15.50	3.274E2	0.19
n 2+ 1994	5.476E1	5.175E0	12.31	3.901E2	0.19
n 2+ 1995	1.961E1	5.366E0	3.60	5.248E2	0.14
n 2+ 1996	8.637E0	4.823E0	2.58	3.264E2	0.21

BOOTSTRAP OUTPUT VARIABLE: r_hat

Predicted indices of abundance for the recruits for years
 1984 1985 1986 1987 1988 1989 1990 1991 1992 1993 1994 1995

PARAMETER	NLLS ESTIMATE	BOOTSTRAP MEAN	BOOTSTRAP STD ERROR	C.V. FOR NLLS SOLN
r 1 1984	5.021E2	5.372E2	5.580E1	0.11
r 1 1985	5.922E2	5.985E2	6.092E1	0.10
r 1 1986	4.881E2	4.816E2	4.954E1	0.10
r 1 1987	3.864E2	3.751E2	3.802E1	0.10
r 1 1988	4.667E2	4.700E2	4.652E1	0.10
r 1 1989	6.650E2	6.575E2	6.944E1	0.10
r 1 1990	4.618E2	4.446E2	4.840E1	0.10
r 1 1991	3.387E2	3.258E2	3.351E1	0.10
r 1 1992	2.857E2	2.784E2	2.647E1	0.09
r 1 1993	4.069E2	4.190E2	4.770E1	0.12
r 1 1994	4.742E2	5.386E2	6.012E1	0.13
r 1 1995	5.104E2	5.506E2	6.731E1	0.13

PARAMETER	MIN	PERCENTILES					MAX
		10	25	MEDIAN	75	90	
r 1 1984	3.719E2	4.749E2	4.970E2	5.342E2	5.767E2	6.083E2	7.167E2
r 1 1985	4.148E2	5.189E2	5.575E2	6.012E2	6.359E2	6.759E2	7.778E2
r 1 1986	3.617E2	4.163E2	4.495E2	4.785E2	5.159E2	5.473E2	6.620E2
r 1 1987	2.690E2	3.287E2	3.479E2	3.763E2	4.014E2	4.248E2	4.737E2
r 1 1988	3.415E2	4.189E2	4.377E2	4.644E2	4.994E2	5.277E2	6.084E2
r 1 1989	5.051E2	5.695E2	6.106E2	6.576E2	7.052E2	7.482E2	8.754E2
r 1 1990	3.288E2	3.847E2	4.098E2	4.425E2	4.742E2	5.031E2	5.912E2
r 1 1991	2.332E2	2.829E2	3.017E2	3.236E2	3.506E2	3.737E2	4.044E2
r 1 1992	2.100E2	2.450E2	2.606E2	2.756E2	2.951E2	3.168E2	3.450E2
r 1 1993	2.978E2	3.602E2	3.873E2	4.149E2	4.545E2	4.844E2	5.460E2
r 1 1994	3.668E2	4.655E2	5.033E2	5.344E2	5.773E2	6.147E2	7.408E2
r 1 1995	4.159E2	4.694E2	5.080E2	5.407E2	5.919E2	6.395E2	8.964E2

PARAMETER	BIAS ESTIMATE	BIAS STD ERROR	PERCENT BIAS	NLLS EST CORRECTED FOR BIAS	C.V FOR CORRECTED ESTIMATE
r 1 1984	35.18845868	3.94547188	7.01	466.8652	0.12
r 1 1985	6.30562642	4.30775924	1.06	585.8525	0.10
r 1 1986	-6.49155427	3.50278839	-1.33	494.5426	0.10
r 1 1987	-11.35099780	2.68847090	-2.94	397.7766	0.10
r 1 1988	3.29186582	3.28934349	0.71	463.4287	0.10
r 1 1989	-7.42004167	4.91004665	-1.12	672.3730	0.10
r 1 1990	-17.25408403	3.42262489	-3.74	479.0791	0.10
r 1 1991	-12.84073360	2.36985779	-3.79	351.5106	0.10
r 1 1992	-7.30346831	1.87163634	-2.56	293.0288	0.09
r 1 1993	12.13725257	3.37311690	2.98	394.7556	0.12
r 1 1994	64.41420931	4.25122625	13.58	409.8048	0.15
r 1 1995	40.26546558	4.75965040	7.89	470.0991	0.14

BOOTSTRAP OUTPUT VARIABLE: q_hat
 Catchability of the fully-recruited animals to the survey gear

