ASSESSMENT REPORT

FOR

GULF OF MAINE NORTHERN SHRIMP -- 2004

Prepared
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by the
Atlantic States Marine Fisheries Commission's
Northern Shrimp Technical Committee

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INTRODUCTION

Biological Characteristics

Northern shrimp (*Pandalus borealis*) are hermaphroditic, maturing first as males at roughly 2½ years of age and then transforming to females at roughly 3½ years of age. In the Gulf of Maine, spawning takes place in offshore waters beginning in late July. By early fall, most adult females extrude their eggs onto the abdomen. Egg bearing females move inshore in late autumn and winter, where the eggs hatch. Juveniles remain in coastal waters for a year or more before migrating to deeper offshore waters, where they mature as males. The exact extent and location of these migrations is variable and unpredictable. The males pass through a series of transitional stages before maturing as females. Some females may survive to repeat the spawning process in succeeding years. The females are the individuals targeted in the Gulf of Maine fishery. Natural mortality seems to be most pronounced immediately following hatching, and it is believed that most shrimp do not live past age 5.

Fishery Management

The Gulf of Maine fishery for northern shrimp is managed through interstate agreement between the states of Maine, New Hampshire and Massachusetts. The management framework evolved between 1972-1979 under the auspices of the State/Federal Fisheries Management Program. In 1980, this program was restructured as the Interstate Fisheries Management Program (ISFMP) of the Atlantic States Marine Fisheries Commission (ASMFC). The Fishery Management Plan (FMP) for Northern Shrimp was approved under the ISFMP in October 1986 (FMR No. 9., ASMFC). The full Commission in May 2004 approved Amendment 1 to the FMP (FMR No. 42). Amendment 1, which entirely replaces the original FMP, establishes biological reference points for the first time in the shrimp fishery and expands the tools available to manage the fishery. Any new tools proposed to manage the shrimp fishery must be implemented through the ASMFC addendum process.

Within the ISFMP structure, the Northern Shrimp Technical Committee (NSTC) provides annual stock assessments and related information to the ASMFC Northern Shrimp Section. Annually, the Section decides on management regimes after thorough consideration of the NSTC stock assessment, input from the Northern Shrimp Advisory Panel and comment from others knowledgeable about the shrimp fishing industry. Management under the 1986 FMP was conducted primarily by seasonal closures and mesh size restrictions and was intended “to optimize yield, recognizing that natural fluctuations in abundance will occur” (FMP, p ii.). The goal of Amendment 1 is “to manage the northern shrimp fishery in a manner that is biologically, economically, and socially sound, while protecting the resource, its users, and opportunities for participation by all stakeholders.”

At its fall 2003 meeting, the Northern Shrimp Section approved a 40-day season from January 19, 2004, to March 12, 2004, inclusive with Saturdays and Sundays off. In addition, it continued to require the use of a finfish excluder device known as the "Nordmore Grate" throughout the shrimp fishing season. The Section also, for the first time in the 2004 fishery, made it unlawful to use mechanical “shaking” devices to cull, grade, or separate catches of shrimp.

Fishery Assessment

Stock assessments conducted in the 1980's and 1990's have keyed on strong year classes, (i.e. those hatched in 1982, 1987 and 1992). Each strong year class supports the shrimp fishery for about three years commencing about three years after hatching. The fishery was supported during the late 1980s and early and mid 1990s by the strong 1982, 1987 and 1992 year classes with other years depending on less robust year classes. The 1993 year class proved to be strong also, producing the first back-to-back strong year classes since the late 1960's. Based on the abundance of the 1992 and 1993 year classes, the NSTC recommended a full season for 1995-1996, but recommended reductions in fishing effort for December, April and May for the 1996-97 fishery to afford some protection for small shrimp in the offshore areas. The NSTC recommended limiting the fishery to February and March for the 1997-98 season and a 40-day season during the months of February and March in 1998-99 to protect the berried females and young shrimp in light of a rapidly declining resource.

The NSTC recommended two options for the 1999-2000 fishing season: 1) closed season; 2) open February 14-March 18 or February 16-March 14 and May 7-31. Due to an increase in the exploitable biomass in the 2000-2001 season, the Committee recommended a modest increase in landings and a corresponding extension of the season to 61 days. In 2001, however, the low numbers of large shrimp, the lack of new recruits, and the presence of a single year class of medium sized shrimp led the committee to advise that no fishing be conducted in the 2002 season. In 2002, the committee recommended no fishing season that would threaten the reproductive capacity of the 1999 year class or would allow significant catches of the 2001 year class. Again, in 2003 it advised no fishing season to protect the 2001 year class and allow the depressed stock to recover.

The following report presents the results of the Technical Committee's 2004 stock assessment. Analyses and recommendations are based on: 1) research vessel survey data collected by the Committee during summer and by the Northeast Fisheries Science Center (NEFSC) during spring and autumn, 2) commercial landings data collected by the National Marine Fisheries Service (NMFS) port agents, 3) biological sampling of the commercial landings by personnel from the participating states and the NMFS, and 4) data from vessel trip reports filed by shrimp fishers. In addition to previously used traditional methods of assessing the stock (i.e. landings data, commercial effort and CPUE estimates, indices of abundance, etc.) more innovative, quantitative tools, such as the Collie-Sissenwine Analysis, ASPIC surplus production, yield per recruit, and eggs per recruit models were introduced in 1997 and continue to be used to provide guidance for management of the stock.

COMMERCIAL FISHERY TRENDS

Landings

Annual landings of Gulf of Maine northern shrimp declined from an average of 11,400 metric tons (mt) during 1969-1972 to about 400 mt in 1977, culminating in a closure of the fishery in 1978 (Table 1). The fishery reopened in 1979 and landings increased steadily to over 5,000 mt by 1987. Landings ranged from 2,300-4,400 mt between 1988-1994, and then rose dramatically to 9,200 mt in 1996, the highest since 1973. Landings declined between 1996 and 1999 to 1,816 mt. This was followed by a slight increase to 2,390 mt in the 2000 season. The 2001 fishing season landings dropped to 1,327 mt, and dropped further in the 25-day 2002 season to 430 mt, the lowest northern shrimp landings since the fishery was closed in 1978. Landings in the 2003 38-day season were 1,209 mt (preliminary data), and 1,705 mt (preliminary data) in a 40-day season in 2004.

Maine landed 89% (1,521 mt) of the 2004 season total while New Hampshire and Massachusetts landed 10% (169 mt) and 1% (15 mt), respectively. The proportional distribution of landings among the states was similar to 2002 and 2003, but has shifted gradually since the 1980’s when Massachusetts accounted for about 30% of the catch, (Table 1 and Figure 1).

The relative proportion of landings by month remained similar to past years. The month of February (20 open days) yielded the highest proportion of the catch while the greatest catch per open day occurred in January (10 open days). March (10 open days) exhibited the lowest proportion of the catch and the lowest catch per open day (Table 2a).

Most northern shrimp fishing in the Gulf of Maine is conducted by otter trawls, although traps are also employed off the central Maine coast. According to Vessel Trip Reports (VTRs), trappers accounted for about 11.0, 13.0, 19.0 (preliminary data), and 2.0% (preliminary data) of the three states' landings in 2001, 2002, 2003, and 2004 respectively (Table 2b).

Size, Sex, and Maturity Stage Composition of Landings

Size composition data (Figures 2-4), collected since the early 1980's, indicate that trends in landings have been determined primarily by recruitment of strong (dominant) year classes. Landings more than tripled with recruitment of a strong 1982 year class in 1985 and 1986. The 1987 season landings of 5,253 mt (Table 1) were supported in large part by mature females (assumed age 5) from this year class. 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 (NSTC Assessment Reports, 1988-1993). The 1992 year class was the first year class of notable size since 1987 and began recruiting to the fishery in March and April 1995. The 1992 year class was supplemented by a moderate sized 1993 year class, which partially supported the relatively large annual landings in 1995, 1996 and 1997. The early months of the 1998 season showed high catches from the last of the 1993 year class coming ashore as second year females. Landings were low in the 1999 season due to very poor recruitment in 1994 and 1995, and moderate recruitment in 1996. The increase in landings observed in 2000 was dominated by first year berried females from the 1996 year class. The poor landings observed in 2001 were composed primarily of egg-bearing females landed early in the season, and males caught in January, March, and April, the males accounting for approximately 30% of the catch during these months and representing the 1999 year class. This catch profile is indicative of the low survival of the females from the 1996 year class and the poor recruitment of the 1997 and 1998 year classes. In the 2002 fishery, the 1997 and 1998 yearclasses (4- and 5- year old females) continued to be weak, and the moderate 1999 yearclass (3-year old males, transitionals, and early-maturing females) dominated the catches. Two-year old shrimp (2000 year class) were generally absent, but a noticeable quantity of 1-year-old shrimp (2001 year class) were caught. 2003 catches were composed primarily of 4-year-old females from the 1999 year class, early-maturing 2-year-old females (carrying what appeared to be viable eggs) and 2-year-old juveniles, males, and transitionals, 2004 catches were composed primarily of egg-bearing, early-maturing, presumed 3-year-old females from the 2001 year class and a few larger females probably from the 1999 year class (Figures 2-4). Samples from New Hampshire and Massachusetts landings had higher proportions of the large females, especially in February and March, than Maine landings (compare figures 2 and 3). New Hampshire and Massachusetts also caught the most very small shrimp (less than 13mm), presumably from the 2003 year class. In past years, Maine trappers produced a smaller proportion of small shrimp in the landed catch than trawling, and generally were more apt to catch large females after egg hatch, but these trends were not evident in 2004, possibly because of the small number of samples taken (Figure 2). See the table below for average counts per pound.

2004 commercial shrimp fishery average counts per pound, from port samples

	Pandalus borealis only			All shrimp species		
	January	February	March	January	February	March
Maine trawls	48	47	48	49	50	50
Maine traps	46	44	47	47	57	48
Maine total	47	47	48	49	50	49
Massachusetts	no samples	51	44	no samples	51	42
New Hampshire	55	51	48	57	52	47

Spatial and temporal differences in the timing of egg-hatch can be estimated by noting the relative abundance of ovigerous females to females that have borne eggs in the past but are no longer carrying them (female stage II). In January 2004, in Maine, only 1.8% of the trawled catch was female stage II, but for the month of February, this increased to 5.6% and for the month of March this further increased to 26.7%. Maine trappers caught 2.6% stage II in January, 10.1% in February and 24.0% in March (Figure 2). In Massachusetts and New Hampshire, the percentage of female stage II shrimp was 20.4% in January, 39.3% in February and 71.0% in March (Figure 3), possibly reflecting the eastern Gulf lagging the west in the timing of egg hatch. Also note that in February, in Maine, 90% of the shrimp caught were still carrying some eggs, confirming reports from harvesters that egg drop was later than usual.

Discards

Reports from port samplers do not indicate that the discarding of small shrimp was common in 2004. They do mention one harvester picking out his catch by hand.

Black Gill Syndrome

Shrimp collected during routine port-sampling in Maine in 2003 exhibited a high incidence (greater than 70%) of Black Gill Syndrome, also called Black Gill Disease or Black Spot Syndrome. Affected shrimp displayed melanized, or blackened gills, with inflammation, necrosis, and significant loss of gill filaments. Black Gill Syndrome has also been documented recently in white shrimp in South Carolina (http://lama.kcc.hawaii.edu/praise/news/eh216.html) and in the Gulf of Maine in the 1960s and 1970s (Apollonio and Dunton, 1969; Rinaldo & Yevitch, 1974). Its etiology is unknown, although fungal and ciliated protist parasites have been implicated. In samples collected in Maine during the 2004 fishery, the incidence of Black Gill Syndrome was much lower than in 2003, and detected cases were less severe than in 2003.

Effort and Distribution of Effort

Maine trapping operations accounted for 4% to 8% of the state's total number of trips from 1987 to 1994, and for 17%, 23%, 28% (preliminary), and 11% (preliminary) in 2001, 2002, 2003, and 2004 respectively, according to 2001-2004 Vessel Trip Report (VTR) data (Tables 3a-b).

Since the late 1970's, effort in the fishery (measured by numbers of trips in which shrimp gear is used) has increased and then declined on two occasions. The total number of trawl trips in the fishery peaked at 12,285 during the 1987 season (Table 3a, Figure 5). Increases in season length, shrimp abundance and record ex-vessel prices coupled with reduced abundance of groundfish all contributed to this increase. Effort subsequently fell to an average of 9,500 trips for the 1988, 1989, and 1990 seasons, fell further to an average of 7,900 trips in the 1991 and 1992 seasons, and declined to 6,000 trips in the 1994 season. Effort nearly doubled between 1994 and 1996 and then declined again from the 1996 level of 11,791 to 3,811 trips in 1999, 3,335 in 2000, 3,599 in 2001, 1,009 in 2002, 2,108 in 2003 (preliminary data) and 1,892 in 2004 (preliminary data) (Table 3a).

Approximately 310 vessels participated in the shrimp fishery in 1997, 260 in 1998, and about 238 in 1999. In 2000, 2001 2002, and 2003 there were 285, 288, 200 and 248 (preliminary) vessels participating, respectively. In 2004, there were 129 vessels from Maine, 9 from Massachusetts, and 15 from New Hampshire, for a total of 153 vessels that reported shrimp trips (preliminary data). 31 of these were trapping.

Prior to 1994, effort (numbers of trips by state and month) was estimated from landings data collected from dealers, and landings per trip information (LPUE) from dockside interviews of vessel captains: $Effort = \frac{Landings}{LPUE}$

Beginning in the spring of 1994, a vessel trip reporting system (VTR) supplemented the collection of effort information from interviews. From 1995 to 2000, landings per trip (LPUE) from these logbooks were expanded to total landings from the dealer weighouts to estimate the total trips: $Total.Trips = VTR.Trips \frac{Total.Landings}{VTR.Landings}$

Since 2000, VTR landings have exceeded dealer weighout landings, and the above expansion is not necessary. However, VTRs for 2003 and 2004 are still being received and processed. The vessel logbook database is currently incomplete and has not been thoroughly audited (for an evaluation of vessel trip report data see NEFSC 1996). Therefore, landings and effort estimates reported here for recent years should be considered extremely preliminary. The 1996 assessment report (Schick et al. 1996) provides a comparison of 1995 shrimp catch and effort data from both the NEFSC interview and logbook systems and addresses the differences between the systems at that time. It showed a slightly larger estimate from the logbook system than from the interview system. Thus effort statistics reported through 1994 are not directly comparable to those collected after 1994. However, patterns in effort can be examined if the difference between the systems is taken into account. An additional complication of the logbook system is that one portion of the shrimp fishery may not be adequately represented by the logbook system during 1994-1999. Smaller vessels fishing exclusively in Maine coastal waters are not required to have federal groundfish permits and were not required to submit shrimp vessel trip reports until 2000. In the 1994-2000 assessments, effort from unpermitted vessels was characterized by catch per unit effort of permitted vessels.

Seasonal trends in distribution of effort can be evaluated from port interview data. The relative magnitude of offshore fishing effort (deeper than 55 fathoms) has varied, reflecting seasonal movements of mature females (inshore in early winter and offshore following larval hatching), but also reflecting harvesters' choices for fishing on concentrations of shrimp. As an example, the 1994 fishery stayed in deep water only through the beginning of January, shifted inshore through the middle of March and then moved into deeper water for the duration of the season. The 1995 fishing patterns revealed an early inshore migration in December and an early offshore migration with most fishing occurring offshore even during March. The 1999 season's effort was all offshore in December and almost all offshore in January. Effort moved inshore in February and remained primarily inshore throughout March. Effort in April and May was all offshore. This distribution of effort reflects the fact that the main body of shrimp available to the fleet was from the three-year-old 1996 year class, and they were split between transitionals that remained offshore and early maturing females that made some shoreward migration during the winter. During the 2000 season, effort was almost entirely inshore in January and February and increasingly offshore in March. In 2001, 17% of fishing was offshore in January, decreasing to 5% in February, increasingly offshore (78%) in March and entirely offshore in April, from Maine port interview data. In the 2002 season, 100% of fishing was inshore in February, and 20% was inshore in March, from Maine, New Hampshire, and Massachusetts port interview data. The 2003 fishery was conducted almost entirely inshore. In 2004, 100% of fishing trips in Massachusetts and New Hampshire were inshore, according to 16 port interviews. In Maine, 85% were inshore, based on 93 port interviews.

Catch per Unit Effort

Catch per unit effort (CPUE) indices have been developed from NMFS interview data (1983-1994) and logbook data (1995-2004) and are measures of resource abundance and availability. (See table below and Figure 5). They are typically measured in catch per hour or catch per trip. A trip is a less precise measure of effort, because trips from interviews and logbooks include both single day trips and multiple day trips (in the spring), and the proportion of such trips can vary from season to season.

Pounds landed per trip increased from 844 pounds in 1983 to over 1,300 pounds in 1985 when the strong 1982 year class entered the fishery. CPUE subsequently dropped to below 750 pounds/trip in 1988 but increased to 1,053 pounds in 1990 with entry of the strong 1987 year class. This index averaged 980 pounds between 1991-1992, declined to 767 pounds in 1993, and increased in 1994 to 1,073 pounds. The 1995, 1996 and 1997 CPUEs, from logbooks, rose sharply to 1,362 pounds in 1995, rose again to 1,714 in 1996 and declined to 1,454 in 1997. The CPUEs for 1996 and 1997 were the highest since the early 1970's. The 1998 CPUE was 1,317, showing a continued high level compared to earlier years and the 1999 CPUE dropped to 1,067 pounds per trip, which is still considerably higher than in previous years with poor recruitment. The 2000 CPUE increased to 1,444 pounds per trip. In 2001, the catch per trip dropped to 739 pounds per trip, the lowest since 1988. In 2002, the catch per trip was 820 pounds, and in 2003 it was 1,082 pounds per trip and in 2004 it was 1,986 pounds per trip, one of the highest values in the past 30 years. (Figure 5 and table below).

More precise CPUE indices (pounds landed per hour fished) have also been developed for both inshore (depth less than 55 fathoms) and offshore (depth more than 55 fathoms) areas using information collected by Maine's port sampling program, and agree well with the (less precise) catch per trip data from logbooks (see text table below and Figure 5). Inshore CPUE for 2004 was 361 lbs/hr, offshore was 310 lbs/hr, and the season average was 351 lbs/hr. These CPUE values are the highest in the time series. We speculate that these unusually high catch rates were due in part to unusual migrating and aggregating behavior: fishers reported that shrimp stayed inshore throughout the spring and summer of 2003 (possibly because of unusually cold bottom temperatures inshore), instead of moving offshore in the spring as they usually do, and were already in place in dense aggregations when the 2004 fishery opened.

Maine CPUE in lbs./hour towed, from port sampling. Catch in lbs./trip is from NMFS weighout and logbook data for all states.

Year	Inshore (<55F)	Offshore (>55F)	Total	Catch/trip
1991	94	152	140	988
1992	132	93	117	974
1993	82	129	92	767
1994	139	149	141	1,073
1995	172	205	193	1,362
1996	340	203	251	1,714
1997	206	192	194	1,454
1998	158	151	154	1,317
1999	159	146	152	1,06[illegible]
2000	288	337	292	1,444
2001	100	135	109	739
2002	223	91	194	820
2003	174	215	182	1,082
2004	361	310	351	1,986

RESOURCE CONDITIONS

Trends in abundance have been monitored since the late 1960's from data collected in Northeast Fisheries Science Center (NEFSC) spring and autumn bottom trawl surveys and in summer surveys by the State of Maine (discontinued in 1983). A state-federal shrimp survey was initiated by the NSTC in 1984. The latter survey is conducted each summer aboard the *R/V Gloria Michelle* employing a stratified random sampling design and gear specifically designed for Gulf of Maine conditions. Strata sampled, and catch per tow data for the 2004 summer survey cruise are plotted in Figure 6a. The NSTC has placed primary dependence on the summer survey for fishery-independent data used in stock assessments, although NEFSC autumn survey data have been valuable as well.

There has generally been good agreement between the NEFSC autumn survey index (stratified mean catch per tow, kg) and fishery trends (Figure 7). The index declined precipitously as the fishery collapsed during the 1970s; this was followed by a substantial increase in the middle 1980’s to early 1990’s, with peaks in 1986, 1990 and 1994. This reflects recruitment and growth of the strong 1982, 1987 and 1992 year classes and the above average 1993 year class.

After declining to 1.1 kg/tow in 1996, the index rose sharply in 1998 and 1999 to 2.30 and 2.54 kg per tow respectively, both well above the time series mean of 1.51 kg/tow. This is likely due to recruitment of the 1996 year class to the survey gear at age 2 in 1998 and age 3 in 1999. Beginning in 2000 the fall survey index declined precipitously for three consecutive years reaching a time series low of 0.17 kg/tow in 2002, indicating very poor 1997, 1998, and 2000 year classes. The fall survey index increased to 0.95 kg/tow in 2003, and then decreased to 0.83 kg/tow in 2004, both of which are below the time series mean (1.51 kg/tow).

Abundance and biomass indices (stratified mean catch per tow in numbers and weight) for the state-federal summer survey from 1984-2003 are given in Table 4, and length-frequencies by cruise are provided in Figure 9. The $\log_e$ transformed mean weight per tow averaged 15.8 kg/tow between 1984 and 1990. Beginning in 1991 this index began to decline and averaged 10.2 kg/tow between 1991 and 1996. The index then declined further, averaging 6.1 kg/tow from 1997 to 2001, and reaching a time series low of 4.3 kg/tow in 2001. In 2002 the index increased markedly to 9.2 kg/tow, and then declined to the second lowest value in the time series (5.5 kg/tow) in 2003, then rose to 10.3 kg/tow in 2004, the highest value since 1995, though still slightly below the time series mean. The total mean number per tow demonstrated the same general trends over the time series.

The stratified mean catch per tow in numbers of 1.5-year old shrimp (Table 4, Figure 8, and graphically represented as the total number in the first size modes in Figure 9) represents a recruitment index. Although these shrimp are not fully recruited to the survey gear, this index appears sufficient as a preliminary estimate of year class strength. This survey index indicated strong year classes in 1987, 1992, and 2001, and moderately strong year classes in 1990, 1993, 1996, and 1999. The strong 1992 year class observed at (assumed) age 1.5 in the 1993 summer survey (Figure 9) was smaller than the dominant 1982 and 1987 year classes, but was followed by the above-average 1993 year class. These two year classes supported the fishery in 1995-1998. The 1996 year class appeared comparable to the moderately strong 1993 year class (Table 4, Figures 8 and 9). The 1997 and 1998 age classes were very weak, both well below the time series mean of 343 individuals per tow. The above-average 1999 year class was comparable to the 1996 year class. In 2001 the age 1.5 recruitment index was at its lowest level since 1984, with a stratified mean of 36 individuals per tow on the transformed scale, representing recruitment failure of the 2000 year class. In 2002 the age 1.5 recruitment index increased dramatically to 1,059, which is a time series high and represents an extremely strong 2001 year class. It is interesting to note that, in the 2002 summer survey, more small females (< 19 mm CL, assumed 1.5 years old) were caught than at any other time in the history of the survey (Figure 9). The index subsequently dropped to 49 individuals per tow in 2003, indicating a very poor 2002 year class, the third worst in the time series. In 2004, the index increased to 283 individuals per tow, which is still below the time series mean. In addition, the 2004 survey results also indicated a very poor 2002 year class, which supports the low index of recruitment observed in the 2003 survey. In general, recruitment has been below average in 5 out of the last 7 years.

The relative strengths of the 1999 and 2000 year classes described above as age 1.5 recruits have been confirmed by subsequent summer surveys, that is, the assumed 1999 year class continued to appear as a moderate year class in 2001, 2002, and 2003 surveys, and the 2000 year class was again virtually absent in 2002 and 2003. The record 2001 year class appeared in a greatly diminished state in the 2003 survey, yet stabilized in the 2004 survey. The re-appearance of the 2001 year class as indicated by the increased abundance of presumed 3.5 year old shrimp in the 2004 summer survey, is evidence that the distribution of shrimp in the summer of 2003 made them largely unavailable to the summer survey that year. This also supports anecdotal reports that shrimp stayed “inshore” in 2003, in areas not visited by the survey. The virtually absent 2002 year class first observed in the 2003 survey remained very weak in the 2004 survey, however.

Individuals >22 mm will be fully recruited to the upcoming winter fishery (primarily age 3 and older) and thus survey catches of shrimp in this size category provide indices of harvestable numbers and biomass for the coming season. (Table 4, bottom, and Figure 8). The harvestable biomass index exhibited large peaks in 1985 and 1990, reflecting the very strong 1982 and 1987 year classes respectively. This index has varied from year to year but generally trended down since 1990. The 2001 index of 1.5 kg/tow represented a time series low, and is indicative of poor 1997 and 1998 year classes. In 2002 the index increased slightly to 2.9 kg/tow, reflecting recruitment of the moderate 1999 year class to the index. The index subsequently dropped to second lowest value in the time series (1.7 kg/tow) in 2003. The index increased to 5.1 kg/tow in 2004 and is reflective of strong recruitment of the 2001 year class. The 2004 index is the first harvestable biomass level above the time series median (3.4 kg/tow) since 1996. Harvestable biomass has been below average in 7 of the past 8 years. Spawning stock biomass (Figure 15) has been below average in every year since 1996.

It is interesting to note that in the 2004 survey, about half of the presumed 2001 year class consisted of 3.5 year-old, unusually large males. This phenomenon of late-transitioning males was also observed for the large 1987 year class in the 1990 survey (Figure 9).

ANALYTICAL STOCK ASSESSMENT

Descriptive information for the Gulf of Maine shrimp fishery (total catch, port sampling, trawl selectivity, survey catches, and life history studies) were modeled to estimate fishing mortality, stock abundance, and candidate target fishing levels. The analytical stock assessment comprises three fishery models: the Collie-Sissenwine Analysis (CSA) (Collie and Sissenwine 1983; Collie and Kruse 1998) tracks the removals of shrimp using summer survey indices of recruits and fully-recruited shrimp scaled to total catch in numbers; surplus production analysis models the biomass dynamics of the stock with a longer time series of total landings and three survey indices of stock biomass; and a yield-per-recruit and eggs-per-recruit model simulates the life history of shrimp (including growth rates, transition rates, natural mortality, and fecundity) and fishing mortality on recruited shrimp using estimates of trawl selectivity to estimate yield and egg production at various levels of fishing mortality, for guidance in determining the levels of fishing that are most productive and sustainable.

CSA results are summarized in Table 5 and Figures 10 and 11. Abundance and catchability were relatively well estimated, and the model fit the data well. Estimates of recruitment to the fishery averaged 1.0 billion individuals, peaked at 1.3 billion before the 1990 fishing season, but declined steadily to less than 0.4 billion before the 2002 fishing season. The current estimate indicates a sharp rise up to 0.8 billion prior to the fishing year 2003, followed by a decline to 0.6 billion prior to the next (2005) season. Fully-recruited abundance averaged 1.2 billion individuals and peaked at 1.5 billion before the 1991 season. Fully-recruited abundance decreased to a time series low of less than 0.4 billion in 2000 and increased to 0.7 billion in the current year. Total stock biomass estimates averaged about 18,500 mt, with a peak at over 22,000 mt before the 1991 season, and a decrease to a time series low of 5,600 mt in 1999. Total stock biomass has increased over recent years to its current value of 10,800 mt (Table 5, Figures 10, 11).

In this assessment, fishing mortality rates (F) are being expressed as "harvest rate" derived F's. This is based on advice by the most recent peer review of Northern shrimp assessment methodology (NEFSC, 2003), which concluded that the harvest rate F is a more precise approximation than the log-ratio F used in previous assessments.

Annual estimates of fishing mortality (F) averaged 0.22 (17% exploitation) for the 1985 to 1994 fishing seasons, peaked at 1.17 (62% exploitation) in the 1997 season and decreased to 0.24 (19% exploitation) in the 2001 season (Table 5; Figures 10, 11). In 2002 F dropped to 0.08 (6% exploitation), due in part to a short season and poor stock conditions. The most recent fishing years, with increases in season length, continued poor stock conditions (in terms of exploitable shrimp), along with an exceptional recruitment pulse, resulted in F rising slightly to 0.12 (10% exploitation) in 2003 and 0.22 (18% exploitation) in 2004. The recent pattern in F reflects the pattern in nominal fishing effort (Tables 3 and 5, Figures 10 and 11).

Precision of CSA estimates was assessed by "bootstrap" analysis, in which survey measurement errors were randomly shuffled 2000 times to provide simulated replications of the model. Bootstrap results suggest that estimates of abundance, biomass and mortality were relatively precise.

In the last assessment (2003) analyses were done to examine the potential effects of discarding. It is clear that discarding of small shrimp will occur more frequently when stock conditions are similar to those in 2003 (a large year class vulnerable to the gear, but of low value in the market).

However, the TC did not find any indication that this was the case in the 2004 fishery, and information from the AP and other industry members corroborated this. Therefore, there were no discarding analyses performed for this assessment.

An alternative method of estimating stock size and F was used to corroborate results from CSA analysis. A surplus production model (ASPIC) was fit to seasonal catch and survey biomass indices from 1968 to 2004 (summarized in Table 6). Estimates of F and Biomass from the surplus production model generally confirm the pattern of estimates from the CSA model (Figures 12 & 13). F in 2004 (F = 0.12) is below the fishing mortality target ($F_{50\%}$ = 0.22) established in Amendment 1 to the northern shrimp Fishery Management Plan. The 2004 starting biomass (13,430 mt) was at its highest level since 1997, but still remains below the average observed in the time period between 1985 and 1994 when the Gulf of Maine Northern shrimp biomass was stable (18,813 mt). Precision of surplus production model estimates was assessed by "bootstrap" analysis, in which survey measurement errors were randomly sampled 1000 times to provide simulated replications of the model. Bootstrap results suggest that estimates of biomass and mortality were relatively precise.

Yield per recruit and percent maximum spawning potential were estimated for the Gulf of Maine northern shrimp fishery (Figure 14). Yield per recruit was maximum at F=0.77 (F_{max}) (48% exploitation) (Table 7). The increase in yield per unit F decreased to one tenth the initial increase at F=0.46 ($F_{0.1}$) (33% exploitation). Maximum spawning potential (i.e., with no F) was 2,395 eggs per recruit. Spawning potential was reduced by half at F=0.25 ($F_{50\%,}$ 20% exploitation).

As concluded by the Stock Assessment Review Committee (SARC) in 1997, the stock was not replacing itself when spawning potential was reduced to less than 20% of maximum, and the stock collapsed when egg production was reduced further. Reproductive success for Gulf of Maine northern shrimp may be a function of population fecundity and spring seawater temperature (Figure 15). Therefore, $F_{20\%}$ may be an appropriate overfishing threshold, which would result in a target F well below 0.6. A sustainable target F may be the average F from 1985 to 1994, which was 0.22 (which allows 50% egg production per recruit) (Table 7, Figure 13).