PARAMETER	NLLS ESTIMATE	BOOTSTRAP MEAN	BOOTSTRAP STD ERROR	C.V. FOR NLLS SOLN
Surv q_n	7.081E-1	7.671E-1	5.901E-2	0.08

PARAMETER	PERCENTILES						
	MIN	10	25	MEDIAN	75	90	MAX
Surv q_n	6.370E-1	6.958E-1	7.257E-1	7.647E-1	8.031E-1	8.368E-1	9.547E-1

PARAMETER	BIAS ESTIMATE	BIAS STD ERROR	PERCENT BIAS	NLLS EST CORRECTED FOR BIAS	C.V FOR CORRECTED ESTIMATE
Surv q_n	5.900E-2	4.173E-3	8.33	6.491E-1	0.09

BOOTSTRAP OUTPUT VARIABLE: F_RN_bar
 Average fishing mortality rate for all animals of recruitment size and larger i.e. recruits plus the fully-recruited group during survey years
 Average fishing mortality rates on the fully-recruited animals
 1st Row: F in 1995
 2nd Row: Average F for 1994 1995
 3rd Row: Average F for 1993 1994 1995

SURVEY YEAR(S)	NLLS ESTIMATE	BOOTSTRAP MEAN	BOOTSTRAP STD ERROR	C.V. FOR NLLS SOLN
1995 0	0.8969	0.9437	0.1635	0.18
1994 95	0.6460	0.7162	0.1039	0.16
1993 95	0.5406	0.5803	0.0844	0.16

SURVEY YEAR(S)	PERCENTILES						
	MIN	10	25	MEDIAN	75	90	MAX
1995 0	0.4579	0.7384	0.8329	0.9332	1.0489	1.1432	1.4117
1994 95	0.3332	0.5900	0.6441	0.7208	0.7791	0.8427	0.9974
1993 95	0.2590	0.4696	0.5206	0.5816	0.6404	0.6736	0.8249

SURVEY YEAR(S)	BIAS ESTIMATE	BIAS STD ERROR	PERCENT BIAS	NLLS EST CORRECTED FOR BIAS	C.V FOR CORRECTED ESTIMATE
1995 0	0.04680371	0.01155837	5.22	0.8501	0.19
1994 95	0.07026125	0.00734907	10.88	0.5757	0.18
1993 95	0.03968035	0.00597031	7.34	0.5009	0.17

BOOTSTRAP OUTPUT VARIABLE: F_RN
 Fishing mortality rate for all animals of recruitment size and larger
 i.e. recruits plus the fully-recruited group during survey years

SURVEY YEAR	NLLS ESTIMATE	BOOTSTRAP MEAN	BOOTSTRAP STD ERROR	C.V. FOR NLLS SOLN
1984	0.1335	0.2436	0.0918	0.69
1985	0.3076	0.2847	0.0888	0.29
1986	0.4566	0.4013	0.0855	0.19
1987	0.4632	0.3305	0.0959	0.21
1988	0.1930	0.2370	0.0866	0.45
1989	0.3514	0.3574	0.0814	0.23
1990	0.4501	0.3843	0.0957	0.21
1991	0.4671	0.4091	0.0972	0.21
1992	0.4262	0.3377	0.0991	0.23
1993	0.3298	0.3083	0.1029	0.31
1994	0.3951	0.4888	0.0901	0.23
1995	0.8969	0.9437	0.1635	0.18

SURVEY YEAR	----- PERCENTILES -----						MAX
	MIN	10	25	MEDIAN	75	90	
1984	0.0174	0.1218	0.1774	0.2515	0.3031	0.3484	0.5163
1985	0.0162	0.1751	0.2263	0.2773	0.3311	0.4084	0.5797
1986	0.1796	0.2864	0.3482	0.4055	0.4551	0.5119	0.6972
1987	0.0903	0.2052	0.2698	0.3302	0.3875	0.4438	0.6631
1988	0.0413	0.1277	0.1844	0.2313	0.2956	0.3462	0.4740
1989	0.1456	0.2584	0.3110	0.3545	0.4135	0.4634	0.5923
1990	0.1554	0.2605	0.3188	0.3862	0.4451	0.5121	0.6238
1991	0.0917	0.2839	0.3445	0.4097	0.4770	0.5288	0.6959
1992	0.0935	0.2062	0.2702	0.3378	0.3934	0.4607	0.6612
1993	0.0692	0.1852	0.2371	0.3038	0.3729	0.4411	0.6281
1994	0.2084	0.3742	0.4282	0.4893	0.5520	0.5904	0.8496
1995	0.4579	0.7384	0.8329	0.9332	1.0489	1.1432	1.4117

SURVEY YEAR	BIAS ESTIMATE	BIAS STD ERROR	PERCENT BIAS	NLLS EST CORRECTED FOR BIAS	C.V FOR CORRECTED ESTIMATE
1984	0.11008559	0.00649237	82.44	0.0234	3.92
1985	-0.02287962	0.00627852	-7.44	0.3305	0.27
1986	-0.05528511	0.00604603	-12.11	0.5119	0.17
1987	-0.13267163	0.00677772	-28.64	0.5959	0.16
1988	0.04402055	0.00612300	22.81	0.1489	0.58
1989	0.00606796	0.00575645	1.73	0.3453	0.24
1990	-0.06580524	0.00676405	-14.62	0.5159	0.19
1991	-0.05800399	0.00687155	-12.42	0.5251	0.19
1992	-0.08856496	0.00700931	-20.78	0.5148	0.19
1993	-0.02148144	0.00727384	-6.51	0.3513	0.29
1994	0.09371879	0.00637264	23.72	0.3013	0.30
1995	0.04680371	0.01155837	5.22	0.8501	0.19

BOOTSTRAP OUTPUT VARIABLE: B_RN_0_expl
 Exploited biomass at time of the survey
 i.e. 0% into the survey year

YEAR	NLLS ESTIMATE	BOOTSTRAP MEAN	BOOTSTRAP STD ERROR	C.V. FOR NLLS SOLN
1984	8.951E0	8.687E0	9.112E-1	0.10
1985	1.373E1	1.233E1	1.575E0	0.11
1986	1.472E1	1.372E1	1.852E0	0.13
1987	1.179E1	1.144E1	1.567E0	0.13
1988	8.778E0	9.212E0	1.205E0	0.14
1989	1.293E1	1.231E1	1.479E0	0.11
1990	1.467E1	1.367E1	1.679E0	0.11
1991	1.161E1	1.133E1	1.480E0	0.13
1992	8.357E0	8.359E0	1.193E0	0.14
1993	6.000E0	6.266E0	8.304E-1	0.14
1994	7.896E0	8.255E0	8.660E-1	0.11
1995	1.000E1	9.719E0	1.021E0	0.10
1996	6.110E0	5.821E0	1.203E0	0.20

YEAR	MIN	PERCENTILES					MAX
		10	25	MEDIAN	75	90	
1984	6.145E0	7.494E0	8.083E0	8.651E0	9.238E0	9.758E0	1.149E1
1985	8.124E0	1.048E1	1.124E1	1.225E1	1.337E1	1.449E1	1.785E1
1986	9.252E0	1.128E1	1.248E1	1.378E1	1.491E1	1.625E1	1.822E1
1987	7.407E0	9.219E0	1.048E1	1.132E1	1.260E1	1.343E1	1.572E1
1988	6.627E0	7.740E0	8.464E0	9.100E0	9.982E0	1.075E1	1.294E1
1989	8.882E0	1.045E1	1.116E1	1.225E1	1.334E1	1.416E1	1.691E1
1990	9.234E0	1.155E1	1.245E1	1.355E1	1.481E1	1.606E1	1.770E1
1991	7.640E0	9.498E0	1.031E1	1.119E1	1.236E1	1.324E1	1.607E1
1992	5.612E0	6.884E0	7.563E0	8.238E0	9.061E0	1.013E1	1.199E1
1993	4.421E0	5.160E0	5.734E0	6.199E0	6.786E0	7.383E0	8.668E0
1994	6.067E0	7.236E0	7.632E0	8.274E0	8.752E0	9.376E0	1.145E1
1995	7.745E0	8.525E0	9.052E0	9.583E0	1.033E1	1.098E1	1.470E1
1996	3.403E0	4.429E0	4.965E0	5.749E0	6.460E0	7.340E0	1.171E1