SUMMARY

Landings in the Gulf of Maine northern shrimp fishery have declined since the mid 1990's, from a high for the decade of 9,166 mt in 1996 to 1,704 mt in 2004 (preliminary), the result of low abundances of shrimp and reductions in fishing effort. The number of fishing vessels and trawl trips have dropped from about 310 and 10,734 respectively in 1997 to 153 and 1,892 in 2004, although vessel reporting, particularly from the Maine small boat fleet, has probably improved. Fishing mortality rates, as calculated by CSA, have declined from 0.87 in 1997 to 0.22 in 2004. Although low in 2002 and 2003, F was considerably above the 1985-1994 average (the target F in the FMP) each year from 1995 through 2000.

Current landings, vessels, and trips are calculated from vessel trip reports (VTRs). Note that 2002 landings were incomplete when calculated from VTRs in October of 2002 (Tables 1-2, 2002 assessment), and went up by 19% when recalculated in September 2004 (Tables 1-2 here). Thus it must be assumed that 2004 vessel trip reports are also incomplete at this time, particularly for Maine harvesters who do not hold federal permits. However, it can be concluded that the 2004 fishery was mostly inshore, with limited participation, very large catches per trip and per hour, and high occurrences of medium-sized shrimp (assumed 3-year-old, 2001 year class).

Exploitable biomass as estimated from CSA declined from 15,400 mt in 1995 to a time series low of 5,600 in 1999. Since then the biomass estimate has risen to 10,600 mt in 2004, as a result of the appearance of the strong 2001 year class. This estimate is still below the time-series average of 12,700 mt, and well below the average of the relatively stable 1985-1994 period of 17,200 mt (Table 5).

Size composition data from both the fishery and summer surveys indicate that good landings have followed the recruitment of strong (dominant) year classes. Poor landings since 1997, as well as low biomass estimates, can be attributed in part to the below-average recruitment of the 1994, 1995, 1997, 1998, and 2000 year classes.

In 2005, the 1999 year class will have passed out of the fishery, and the virtually absent 2000 year class (assumed 5-year-old females), moderately strong 2001 year class (assumed 4-year-old females, transitionals, and males), virtually absent 2002 year class (males), and weak to moderate 2003 year class (juveniles) will remain.

RECOMMENDATIONS

The Northern Shrimp Technical Committee bases its recommendation to the Section on its assessment of current stock status, the biology of the species, and the stated management goal of protecting and maintaining the stock at levels that will support a viable fishery (Amendment 1 to the FMP, June 2004).

The committee recommends that the Section continue its recent efforts to maintain fishing mortality at conservative rates, that is, below the management target value of 0.22. The stock biomass has grown in recent years but still remains well below the time-series average and the average of the "stable" 1985-94 period. Recruitment and spawning stock biomass are also below average. The moderately strong 2001 year class, and a weak to moderate 2003 year class present welcome opportunities to continue rebuilding the stock. Recruitment failures of the 2000 and 2002 year classes continue to be serious concerns, making the 2001 class the only significant source of egg production for 2005 and 2006. The unusual maturation patterns in the 2001 year class are also worrying.

Short-term commercial prospects are relatively favorable: the abundance of shrimp greater than 22 mm is at its highest level since the 1995 survey. If these larger shrimp follow traditional patterns of migrating and aggregating behavior, a 2005 fishery can anticipate good catches at current levels of fishing effort, of predominantly 4-year-old shrimp. Unusually high proportions of these animals are males and can be expected to remain offshore in the coming winter, however. Four-year-old females can be expected to be about 33 count per pound (Table 7).

Catch in numbers (C) is a function of abundance (N) and exploitation rate (μ, which is a function of fishing mortality F and natural mortality M).

$$C = N\mu = NF\frac{1-e^{-(F+M)}}{F+M}$$

Using this relationship, the estimated abundance of recruits and new recruits for 2004 from Figure 11, an estimate of 0.25 for M, and assuming that 2005 landings will be mostly 4-year-old females averaging 13.58g each (Table 7), it is possible to estimate landings for different levels of F:

F (Fishing mortality for 2005)	Estimated landings (mt)	Estimated landings (lb)
0.05	666	1,467,585
0.10	1,300	2,866,573
0.15	1,905	4,200,238
0.20	**2,481**	**5,471,696**
0.22	2,705	5,963,531
0.25	3,031	6,683,916
0.30	3,555	7,839,719
0.40	4,532	9,992,703
0.50	5,420	11,950,638
0.60	6,228	13,731,639

Although an average F of 0.22 produced stable landings from 1985 to 1994, the stock would not be expected to rebuild at that level. Therefore, **the committee strongly urges that 2005 shrimp landings be less than 2,500 metric tons**. Landings of 2,500mt would probably be a 30-40% increase over final 2004 landings, which are still preliminary at this time.

If shrimp smaller than 13.58g are caught in significant numbers, the fishing mortality rate (F) will be higher for the same landed weight. Yield-per-recruit and egg-per-recruit analyses (Table 7) show that shrimp reach both their potential maximum weight yield and maximum egg production at about ages 4-5. Therefore, protecting younger shrimp and late-maturing males is recommended for both economical and biological reasons. Protecting egg-bearing females prior to egg hatch, which usually occurs during February and/or March, is also recommended.

The committee notes the uncertainty in the estimates of F and stock abundance associated with the terminal years of the CSA model, particularly when landings data are incomplete. There is also considerable uncertainty in projecting the exploitable biomass from the time of the summer survey to the fishing season, and in predicting the size distribution of the catch in the upcoming season. The committee urges caution in selecting management options, since estimates of both F and stock abundance are subject to change in either direction, that is, these parameters may be over- or underestimated in any given year.

The committee also urges managers to take whatever action is necessary to ensure a more timely reporting of landings.

DEDICATION

The ASMFC NSTC dedicates this assessment to Stephen H. Clark (1940-2004) and his many contributions to providing sound scientific advice for the management of Gulf of Maine shrimp. While future surveys and assessments will always benefit from his input, they shall also miss his seemingly endless hard work and dedication.

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Table 1. Commercial landings (mt) of northern shrimp in the western Gulf of Maine, 1958-2004.

Year	Maine		Massachusetts		New Hampshire		Total		$/Lb
1958	2.3		0.0		0.0		2.3		0.32
1959	5.4		2.3		0.0		7.7		0.29
1960	40.4		0.5		0.0		40.9		0.23
1961	30.4		0.5		0.0		30.9		0.20
1962	159.7		16.3		0.0		176.0		0.15
1963	244.0		10.4		0.0		254.4		0.12
1964	419.4		3.1		0.0		422.5		0.12
1965	947.0		8.0		0.0		955.0		0.12
1966	1,737.8		10.5		18.1		1,766.4		0.14
1967	3,141.1		10.0		20.0		3,171.1		0.12
1968	6,515.0		51.9		43.1		6,610.0		0.11
1969	10,992.9		1,772.9		58.1		12,823.9		0.12
1970	7,712.8		2,902.1		54.4		10,669.3		0.20
1971	8,354.7		2,723.8		50.8		11,129.3		0.19
1972	7,515.6		3,504.5		74.8		11,094.9		0.19
1973	5,476.7		3,868.2		59.9		9,404.8		0.27
1974	4,430.7		3,477.3		36.7		7,944.7		0.32
1975	3,177.0		2,080.2		29.5		5,286.7		0.26
1976	617.2		397.8		7.3		1,022.3		0.34
1977	148.0		236.9		2.3		387.2		0.55
1978	0.0		0.0		0.0		0.0		0.24
1979	32.9		451.3		2.3		486.5		0.33
1980	71.4		260.3		7.4		339.1		0.65
1981	528.6		538.1		4.5		1,071.2		0.64
1982	883.2	*(853.3)	658.5	*(655.3)	32.8	*(21.6)	1,574.5	*(1,530.2)	0.60
1983	1,022.0	(892.5)	508.0	(458.4)	36.5	(46.2)	1,566.5	(1,397.1)	0.67
1984	2,564.7	(2,394.9)	565.3	(525.1)	96.8	(30.7)	3,226.8	(2,950.7)	0.49
1985	2,956.9	(2,946.4)	1,030.6	(968.0)	207.4	(216.5)	4,194.9	(4,130.9)	0.44
1986	3,407.3	(3,268.2)	1,085.6	(1,136.3)	191.1	(230.5)	4,684.0	(4,635.0)	0.63
1987	3,534.2	(3,673.2)	1,338.7	(1,422.2)	152.5	(157.8)	5,025.4	(5,253.2)	1.10
1988	2,272.4	(2,257.2)	631.5	(619.6)	173.1	(154.5)	3,077.0	(3,031.3)	1.10
1989	2,542.6	(2,384.0)	749.6	(699.9)	314.3	(231.5)	3,606.5	(3,315.4)	0.98
1990	2,961.5	(3,236.1)	993.2	(974.3)	447.3	(451.2)	4,402.0	(4,661.6)	0.72
1991	2,431.1	(2,488.1)	727.6	(801.1)	208.2	(282.2)	3,366.9	(3,571.4)	0.93
1992	2,973.9	(3,054.1)	291.6	(289.1)	100.1	(100.0)	3,365.6	(3,443.6)	0.99
1993	1,562.8	(1,492.2)	300.3	(292.8)	441.1	(357.4)	2,304.7	(2,142.9)	1.03
1994	2,815.5	(2,239.3)	374.4	(247.5)	520.9	(428.0)	3,710.8	(2,914.8)	0.79
1995		(5,022.7)		(678.8)		(764.9)		(6,466.4)	0.88
1996		(7,737.0)		(658.0)		(771.0)		(9,166.1)	0.72
1997		(6,050.0)		(362.8)		(666.3)		(7,079.1)	0.82
1998		(3,482.0)		(247.2)		(445.2)		(4,174.4)	0.94
1999		(1,523.4)		(75.7)		(217.0)		(1,816.1)	0.93
2000		(2,067.3)		(109.9)		(212.3)		(2,389.5)	0.79
2001		(1,071.8)		(49.1)		(205.8)		(1,326.7)	0.86
2002		**(370.7)		**(7.7)		(51.2)		**(429.6)	1.07
2003		**(1079.6)		**(23.1)		(106.7)		**(1209.4)	
2004		**(1520.6)		**(15.0)		(169.0)		**(1704.5)	

*Numbers in parentheses are computed on a seasonal basis.
**Includes removals by experimental studies
2003 and 2004 are preliminary.

Table 2a. Distribution of landings (metric tons) in the Gulf of Maine northern shrimp fishery by state and month, 1987-2004.

	Dec	Jan	Feb	Mar	Apr	May	Other	Season Total
1987 Season, 182 days, Dec 1 - May 31								
Maine	485.9	906.2	1,192.7	672.9	287.6	127.9	7.0	3,680.2
Mass.	103.5	260.0	384.9	310.2	180.8	182.8	5.7	1,427.9
N.H.	18.4	53.6	62.8	15.7	7.3	0.0	0.1	157.9
Total	607.8	1,219.8	1,640.4	998.8	475.7	310.7	12.8	5,266.0
1988 Season, 183 days, Dec 1 - May 31								
Maine	339.7	793.9	788.1	243.6	24.6	67.3	1.2	2,258.4
Mass.	14.4	225.8	255.0	104.9	8.6	10.9	0.0	619.6
N.H.	13.0	72.6	53.7	14.9	0.3	0.0	3.1	157.6
Total	367.1	1,092.3	1,096.8	363.4	33.5	78.2	4.3	3,035.6
1989 Season, 182 days, Dec 1 - May 31								
Maine	353.6	770.5	700.6	246.4	218.7	94.2		2,384.0
Mass.	26.2	197.5	154.9	104.8	160.9	55.6		699.9
N.H.	28.5	106.9	77.0	15.4	3.7	0.0		231.5
Total	408.3	1,074.9	932.5	366.6	383.3	149.8		3,315.4
1990 Season, 182 days, Dec 1 - May 31								
Maine	512.4	778.2	509.7	638.5	514.0	282.8	0.1	3,235.7
Mass.	75.6	344.4	184.8	100.2	158.9	110.0	4.3	978.2
N.H.	111.3	191.7	116.1	30.7	1.4			451.2
Total	699.3	1,314.3	810.6	769.4	674.3	392.8	4.4	4,665.1
1991 Season, 182 days, Dec 1 - May 31								
Maine	238.2	509.1	884.0	454.9	251.7	148.2	2.0	2,488.1
Mass.	90.5	174.7	175.9	131.2	93.3	133.8	1.6	801.0
N.H.	107.3	104.4	33.8	27.8	7.8	1.0		282.1
Total	436.0	788.2	1,093.7	613.9	352.8	283.0	3.6	3,571.2
1992 Season, 153 days, Dec 15 - May 15								
Maine	181.1	880.9	1,278.9	462.5	163.6	87.2		3,054.2
Mass.	17.1	148.2	73.3	47.5	2.9		0.1	289.1
N.H.	33.4	47.0	11.9	6.8	1.0			100.1
Total	231.6	1,076.1	1,364.1	516.8	167.5	87.2	0.4	3,443.7
1993 Season, 138 days, Dec 14 - April 30								
Maine	100.9	369.0	597.0	297.5	127.8			1,492.2
Mass.	19.6	82.0	81.9	62.3	42.0	5.0		292.8
N.H.	33.5	85.4	101.7	77.0	59.8			357.4
Total	154.0	536.4	780.6	436.8	229.6	5.0	0.4	2,142.8
1994 Season, 122 days, Dec 15 - Apr 15								
Maine	171.5	647.7	971.9	399.5	48.7			2,239.3
Mass.	27.1	68.0	100.8	38.8	12.8			247.5
N.H.	117.2	124.3	128.7	49.6	8.2			428.0
Total	315.8	840.0	1,201.4	487.9	69.7			2,914.8
1995 Season, 128 days, Dec 1 - Apr 30, 1 day per week off								
Maine	747.6	1,397.7	1,338.2	912.0	627.2			5,022.7
Mass.	210.7	154.0	104.1	111.0	99.0			678.8
N.H.	160.6	186.8	118.3	158.5	140.7			764.9
Total	1,118.9	1,738.5	1,560.6	1,181.5	866.9			6,466.4

	Dec	Jan	Feb	Mar	Apr	May	Other	Season Total
1996 Season, 152 days, Dec 1- May 31, 1 day per week off								
Maine	1,124.1	1,678.3	3,004.6	785.2	350.4	794.5		7,737.1
Mass.	167.9	106.7	188.7	67.8	66.5	60.3		657.9
N.H.	189.8	169.5	234.0	81.9	78.8	17.1		771.1
Total	1,481.8	1,954.5	3,427.3	934.9	495.7	871.9		9,166.1
1997 Season, 156 days, Dec 1- May 27, two 5-day and four 4-day blocks off								
Maine	1,178.5	1,114.9	1,713.1	758.4	754.8	530.3		6,050.0
Mass.	90.2	110.4	111.4	49.0	1.2	0.5		362.7
N.H.	185.6	104.1	140.1	108.6	85.8	42.2		666.4
Total	1,454.3	1,329.4	1,964.6	916.0	841.8	573.0		7,079.1
1998 Season, 105 days, Dec 8-May 22, weekends off except Mar 14-15, Dec 25-31 and Mar 16-31 off.								
Maine	511.1	926.8	1,211.1	401.7	228.7	202.6		3,482.0
Mass.	49.1	78.0	90.5	14.3	15.3	0.0		247.2
N.H.	89.4	106.9	143.5	54.3	49.0	2.1		445.2
Total	649.6	1,111.7	1,445.1	470.3	293.0	204.7		4,174.4
1999 Season, 90 days, Dec 15 - May 25, weekends, Dec 24 - Jan 3, Jan 27-31, Feb 24-28, Mar 16-31, and Apr 29 - May 2 off.								
Maine	79.9	192.7	590.8	240.6	204.5	214.9		1,523.4
Mass.	25.0	23.8	16.0	2.5	8.4			75.7
N.H.	46.5	63.2	52.2	10.0	36.5	8.6		217.0
Total	151.4	279.7	659.0	253.1	249.4	223.5		1,816.1
2000 Season, 51 days, Jan 17 - Mar 15, Sundays off								
Maine		607.4	1,271.4	188.5				2,067.3
Mass.		17.4	78.7	13.8				109.9
N.H.		39.6	131.1	41.6				212.3
Total		664.4	1,481.2	243.9				2,389.5
2001 Season, 83 days, Jan 9 - Apr 30, Mar 18 - Apr 16 off, experimental offshore fishery in May								
Maine		573.0	436.1	35.9	26.5	0.3		1,071.8
Mass.		38.5	8.8	1.9	0.0	0.0		49.1
N.H.		127.4	37.2	12.1	29.0	0.0		205.8
Total		738.9	482.2	49.8	55.5	0.3		1,326.7
2002 Season, 25 days, Feb 15 - Mar 11								
Maine			285.5	76.7			8.4	370.7
Mass.			5.3	2.3				7.7
N.H.			38.0	13.3				51.2
Total			328.8	92.4			8.4	429.6
***2003** Season, 38 days, Jan 15 - Feb 27, Fridays off								
Maine		477.5	599.1				3.0	1,079.6
Mass.		10.5	12.6					23.1
N.H.		28.2	78.5					106.7
Total		516.2	690.2				3.0	1,209.4
***2004** Season, 40days, Jan 19 - Mar 12, Saturdays and Sundays off								
Maine		470.7	719.9	323.2			6.8	1,520.6
Mass.		5.2	8.8	0.9				15.0
N.H.		26.8	86.6	55.6				169.0
Total		502.7	815.3	379.7			6.8	1,704.5

* Preliminary data

Table 2b. Distribution of landings (metric tons) in the Maine northern shrimp fishery by gear type and month, 2001 - 2004.