YEAR	BIAS ESTIMATE	BIAS STD ERROR	PERCENT BIAS	NLLS EST CORRECTED FOR BIAS	C.V FOR CORRECTED ESTIMATE
1984	-2.640E-1	6.443E-2	-2.95	9.215E0	0.10
1985	-1.394E0	1.114E-1	-10.16	1.512E1	0.10
1986	-1.002E0	1.309E-1	-6.81	1.572E1	0.12
1987	-3.523E-1	1.108E-1	-2.99	1.214E1	0.13
1988	4.333E-1	8.522E-2	4.94	8.345E0	0.14
1989	-6.189E-1	1.046E-1	-4.79	1.355E1	0.11
1990	-1.009E0	1.187E-1	-6.88	1.568E1	0.11
1991	-2.814E-1	1.047E-1	-2.42	1.189E1	0.12
1992	1.541E-3	8.436E-2	0.02	8.356E0	0.14
1993	2.663E-1	5.872E-2	4.44	5.733E0	0.14
1994	3.587E-1	6.124E-2	4.54	7.538E0	0.11
1995	-2.843E-1	7.223E-2	-2.84	1.029E1	0.10
1996	-2.892E-1	8.504E-2	-4.73	6.399E0	0.19

APPENDIX B: BIOMASS DYNAMICS MODEL

Gulf of Maine Northern Shrimp -- ASPIC 3.6x -- Three Indices

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29 May 1997 at 13:40

ASPIC -- A Surplus-Production Model Including Covariates (Ver. 3.64)

FIT Mode

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CONTROL PARAMETERS USED (FROM INPUT FILE)

Number of years analyzed:	29	Number of bootstrap trials:	0
Number of data series:	3	Lower bound on MSY:	1.000E+00
Objective function computed:	in EFFORT	Upper bound on MSY:	5.000E+01
Relative conv. criterion (simplex):	1.000E-08	Lower bound on r:	1.000E-01
Relative conv. criterion (restart):	3.000E-08	Upper bound on r:	1.000E+01
Relative conv. criterion (effort):	1.000E-04	Random number seed:	1964295
Maximum F allowed in fitting:	5.000	Monte Carlo search trials:	50000

PROGRAM STATUS INFORMATION (NON-BOOTSTRAPPED ANALYSIS)

code 0

Normal convergence.

CORRELATION AMONG INPUT SERIES EXPRESSED AS CPUE (NUMBER OF PAIRWISE OBSERVATIONS BELOW)

	1	2	3
1 Fall Groundfish Survey	1.000		
2 Maine Summer Survey	0.738	1.000	
3 Summer Shrimp Survey	0.501	0.000	1.000

GOODNESS-OF-FIT AND WEIGHTING FOR NON-BOOTSTRAPPED ANALYSIS

Loss component number and title	Weighted SSE	N	Weighted MSE	Current weight	Suggested weight	R-squared in CPUE
Loss(-1) SSE in yield	0.000E+00					
Loss(0) Penalty for BIR > 2	0.000E+00	1	N/A	1.000E+00	N/A	
Loss(1) Fall Groundfish Survey	5.464E+00	29	2.024E-01	1.000E+00	7.672E-01	0.641
Loss(2) Maine Summer Survey	1.578E+00	14	2.982E-01	1.000E+00	5.207E-01	0.673
Loss(3) Summer Shrimp Survey	8.391E-01	13	7.628E-02	1.000E+00	2.035E+00	0.185

TOTAL OBJECTIVE FUNCTION: 9.88066932E+00

Number of restarts required for convergence: 22
Est. B-ratio coverage index (0 worst, 2 best): 1.3500
Est. B-ratio nearness index (0 worst, 1 best): 1.0000

MODEL PARAMETER ESTIMATES (NON-BOOTSTRAPPED)

Parameter	Estimate	Starting guess	Estimated	User guess
BIR Starting biomass ratio, year 1968	1.453E+00	1.000E+00	1	1
MSY Maximum sustainable yield	5.330E+00	6.000E+00	1	1
r Intrinsic rate of increase	3.432E-01	3.000E-01	1	1
..... Catchability coefficients by fishery:				
q(1) Fall Groundfish Survey	9.892E-02	1.000E-01	1	1
q(2) Maine Summer Survey	5.828E-01	5.000E-01	1	1
q(3) Summer Shrimp Survey	9.017E-01	9.000E-01	1	1

MANAGEMENT PARAMETER ESTIMATES (NON-BOOTSTRAPPED)

Parameter	Estimate	Formula
MSY Maximum sustainable yield	5.330E+00	Kr/4
K Maximum stock biomass	6.212E+01	
Bmsy Stock biomass at MSY	3.106E+01	K/2
Fmsy Fishing mortality at MSY	1.716E-01	r/2
F(0.1) Management benchmark	1.544E-01	0.9*Fmsy
Y(0.1) Equilibrium yield at F(0.1)	5.277E+00	0.99*MSY
B-ratio Ratio of B(1997) to Bmsy	2.054E-01	
F-ratio Ratio of F(1996) to Fmsy	5.792E+00	
Y-ratio Proportion of MSY avail in 1997	3.686E-01	2*Br-Br^2
..... Fishing effort at MSY in units of each fishery:		
fmsy(1) Fall Groundfish Survey	1.735E+00	r/2q(1)
		f(0.1) = 1.561E+00

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ESTIMATED POPULATION TRAJECTORY (NON-BOOTSTRAPPED)

Obs	Year	Estimated total F mort	Estimated starting biomass	Estimated average biomass	Observed total yield	Model total yield	Estimated surplus production	Ratio of F mort to Fmsy	Ratio of biomass to Bmsy
1	1968	0.128	4.514E+01	4.443E+01	5.708E+00	5.708E+00	4.342E+00	7.486E-01	1.453E-00
2	1969	0.304	4.378E+01	3.991E+01	1.214E+01	1.214E+01	4.374E+00	1.772E-00	1.409E+00
3	1970	0.340	3.652E+01	3.331E+01	1.133E+01	1.133E+01	5.285E+00	1.982E+00	1.176E+00
4	1971	0.383	3.047E+01	2.765E+01	1.059E+01	1.059E+01	5.253E+00	2.233E+00	9.810E-01
5	1972	0.517	2.513E+01	2.171E+01	1.122E+01	1.122E+01	4.829E+00	3.012E+00	8.091E-01
6	1973	0.618	1.874E+01	1.568E+01	9.691E+00	9.691E+00	4.009E+00	3.601E+00	6.032E-01
7	1974	0.781	1.305E+01	1.027E+01	8.024E+00	8.024E+00	2.931E+00	4.551E+00	4.203E-01
8	1975	1.132	7.941E+00	5.424E+00	6.142E+00	6.142E+00	1.690E+00	6.599E+00	2.563E-01
9	1976	0.413	3.599E+00	3.359E+00	1.387E+00	1.387E+00	1.090E+00	2.407E+00	1.130E-01
10	1977	0.103	3.212E+00	3.594E+00	3.716E-01	3.716E-01	1.162E+00	6.025E-01	1.034E-01
11	1978	0.004	4.003E+00	4.705E+00	1.680E-02	1.680E-02	1.491E+00	2.081E-02	1.289E-01
12	1979	0.079	5.477E+00	6.163E+00	4.865E-01	4.865E-01	1.904E+00	4.600E-01	1.763E-01
13	1980	0.043	6.895E+00	7.868E+00	3.391E-01	3.391E-01	2.356E+00	2.512E-01	2.220E-01
14	1981	0.110	8.912E+00	9.771E+00	1.071E+00	1.071E+00	2.824E+00	6.388E-01	2.869E-01
15	1982	0.133	1.067E+01	1.150E+01	1.530E+00	1.530E+00	3.214E+00	7.757E-01	3.434E-01
16	1983	0.104	1.235E+01	1.344E+01	1.397E+00	1.397E+00	3.612E+00	6.058E-01	3.976E-01
17	1984	0.196	1.456E+01	1.505E+01	2.951E+00	2.951E+00	3.913E+00	1.143E+00	4.689E-01
18	1985	0.267	1.553E+01	1.545E+01	4.131E+00	4.131E+00	3.984E+00	1.558E+00	4.999E-01
19	1986	0.309	1.538E+01	1.501E+01	4.635E+00	4.635E+00	3.906E+00	1.800E+00	4.951E-01
20	1987	0.379	1.465E+01	1.395E+01	5.253E+00	5.253E+00	3.692E+00	2.211E+00	4.717E-01
21	1988	0.227	1.404E+01	1.338E+01	3.031E+00	3.031E+00	3.602E+00	1.321E+00	4.214E-01
22	1989	0.239	1.366E+01	1.385E+01	3.315E+00	3.315E+00	3.694E+00	1.395E+00	4.398E-01
23	1990	0.345	1.404E+01	1.351E+01	4.662E+00	4.662E+00	3.627E+00	2.011E+00	4.519E-01
24	1991	0.275	1.300E+01	1.298E+01	3.571E+00	3.571E+00	3.524E+00	1.603E+00	4.187E-01
25	1992	0.265	1.296E+01	1.300E+01	3.444E+00	3.444E+00	3.528E+00	1.544E+00	4.171E-01
26	1993	0.155	1.304E+01	1.381E+01	2.143E+00	2.143E+00	3.684E+00	9.045E-01	4.198E-01
27	1994	0.193	1.458E+01	1.509E+01	2.915E+00	2.915E+00	3.920E+00	1.126E+00	4.695E-01
28	1995	0.456	1.559E+01	1.417E+01	6.466E+00	6.466E+00	3.750E+00	2.660E+00	5.018E-01
29	1996	0.994	1.287E+01	9.222E+00	9.166E+00	9.166E+00	2.676E+00	5.792E+00	4.144E-01
30	1997		6.381E+00						2.054E-01