	Dec	Jan	Feb	Mar	Apr	May	Other	Season Total	% of total
2001 Season, 83 days, Jan 9 - Apr 30, Mar 18 - Apr 16 off, experimental offshore fishery in May									
Trawl		530.6	363.3	30.2	26.4	0.3		950.8	89%
Trap		42.4	72.8	5.6	0.1			121.0	11%
Total		573.0	436.1	35.9	26.5	0.3		1,071.8	
2002 Season, 25 days, Feb 15 - Mar 11									
Trawl		2.529	245.3	70.1			5.9	323.9	87%
Trap			40.2	6.6				46.8	13%
Total		2.5	285.5	76.7			5.9	370.7	
***2003** Season, 38 days, Jan 15 - Feb 27, Fridays off									
Trawl		411.3	462.7				3.0	877.0	81%
Trap		66.2	136.4					202.6	19%
Total		477.5	599.1				3.0	1,079.6	
***2004** Season, 40 days, Jan 19 - Mar 12, Saturdays and Sundays off									
Trawl		465.2	700.9	315.603			6.8	1,488.4	98%
Trap		5.5	19.1	7.6				32.2	2%
Total		470.7	719.9	323.2			6.8	1,520.6	

* Preliminary data

Table 3a Distribution of fishing effort (number of trawl trips) in the Gulf of Maine northern shrimp fishery by state and month, 1987-2004.

	Dec	Jan	Feb	Mar	Apr	May	Other	Season Total
1987 Season, 182 days, Dec 1 - May 31								
Maine	993	2,373	3,073	2,241	617	340	16	9,653
Mass.	325	354	414	426	283	317	164	2,283
N.H.	67	164	175	95	28		32	561
Total	1,385	2,891	3,662	2,762	928	657		12,285
1988 Season, 183 days, Dec 1 - May 31								
Maine	972	2,183	2,720	1,231	193	122		7,421
Mass.	28	326	426	315	26	57		1,178
N.H.	72	231	236	99	3			641
Total	1,072	2,740	3,382	1,645	222	179		9,240
1989 Season, 182 days, Dec 1 - May 31								
Maine	958	2,479	2,332	936	249	84		7,038
Mass.	103	479	402	254	297	102		1,637
N.H.	120	369	312	69	16			886
Total	1,181	3,327	3,046	1,259	562	186		9,561
1990 Season, 182 days, Dec 1 - May 31								
Maine	1,036	1,710	1,529	1,986	897	238		7,396
Mass.	147	459	273	202	175	118		1,374
N.H.	178	363	284	157	6			988
Total	1,361	2,532	2,086	2,345	1,078	356		9,758
1991 Season, 182 days, Dec 1 - May 31								
Maine	568	1,286	2,070	1,050	438	139		5,551
Mass.	264	416	401	231	154	147		1,613
N.H.	279	285	135	82	22	1		804
Total	1,111	1,987	2,606	1,363	614	287		7,968
1992 Season, 153 days, Dec 15 - May 15								
Maine	411	1,966	2,700	1,222	318	141		6,758
Mass.	59	337	145	101	41			683
N.H.	96	153	76	29	3			357
Total	566	2,456	2,921	1,352	362	141		7,798
1993 Season, 138 days, Dec 14 - April 30								
Maine	249	1,102	1,777	1,032	227			4,387
Mass.	60	200	250	185	72			767
N.H.	76	246	275	256	151			1,004
Total	385	1,548	2,302	1,473	450			6,158
1994 Season, 122 days, Dec 15 - Apr 15								
Maine	265	1,340	1,889	1,065	122			4,681
Mass.	58	152	147	83	15			455
N.H.	169	228	266	173	18			854
Total	492	1,720	2,302	1,321	155			5,990
1995 Season, 128 days, Dec 1 - Apr 30, 1 day per week off								
Maine	879	2,341	2,641	1,337	694			7,892
Mass.	145	385	275	157	109			1,071
N.H.	189	331	279	359	344			1,502
Total	1,213	3,057	3,195	1,853	1,147			10,465

	Dec	Jan	Feb	Mar	Apr	May	Other	Season Total
1996 Season, 152 days, Dec 1- May 31, 1 day per week off								
Maine	1,341	2,030	3,190	1,461	444	457		8,923
Mass.	299	248	325	269	106	126		1,373
N.H.	331	311	389	248	155	61		1,495
Total	1,971	2,589	3,904	1,978	705	644		11,791
1997 Season, 156 days, Dec 1- May 27, two 5-day and four 4-day blocks off								
Maine	1,674	1,753	2,737	1,178	793	530		8,665
Mass.	184	226	245	114	7	1		777
N.H.	277	245	301	218	189	62		1,292
Total	2,135	2,224	3,283	1,510	989	593		10,734
1998 Season, 105 days, Dec 8-May 22, weekends off except Mar 14-15, Dec 25-31 and Mar 16-31 off.								
Maine	852	1,548	1,653	725	346	189		5,313
Mass.	94	200	148	70	3	1		515
N.H.	141	216	182	134	83	22		778
Total	1,086	1,964	1,983	929	432	212		6,606
1999 Season, 90 days, Dec 15 - May 25, weekends, Dec 24 - Jan 3, Jan 27-31, Feb 24-28, Mar 16-31, and Apr 29 - May 2 off.								
Maine	190	556	1,125	553	324	172		2,920
Mass.	39	57	71	9	40			216
N.H.	82	192	213	44	123	21		675
Total	311	805	1,409	606	487	193		3,811
2000 Season, 51 days, Jan 17 - Mar 15, Sundays off								
Maine		653	1,838	401				2,892
Mass.		23	100	27				150
N.H.		36	179	78				293
Total		712	2,117	506				3,335
2001 Season, 83 days, Jan 9 - Apr 30, Mar 18 - Apr 16 off, experimental offshore fishery in May								
Maine		1,531	1,230	116	39	6		2,922
Mass.		111	47	11	1			170
N.H.		305	145	27	30			507
Total		1,947	1,422	154	70	6		3,599
2002 Season, 25 days, Feb 15 - Mar 11								
Maine			573	221			14	808
Mass.			13	9			1	22
N.H.			126	53				179
Total			712	283			15	1,010
***2003** Season, 38 days, Jan 15 - Feb 27, Fridays off								
Maine		773	1020				49	1842
Mass.		35	39					74
N.H.		82	159					241
Total		890	1218				49	2,157
***2004** Season, 40days, Jan 19 - Mar 12, Saturdays and Sundays off								
Maine		526	763	299			16	1604
Mass.		11	30	5				46
N.H.		46	132	64				242
Total		583	925	368			16	1,892

* Preliminary data

Table 3b. Distribution of fishing trips in the Maine northern shrimp fishery by gear type and month, 2001 - 2004.

	Dec	Jan	Feb	Mar	Apr	May	Other	Season Total	% of total
2001									
Trawl		1,531	1,230	116	39	6		2,922	83%
Trap		191	347	68	1			607	17%
Total		1,722	1,577	184	40	6		3,529	
2002									
Trawl			573	221			14	808	77%
Trap			193	55				248	23%
Total			766	276			14	1,056	
*__2003__									
Trawl		773	1,020				49	1,842	72%
Trap		253	466					719	28%
Total		1,026	1,486					2,561	
*__2004__									
Trawl		526	763	299			16	1,604	89%
Trap		38	117	46				201	11%
Total		564	880					1,805	

Table 4. Stratified mean numbers and weights, per tow,* of northern shrimp collected during R/V Gloria Michelle summer surveys 1984-2004.

Untransformed Year	Age-1.5 Number	>22 mm** Number	>22 mm** Weight (kg)	Total Number	Total Weight (kg)
1984	48	826	8.9	3,005	22.6
1985	643	2,262	22.3	3,531	29.4
1986	703	1,688	19.6	3,327	29.7
1987	545	1,360	15.2	2,441	21.0
1988	2,812	1,012	11.7	4,310	26.6
1989	525	1,072	11.5	3,580	27.3
1990	264	2,097	22.2	3,021	29.4
1991	765	1,042	12.6	1,992	18.2
1992	443	625	7.6	1,503	12.9
1993	2,334	772	8.5	3,569	17.9
1994	1,285	849	9.3	3,435	21.1
1995	576	1,238	13.8	2,856	21.1
1996	793	1,223	13.8	2,651	20.2
1997	1,551	1,017	11.6	3,161	19.8
1998	533	676	7.4	2,319	15.1
1999	471	719	7.8	1,648	11.9
2000	997	647	7.2	1,843	11.9
2001	69	281	2.9	870	6.5
2002	2,313	571	6.3	3,157	15.0
2003	157	554	5.4	1,809	12.3
2004	895	1,582	16.0	2,807	20.0

Log_e transformed Year	Age-1.5 Number	>22 mm** Number	>22 mm** Weight (kg)	Total Number	Total Weight (kg)
1984	18	316	3.4	1,152	10.5
1985	337	1,184	11.7	1,849	17.7
1986	358	860	10.0	1,695	19.6
1987	342	854	9.5	1,385	14.8
1988	828	298	3.4	1,269	12.8
1989	276	564	6.1	1,883	17.0
1990	142	1,127	12.0	1,624	18.1
1991	482	657	8.0	1,255	11.7
1992	282	397	4.8	955	9.4
1993	757	250	2.8	1,156	9.1
1994	368	243	2.7	984	8.7
1995	292	628	7.0	1,449	13.3
1996	232	358	4.0	776	8.8
1997	374	245	2.8	762	7.7
1998	134	170	1.9	583	6.3
1999	114	174	1.9	398	5.8
2000	437	283	3.2	807	6.4
2001	36	146	1.5	451	4.3
2002	1,059	261	2.9	1,446	9.2
2003	49	173	1.7	564	5.5
2004	283	500	5.1	887	10.3
Mean	343	461	5.1	1,111	10.8
Median	292	316	3.4	1,152	9.4

*Based on strata 1, 3, 5, 6, 7 and 8.

**Will be fully recruited to the winter fishery.

Table 5. Summary of results from Collie-Sissenwine Analysis of Gulf of Maine shrimp.

Fishing Season	New Recruits (millions)	Fully-Recruited (millions)	F (NR+FR)	Biomass (mt)	Exploitation Rate
1985	1,003	937	0.26	14,084	21%
1986	1,183	1,368	0.20	21,742	16%
1987	955	1,496	0.25	22,290	20%
1988	754	1,287	0.15	18,668	13%
1989	1,136	983	0.19	13,998	15%
1990	1,279	1,385	0.24	20,277	19%
1991	861	1,496	0.19	22,243	15%
1992	609	1,175	0.21	16,962	17%
1993	509	879	0.20	12,363	16%
1994	710	710	0.28	9,182	22%
1995	938	812	0.59	12,198	40%
1996	883	987	0.77	15,373	48%
1997	535	756	1.17	10,943	62%
1998	492	427	0.72	6,655	46%
1999	400	386	0.43	5,699	31%
2000	296	388	0.49	5,569	35%
2001	438	401	0.24	6,128	19%
2002	344	432	0.08	5,896	6%
2003	769	562	0.12	7,679	10%
2004	465	626	0.22	7,873	18%
2005	573	706		10,786	
Overall avg	728	875	0.35	12,696	24%
1985-94 avg	900	1,172	0.22	17,181	17%

Table 6. Summary of results from surplus production analysis of Gulf of Maine shrimp.

	Input				Results			
Fishing Season	**Fall (kg/tow)**	**Maine (kg/tow)**	**Summer (kg/tow)**	**Catch (mt)**	**Biomass (mt)**	**F**	**F/Fmsy**	**B/Bmsy**
1968	3.20	45.8		5,708	55,730	0.11	0.68	2.02
1969	2.70	31.2		12,140	50,650	0.27	1.69	1.84
1970	3.70	40.8		11,330	40,990	0.31	1.93	1.49
1971	3.00	9.4		10,590	33,490	0.35	2.22	1.22
1972	3.30	7.0		11,220	27,210	0.48	3.02	0.99
1973	1.90	7.8		9,691	20,230	0.57	3.59	0.73
1974	0.80	4.9		8,024	14,260	0.70	4.42	0.52
1975	0.90	6.7		6,142	9,095	0.91	5.77	0.33
1976	0.60	4.8		1,387	4,815	0.29	1.82	0.17
1977	0.20	1.6		372	4,822	0.07	0.44	0.17
1978	0.40	3.2		17	5,990	0.00	0.02	0.22
1979	0.50	4.4		487	7,886	0.06	0.35	0.29
1980	0.50	2.7		339	9,739	0.03	0.20	0.35
1981	1.50	3.0		1,071	12,170	0.08	0.51	0.44
1982	0.30			1,530	14,290	0.10	0.63	0.52
1983	1.00			1,397	16,250	0.08	0.51	0.59
1984	1.90		10.47	2,951	18,630	0.15	0.97	0.68
1985	1.60		17.69	4,131	19,640	0.21	1.33	0.71
1986	2.50		19.61	4,635	19,510	0.24	1.53	0.71
1987	1.70		14.80	5,253	18,840	0.29	1.83	0.68
1988	1.20		12.76	3,031	17,440	0.17	1.07	0.63
1989	1.80		16.95	3,315	18,230	0.18	1.13	0.66
1990	2.00		18.12	4,662	18,820	0.25	1.60	0.68
1991	0.90		11.68	3,571	18,040	0.20	1.24	0.65
1992	0.60		9.43	3,444	18,330	0.19	1.17	0.67
1993	1.60		9.14	2,143	18,790	0.11	0.69	0.68
1994	2.20		8.69	2,915	20,670	0.14	0.86	0.75
1995	1.80		13.29	6,466	21,890	0.31	1.98	0.79
1996	1.10		8.77	9,166	19,520	0.55	3.49	0.71
1997	1.30		7.73	7,079	14,010	0.60	3.79	0.51
1998	2.30		6.33	4,174	9,860	0.47	2.96	0.36
1999	2.54		5.78	1,816	8,053	0.22	1.39	0.29
2000	1.28		6.39	2,389	8,463	0.29	1.80	0.31
2001	0.87		4.33	1,347	8,330	0.15	0.96	0.30
2002	0.17		9.16	430	9,332	0.04	0.26	0.34
2003	0.95		5.45	1,209	11,580	0.10	0.61	0.42
2004	0.83		10.27	1,705	13,430	0.12	0.76	0.49
Average	**1.50**			**4,251**	**17,811**	**0.25**		
				1971-74 average	23,798	0.52		
				1984-94 average	18,813	0.19		
				2002-04 average	11,447	0.09		

Table 7. Yield and egg production per recruit of Gulf of Maine northern shrimp. For an example fishing mortality F = 0.20, natural mortality M = 0.25, and 1,000 age 0 recruits.