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RESULTS FOR DATA SERIES # 1 (NON-BOOTSTRAPPED)

Fall Groundfish Survey

Data type CC: CPUE-catch series

Series weight: 1.000

Obs	Year	Observed effort	Estimated effort	Estim F	Observed yield	Model yield	Resid in log effort	Resid in yield
1	1968	1.784E+00	1.299E+00	0.1285	5.708E+00	5.708E+00	0.31738	0.000E+00
2	1969	4.495E+00	3.074E+00	0.3041	1.214E+01	1.214E+01	0.37995	0.000E+00
3	1970	3.062E+00	3.438E+00	0.3401	1.133E+01	1.133E+01	-0.11585	0.000E+00
4	1971	3.531E+00	3.873E+00	0.3832	1.059E+01	1.059E+01	-0.09245	0.000E+00
5	1972	3.401E+00	5.225E+00	0.5169	1.122E+01	1.122E+01	-0.42937	0.000E+00
6	1973	5.101E+00	6.246E+00	0.6179	9.691E+00	9.691E+00	-0.20265	0.000E+00
7	1974	1.003E+01	7.895E+00	0.7810	8.024E+00	8.024E+00	0.23938	0.000E+00
8	1975	6.824E+00	1.145E+01	1.1324	6.142E+00	6.142E+00	-0.51727	0.000E+00
9	1976	2.312E+00	4.175E+00	0.4130	1.387E+00	1.387E+00	-0.59122	0.000E+00
10	1977	1.858E+00	1.045E+00	0.1034	3.716E-01	3.716E-01	0.57539	0.000E+00
11	1978	4.200E-02	3.610E-02	0.0036	1.680E-02	1.680E-02	0.15143	0.000E+00
12	1979	9.730E-01	7.980E-01	0.0789	4.865E-01	4.865E-01	0.19830	0.000E+00
13	1980	6.782E-01	4.357E-01	0.0431	3.391E-01	3.391E-01	0.44253	0.000E+00
14	1981	7.141E-01	1.108E+00	0.1096	1.071E+00	1.071E+00	-0.43949	0.000E+00
15	1982	5.101E+00	1.346E+00	0.1331	1.530E+00	1.530E+00	1.33255	0.000E+00
16	1983	1.397E+00	1.051E+00	0.1039	1.397E+00	1.397E+00	0.28486	0.000E+00
17	1984	1.553E+00	1.982E+00	0.1961	2.951E+00	2.951E+00	-0.24406	0.000E+00
18	1985	2.582E+00	2.702E+00	0.2673	4.131E+00	4.131E+00	-0.04565	0.000E+00
19	1986	1.854E+00	3.122E+00	0.3088	4.635E+00	4.635E+00	-0.52114	0.000E+00
20	1987	3.090E+00	3.835E+00	0.3794	5.253E+00	5.253E+00	-0.21607	0.000E+00
21	1988	2.526E+00	2.291E+00	0.2266	3.031E+00	3.031E+00	0.09776	0.000E+00
22	1989	1.832E+00	2.420E+00	0.2394	3.315E+00	3.315E+00	-0.27839	0.000E+00
23	1990	2.285E+00	3.488E+00	0.3451	4.662E+00	4.662E+00	-0.42305	0.000E+00
24	1991	3.799E+00	2.781E+00	0.2751	3.571E+00	3.571E+00	0.31190	0.000E+00
25	1992	5.937E+00	2.678E+00	0.2649	3.444E+00	3.444E+00	0.79623	0.000E+00
26	1993	1.299E+00	1.569E+00	0.1552	2.143E+00	2.143E+00	-0.18899	0.000E+00
27	1994	1.343E+00	1.953E+00	0.1932	2.915E+00	2.915E+00	-0.37434	0.000E+00
28	1995	3.592E+00	4.614E+00	0.4564	6.466E+00	6.466E+00	-0.25019	0.000E+00
29	1996	8.184E+00	1.005E+01	0.9940	9.166E+00	9.166E+00	-0.20517	0.000E+00

RESULTS FOR DATA SERIES # 2 (NON-BOOTSTRAPPED)

Maine Summer Survey

Data type ID: Start-of-year biomass index

Series weight: 1.000

Obs	Year	Observed effort	Estimated effort	Estim F	Observed Index	Model index	Resid in log index	Resid in index
1	1968	1.000E+00	1.000E+00	0.0	4.580E-01	2.631E+01	0.55429	1.949E+01
2	1969	1.000E+00	1.000E+00	0.0	3.120E+01	2.552E+01	0.30113	5.694E+00
3	1970	1.000E+00	1.000E+00	0.0	4.080E+01	2.128E+01	0.65078	1.952E+01
4	1971	1.000E+00	1.000E+00	0.0	9.400E+00	1.776E+01	-0.63624	-9.360E+00
5	1972	1.000E+00	1.000E+00	0.0	7.000E+00	1.465E+01	-0.73834	-7.647E+00
6	1973	1.000E+00	1.000E+00	0.0	7.300E+00	1.092E+01	-0.33648	-3.120E+00
7	1974	1.000E+00	1.000E+00	0.0	4.900E+00	7.609E+00	-0.44000	-2.708E+00
8	1975	1.000E+00	1.000E+00	0.0	6.700E+00	4.640E+00	0.36746	2.060E+00
9	1976	1.000E+00	1.000E+00	0.0	4.300E+00	2.045E+00	0.35312	2.755E+00
10	1977	1.000E+00	1.000E+00	0.0	1.600E+00	1.872E+00	-0.15712	-2.722E-01
11	1978	1.000E+00	1.000E+00	0.0	3.200E+00	2.333E+00	0.31607	8.672E-01
12	1979	1.000E+00	1.000E+00	0.0	4.400E+00	3.192E+00	0.32089	1.208E+00
13	1980	1.000E+00	1.000E+00	0.0	2.700E+00	4.019E+00	-0.39767	-1.319E+00
14	1991	1.000E+00	1.000E+00	0.0	3.200E+00	5.194E+00	-0.54894	-2.194E+00

RESULTS FOR DATA SERIES # 3 (NON-BOOTSTRAPPED)

Summer Shrimp Survey

Data type ID: Start-of-year biomass index

Series weight: 1.000

Obs	Year	Observed effort	Estimated effort	Estim F	Observed index	Model index	Resid in log index	Resid in index
17	1984	1.000E+00	1.000E+00	0.0	1.050E+01	1.313E+01	-0.22373	-2.633E+00
18	1985	1.000E+00	1.000E+00	0.0	1.770E+01	1.400E+01	0.23449	3.700E+00
19	1986	1.000E+00	1.000E+00	0.0	1.960E+01	1.387E+01	0.34596	5.732E+00
20	1987	1.000E+00	1.000E+00	0.0	1.490E+01	1.321E+01	0.11361	1.589E+00
21	1988	1.000E+00	1.000E+00	0.0	1.280E+01	1.180E+01	0.09114	9.975E-01
22	1989	1.000E+00	1.000E+00	0.0	1.700E+01	1.232E+01	0.32222	4.683E+00
23	1990	1.000E+00	1.000E+00	0.0	1.810E+01	1.266E+01	0.35761	5.442E+00
24	1991	1.000E+00	1.000E+00	0.0	1.170E+01	1.173E+01	-0.00219	-2.565E-02
25	1992	1.000E+00	1.000E+00	0.0	9.400E+00	1.168E+01	-0.21742	-2.283E+00
26	1993	1.000E+00	1.000E+00	0.0	9.100E+00	1.176E+01	-0.25633	-2.659E+00
27	1994	1.000E+00	1.000E+00	0.0	8.700E+00	1.315E+01	-0.41300	-4.449E+00
28	1995	1.000E+00	1.000E+00	0.0	1.330E+01	1.405E+01	-0.05520	-7.548E-01
29	1996	1.000E+00	1.000E+00	0.0	8.800E+00	1.161E+01	-0.27673	-2.806E+00