	Input Data							Results						
Age	Length (mm)	Transition Rate (% Fem)	Fishery Selectivity	Male wt (g)	Female wt (g)	Fecundity at length	Total N	Male N	Female N	Male Catch	Female Catch	Yield (g)	Egg Production
1	11.17	0	0.033	0.84	1.24	0	774	774	0	4	0	4	0
2	18.43	0	0.230	3.79	4.82	0	575	575	0	31	0	117	0
3	23.50	0.081	0.579	7.87	9.30	1,286	399	367	32	56	0	439	41,581
4	27.04	0.922	0.799	12.00	13.58	1,876	265	21	244	48	4	635	458,156
5	29.51	0.997	0.893	15.60	17.19	2,287	173	0	172	3	35	657	393,661
6	31.23	1.000	0.933	18.50	20.04	2,574	112	0	111	0	26	523	287,027
7	32.43	1.000	1.000	20.72	22.19	2,775	71	0	71	0	18	399	197,299
											total	2,773	1,377,725
											total/recruit	2.773	1,378
											% of max		57.52

Ref. Point	F	YPR	%EPR
F_{max}	0.77	4.25	14.77
$F_{0.1}$	0.46	3.99	29.83
$F_{example}$	0.20	2.77	57.52
$F_{50\%}$	0.25	3.14	50
$F_{40\%}$	0.34	3.62	40
$F_{30\%}$	0.45	3.97	30
$F_{20\%}$	0.63	4.21	20
$F_{10\%}$	0.95	4.21	10

	Count per pound	
Age	Male	Female
1	540	366
2	120	94
3	58	49
4	38	33
5	29	26
6	25	23
7	22	20

Figure 1. Gulf of Maine northern shrimp landings by fishing season.

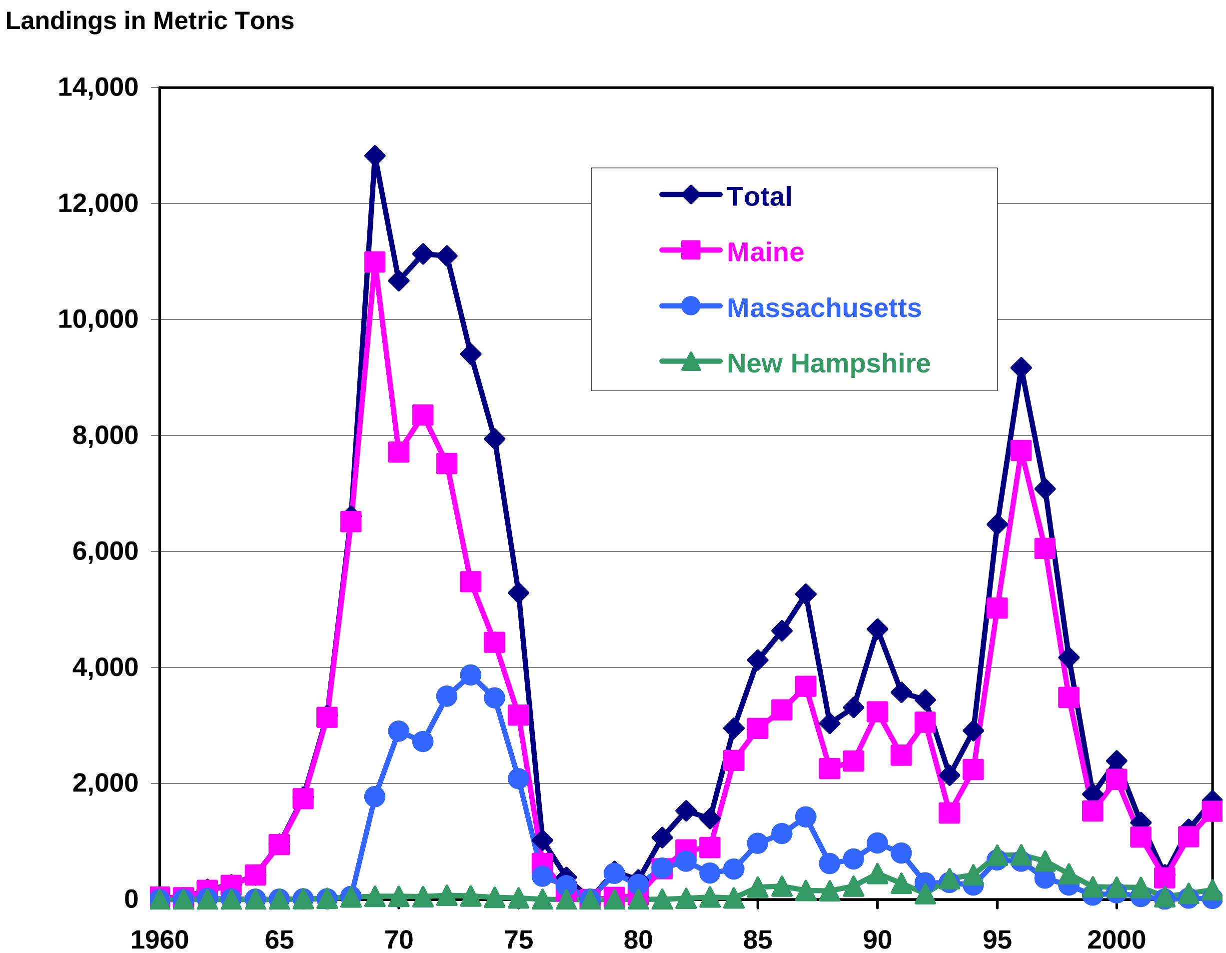


Figure 2. Length frequency distribution from samples of the Maine shrimp catch during the 2004 season.

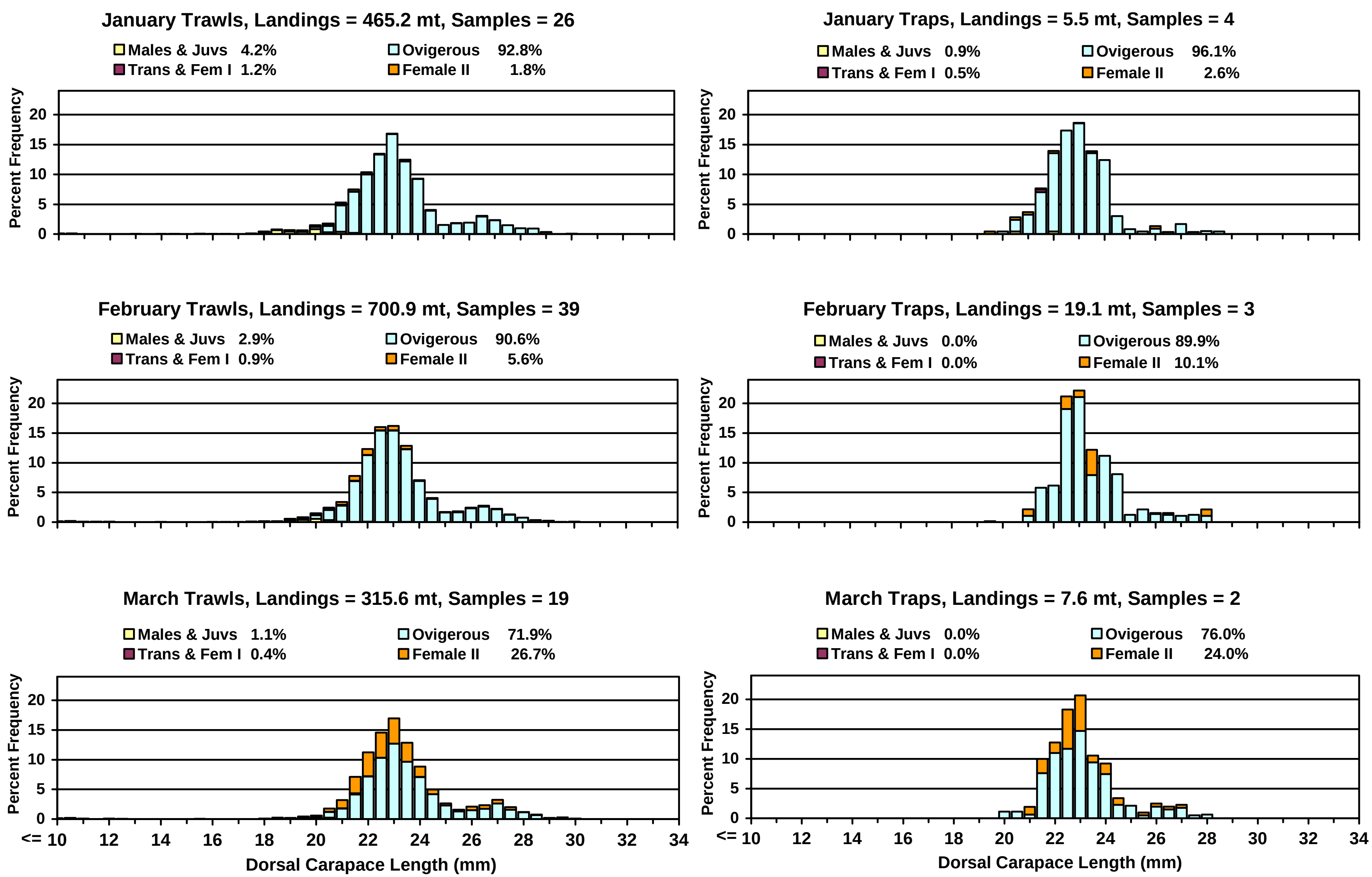


Figure 3. Length frequency distribution from samples of Massachusetts and New Hampshire shrimp catches during the 2004 season.

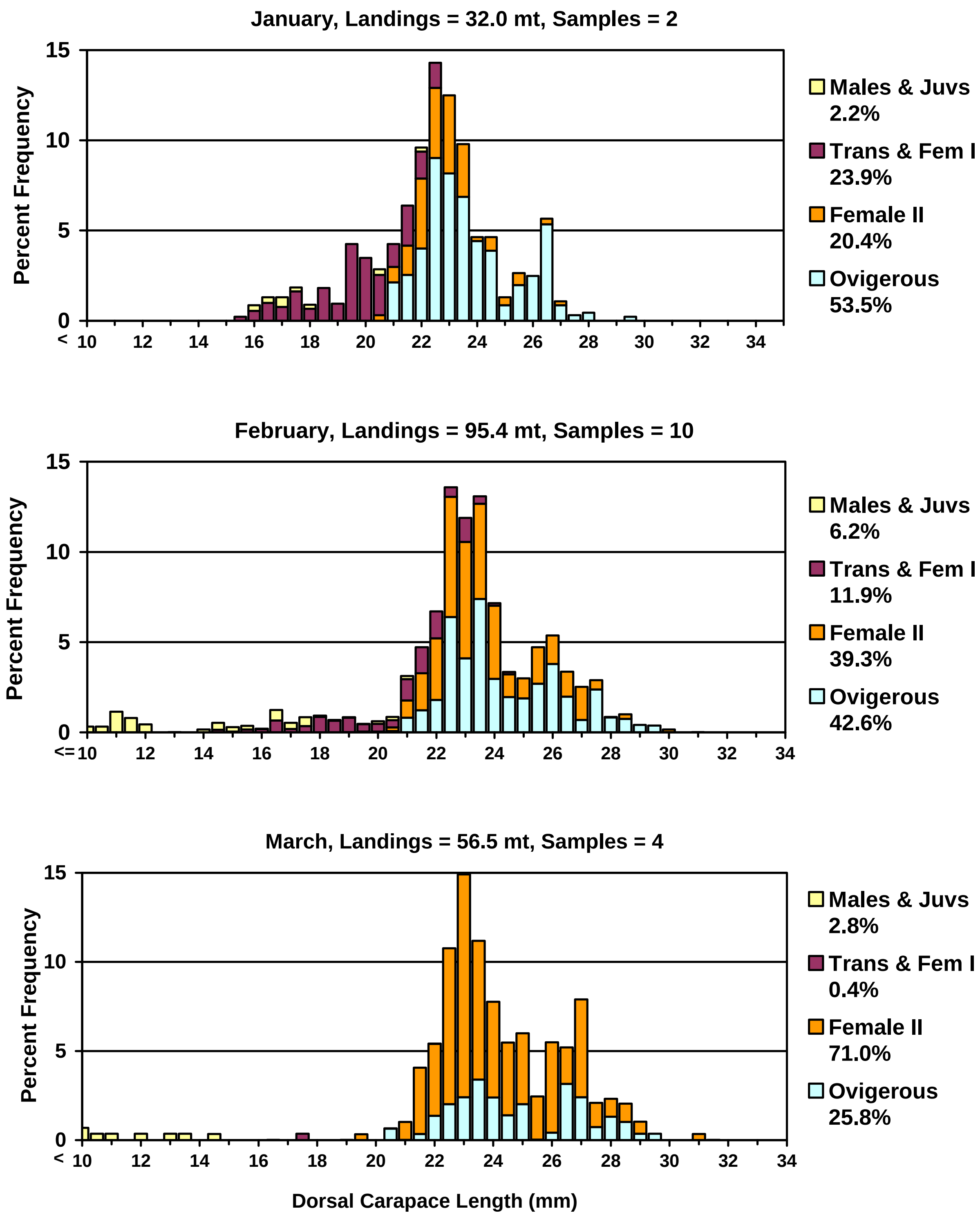


Figure 4. Gulf of Maine northern shrimp landings by length, developmental stage, and fishing season.