RESULTS OF BOOTSTRAPPED ANALYSIS

Param name	Bias-corrected estimate	Ordinary estimate	Relative bias	Approx 80% lower CL	Approx 80% upper CL	Approx 50% lower CL	Approx 50% upper CL	Inter-quartile range	Relative IQ range
Biratio	1.649E+00	1.649E+00	0.01%	1.051E+00	2.319E+00	1.343E+00	2.086E+00	7.435E-01	0.451
K	5.908E+01	5.815E+01	-1.58%	5.038E+01	8.149E+01	5.354E+01	6.849E+01	1.496E+01	0.253
r	3.421E-01	3.456E-01	1.03%	2.926E-01	3.814E-01	3.176E-01	3.601E-01	4.254E-02	0.124
q(1)	9.835E-02	9.715E-02	-1.22%	7.977E-02	1.237E-01	8.912E-02	1.120E-01	2.286E-02	0.232
q(2)	5.669E-01	5.712E-01	0.75%	4.537E-01	7.006E-01	5.047E-01	6.349E-01	1.302E-01	0.230
q(3)	8.978E-01	8.876E-01	-0.00%	6.821E-01	1.079E+00	7.801E-01	9.815E-01	2.015E-01	0.227
MSY	4.925E+00	5.024E+00	2.03%	4.206E+00	5.922E+00	4.551E+00	5.389E+00	8.378E-01	0.170
Ye(1997)	1.870E+00	2.019E+00	7.98%	4.591E-01	2.837E+00	9.976E-01	2.249E+00	1.251E+00	0.669
Bmsy	2.954E+01	2.908E+01	-1.58%	2.519E+01	4.074E+01	2.677E+01	3.425E+01	7.478E+00	0.253
Fmsy	1.710E-01	1.728E-01	1.03%	1.463E-01	1.907E-01	1.588E-01	1.801E-01	2.127E-02	0.124
fmsy(1)	1.763E+00	1.779E+00	0.91%	1.534E+00	2.073E+00	1.626E+00	1.904E+00	2.784E-01	0.158
fmsy(2)	3.003E-01	3.025E-01	0.76%	2.483E-01	3.528E-01	2.700E-01	3.272E-01	5.725E-02	0.191
fmsy(3)	1.928E-01	1.946E-01	0.95%	1.574E-01	2.355E-01	1.761E-01	2.119E-01	3.579E-02	0.186
F(0.1)	1.539E-01	1.555E-01	0.93%	1.317E-01	1.716E-01	1.429E-01	1.621E-01	1.914E-02	0.124
Y(0.1)	4.875E+00	4.974E+00	2.01%	4.164E+00	5.863E+00	4.505E+00	5.335E+00	8.293E-01	0.170
B-ratio	2.236E-01	2.266E-01	1.32%	8.952E-02	4.137E-01	1.531E-01	3.237E-01	1.707E-01	0.763
F-ratio	5.936E+00	5.630E+00	-5.15%	4.069E+00	1.142E+01	4.928E+00	8.405E+00	3.476E+00	0.586
Y-ratio	3.973E-01	4.018E-01	1.14%	1.710E-01	6.563E-01	2.827E-01	5.427E-01	2.600E-01	0.654
f0.1(1)	1.587E+00	1.601E+00	0.81%	1.380E+00	1.865E+00	1.463E+00	1.714E+00	2.505E-01	0.158
f0.1(2)	2.702E-01	2.723E-01	0.68%	2.235E-01	3.175E-01	2.430E-01	2.945E-01	5.153E-02	0.191
f0.1(3)	1.735E-01	1.752E-01	0.85%	1.417E-01	2.119E-01	1.585E-01	1.907E-01	3.221E-02	0.186
q2/q1	5.794E+00	5.879E+00	1.47%	4.841E+00	7.149E+00	5.242E+00	6.476E+00	1.234E+00	0.213
q3/q1	9.262E+00	9.139E+00	-1.33%	7.755E+00	1.155E+01	8.462E+00	1.022E+01	1.759E+00	0.190

NOTES ON BOOTSTRAPPED ESTIMATES:

- The bootstrapped results shown were computed from 200 trials.
 - These results are conditional on the constraints placed upon MSY and r in the input file (ASPIC.INP).
 - All bootstrapped intervals are approximate. The statistical literature recommends using at least 1000 trials for accurate 95% intervals. The 80% intervals used by ASPIC should require fewer trials for equivalent accuracy. Using at least 500 trials is recommended.
 - The bias corrections used here are based on medians. This is an accepted statistical procedure, but may estimate nonzero bias for unbiased, skewed estimators.
- Trials replaced for lack of convergence: 3
 Trials replaced for MSY out-of-bounds: 0
 Trials replaced for r out-of-bounds: 0
 Residual-adjustment factor: 1.0583

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