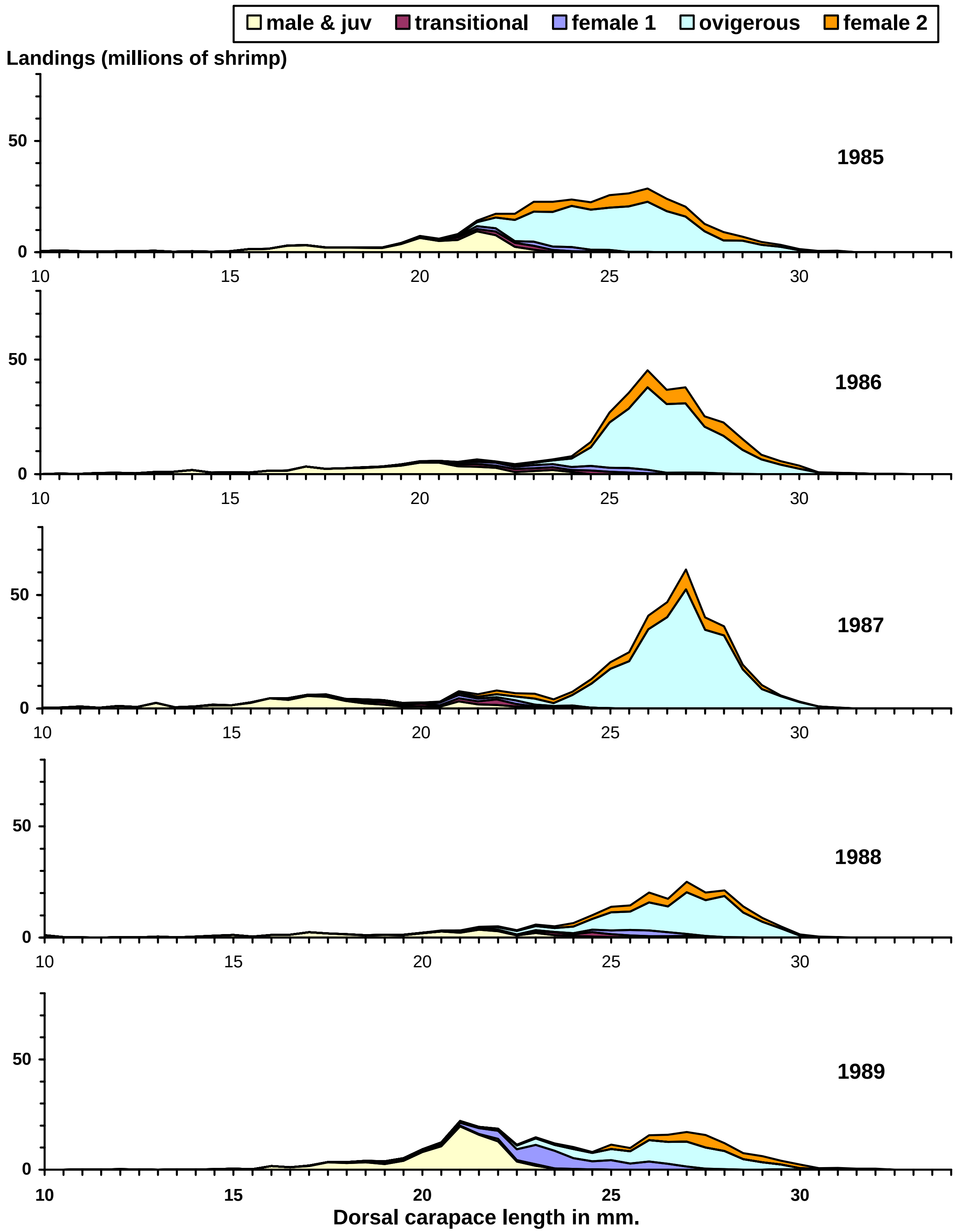


Figure 4. continued.

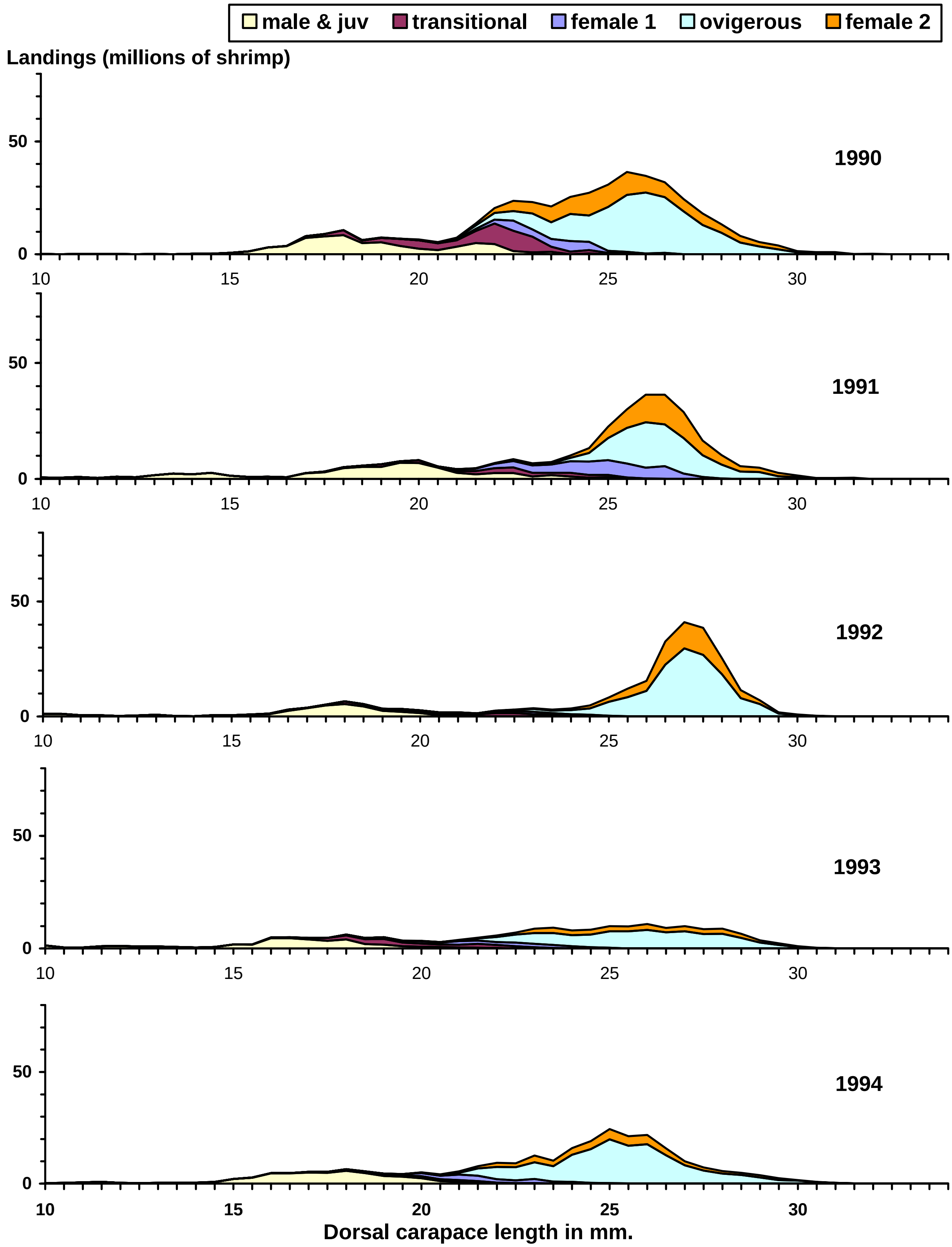


Figure 4. continued.

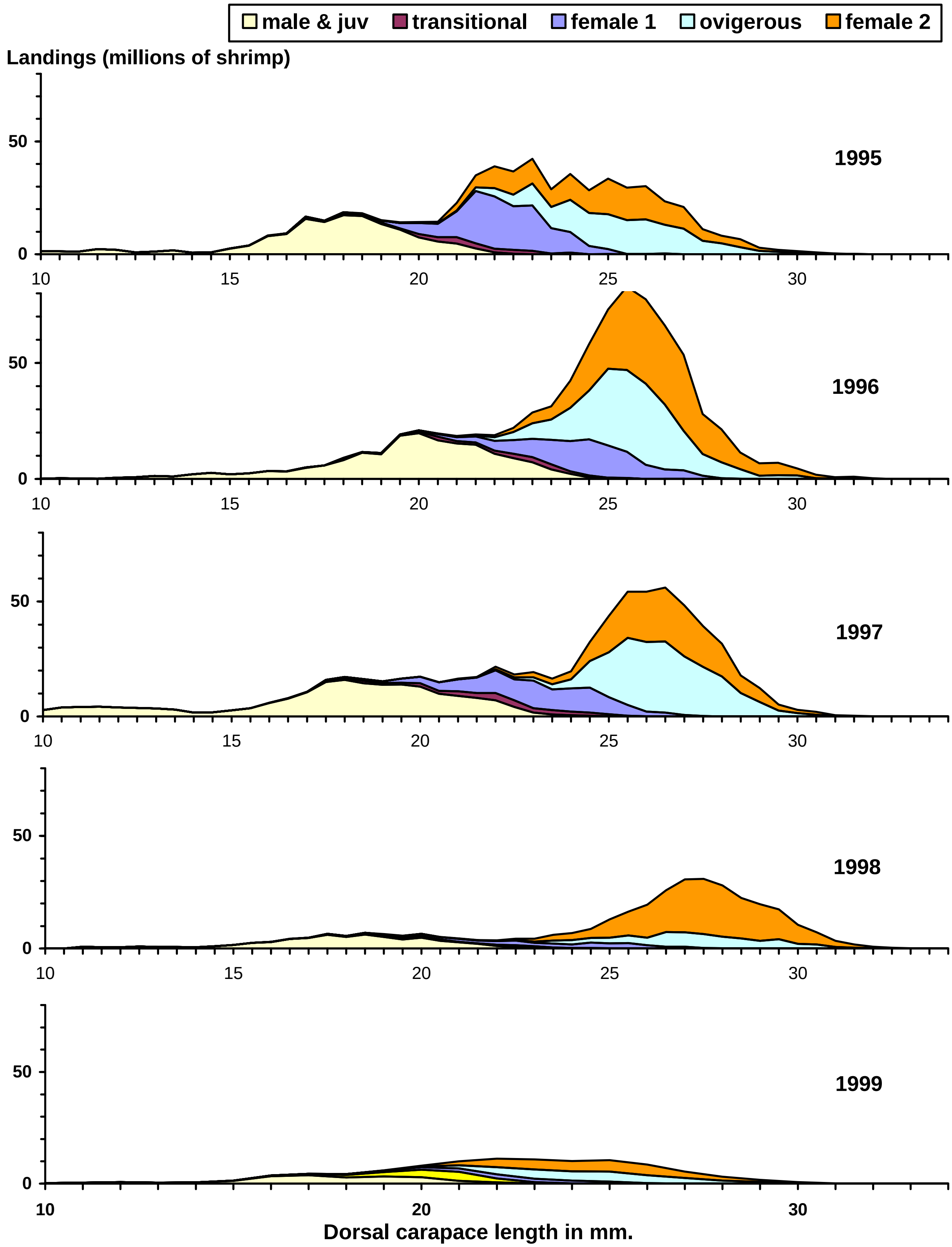


Figure 4. continued.

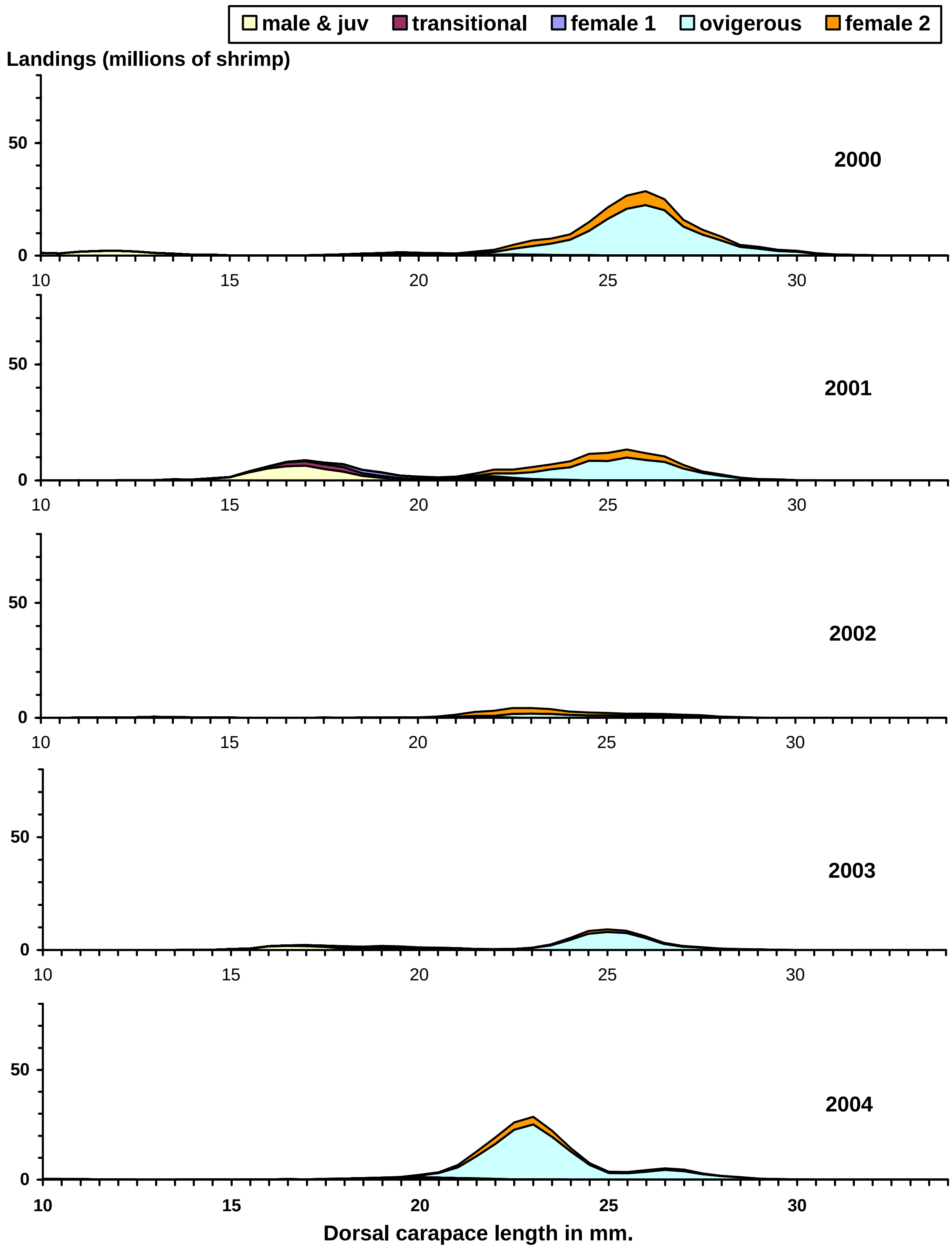
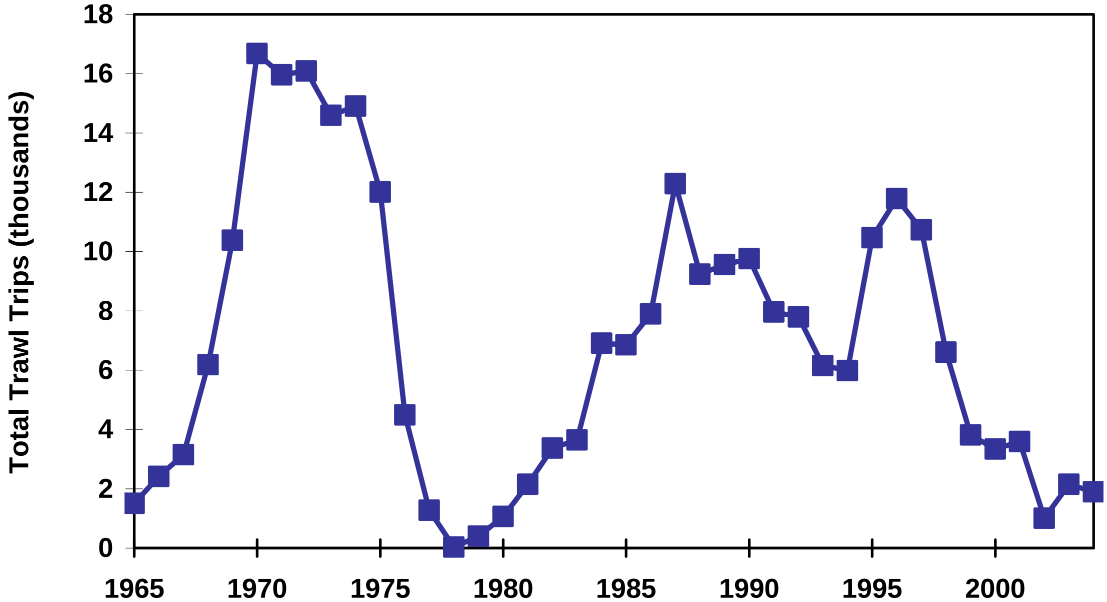
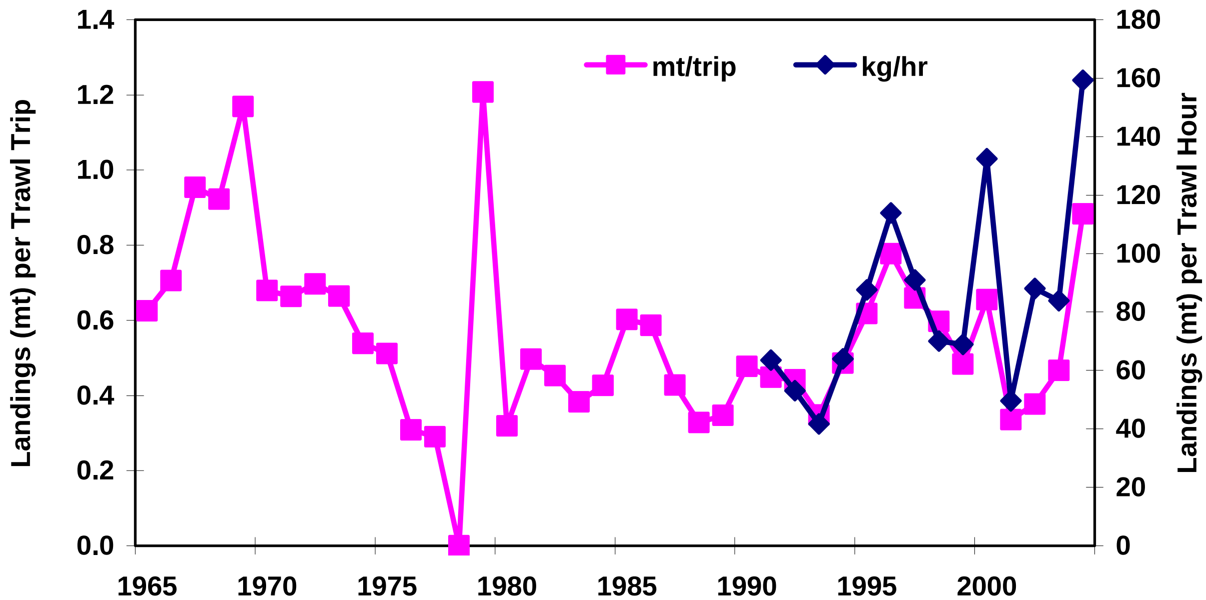


Figure 5. Nominal fishing effort (above) and catch per unit effort (below) in the Gulf of Maine northern shrimp trawl fishery.





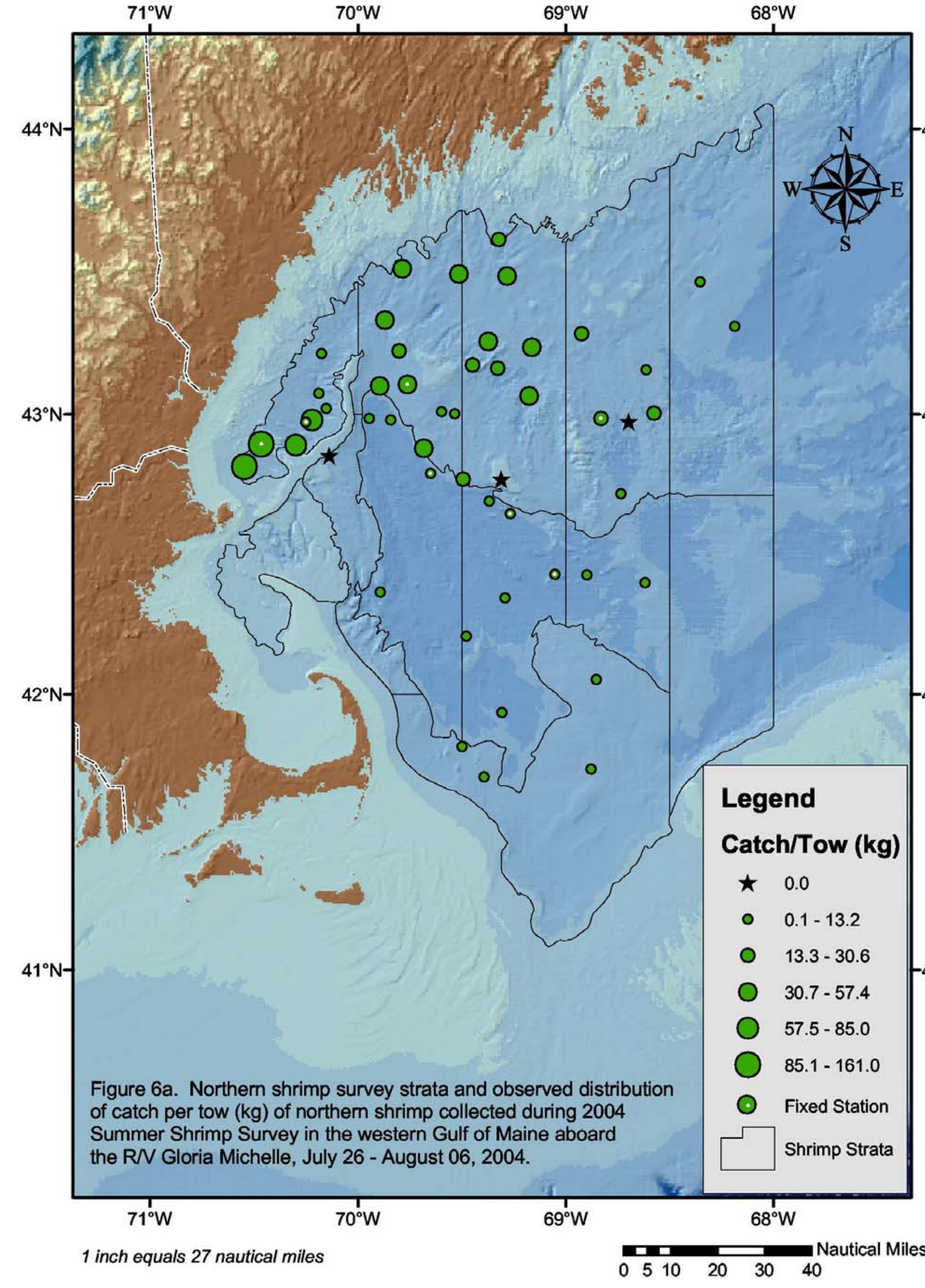


Figure 6a. Northern shrimp survey strata and observed distribution of catch per tow (kg) of northern shrimp collected during 2004 Summer Shrimp Survey in the western Gulf of Maine aboard the R/V Gloria Michelle, July 26 - August 06, 2004.

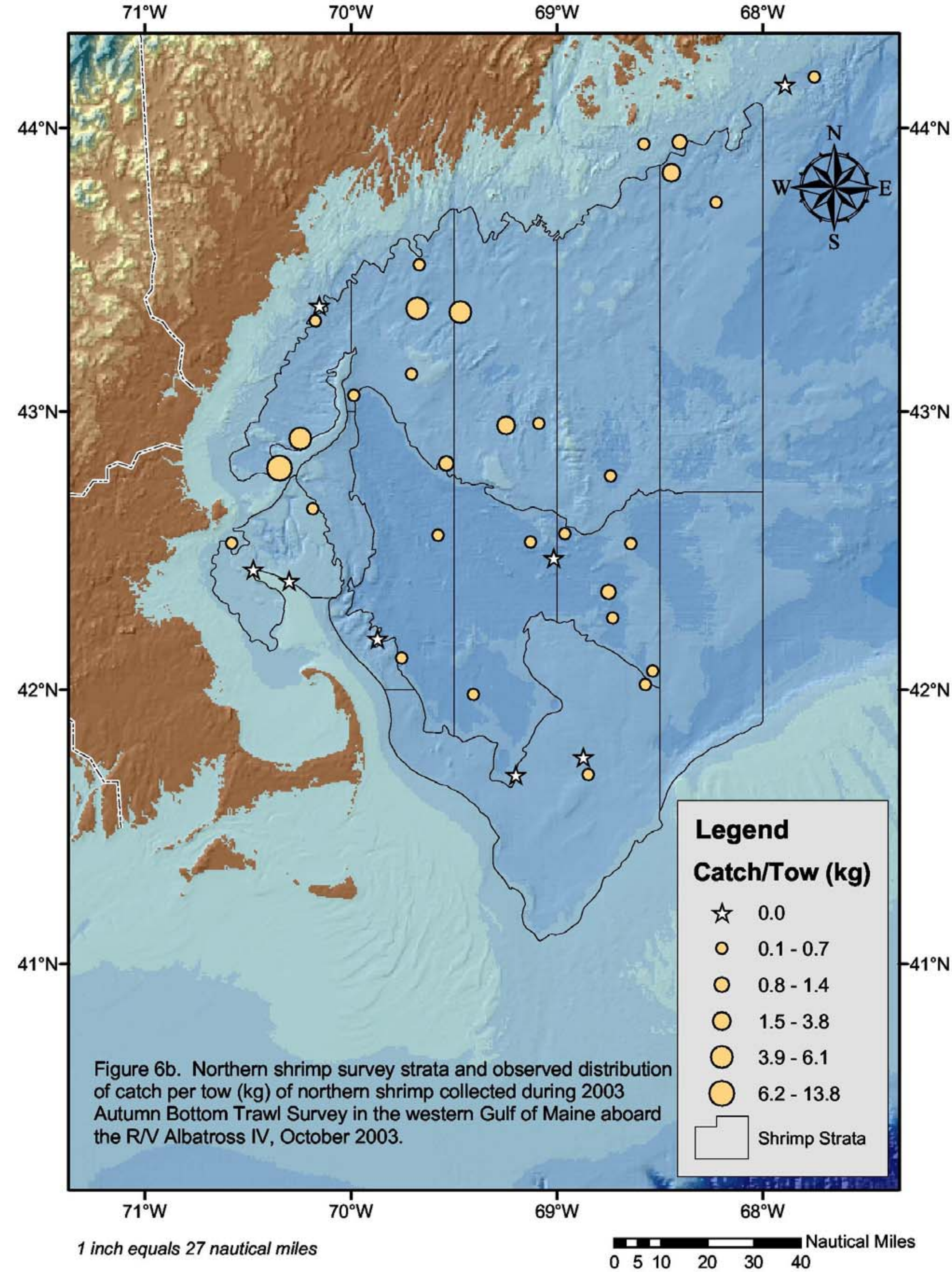

71°W
70°W
69°W
68°W
44°N
43°N
42°N
41°N
N
S
W
E
Legend
Catch/Tow (kg)
0.0
0.1 - 0.7
0.8 - 1.4
1.5 - 3.8
3.9 - 6.1
6.2 - 13.8
Shrimp Strata
Figure 6b. Northern shrimp survey strata and observed distribution of catch per tow (kg) of northern shrimp collected during 2003 Autumn Bottom Trawl Survey in the western Gulf of Maine aboard the R/V Albatross IV, October 2003.
1 inch equals 27 nautical miles
Nautical Miles
0 5 10 20 30 40

Figure 7. Fall survey index and landings of Gulf of Maine northern shrimp the following season.

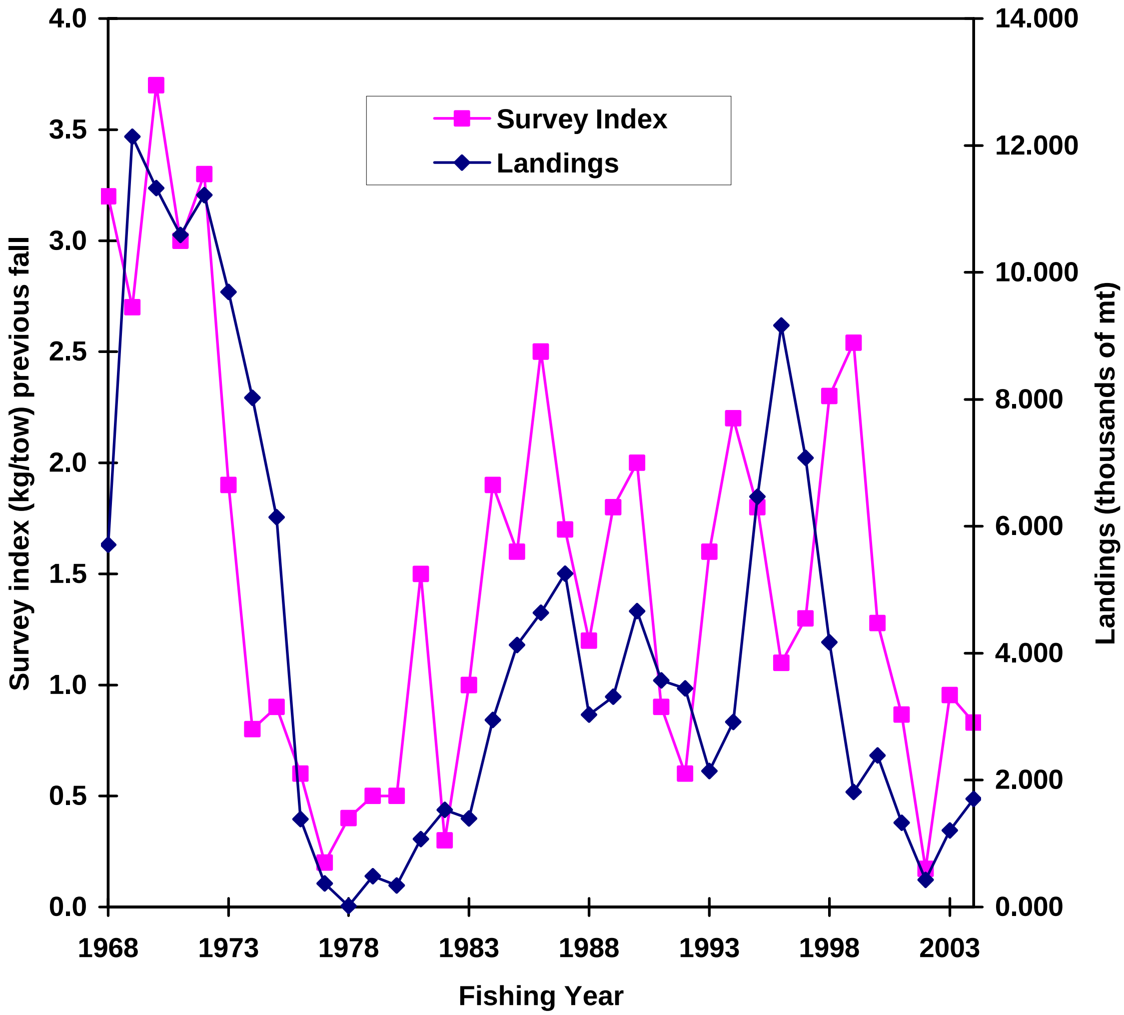


Figure 8. Gulf of Maine northern shrimp summer survey indices of abundance and biomass.

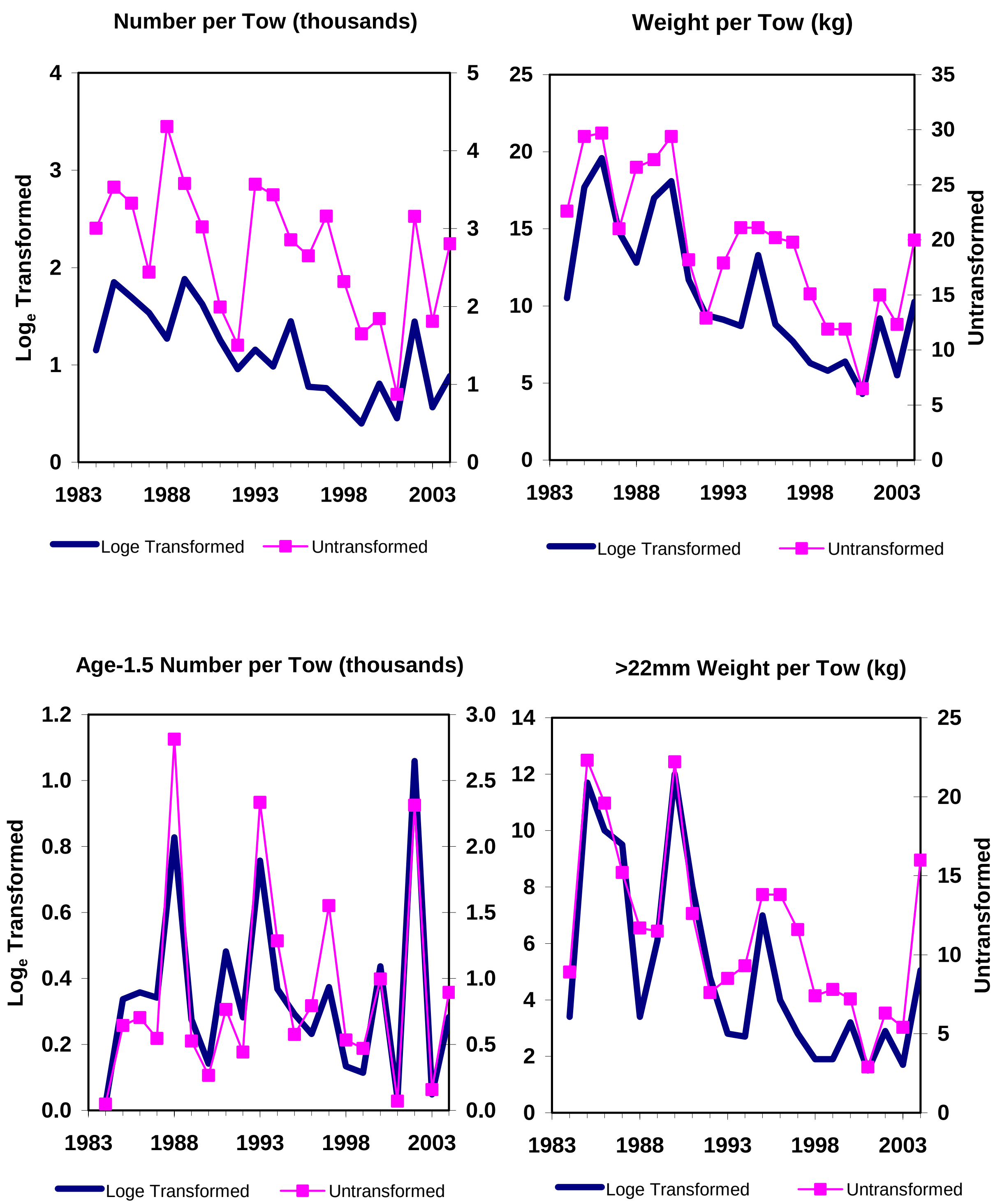


Figure 9. Gulf of Maine northern shrimp summer survey mean catch per tow by length and development stage. 2-digit numbers are assumed 1.5 age year class.

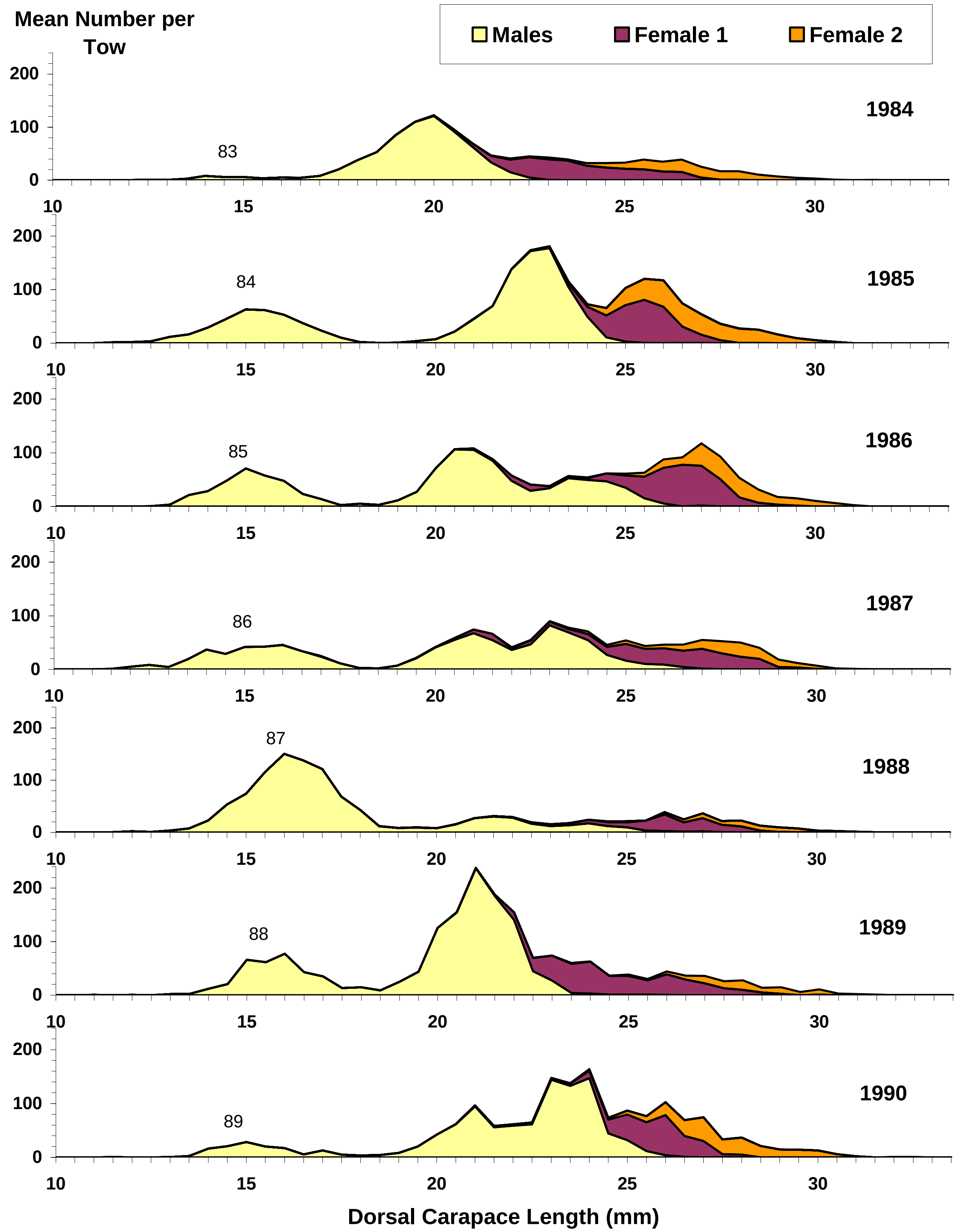


Figure 9. continued

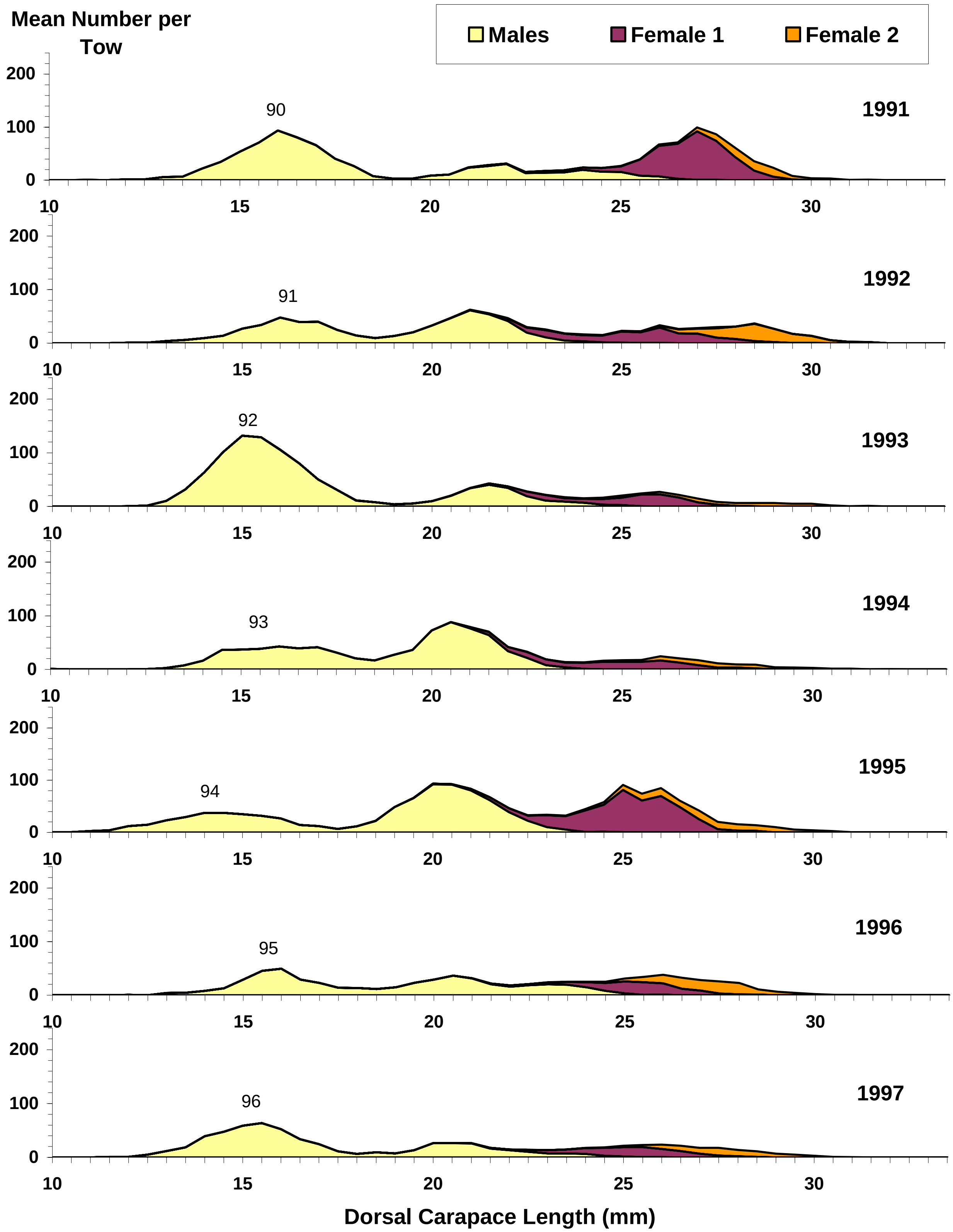


Figure 9. continued

Note that in 2004, a relatively large number of transitionals were observed, and are shown here combined with the males.

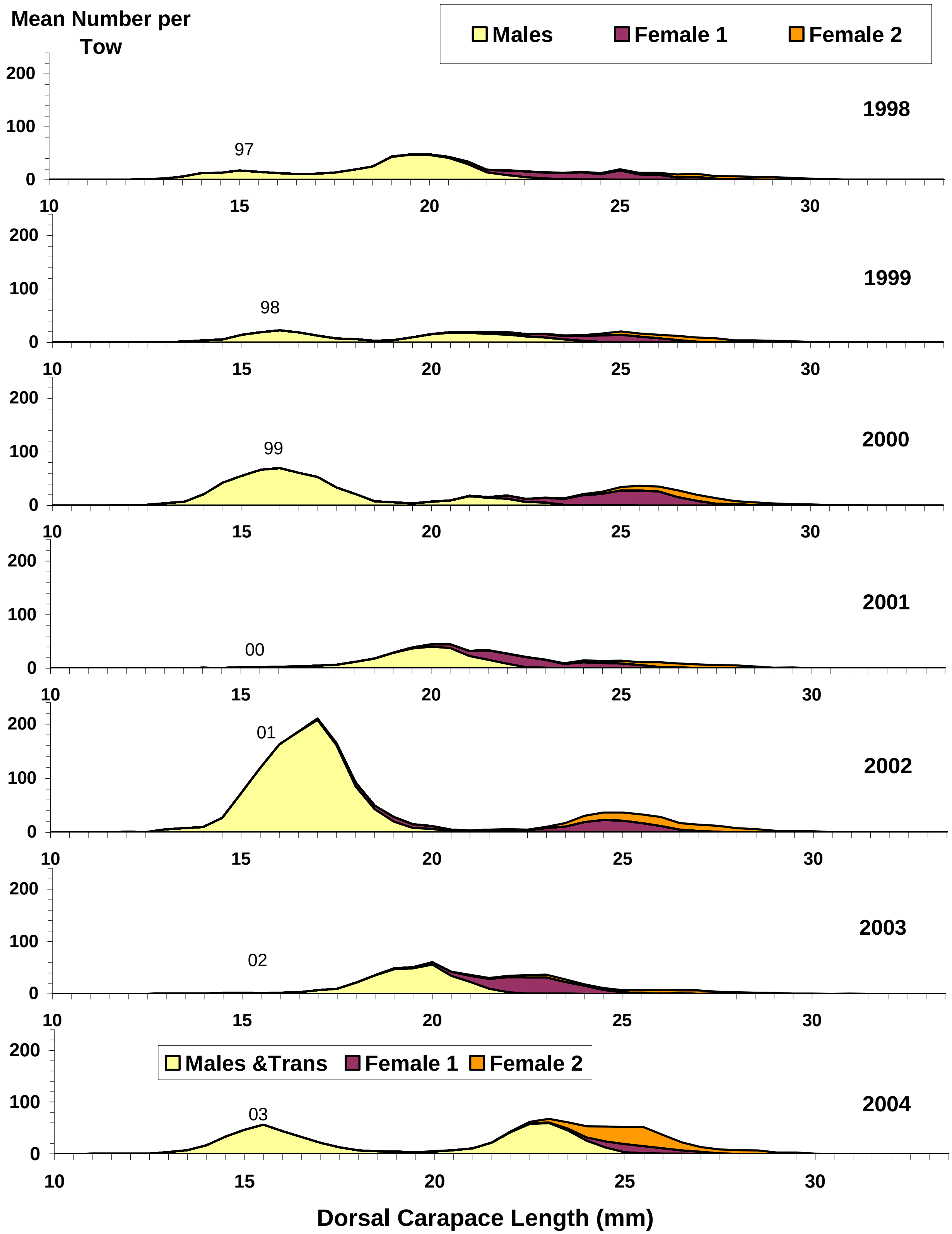


Figure 10. Fishing mortality, abundance, and biomass of Gulf of Maine northern shrimp, least squares estimates, bootstrapped means, and 80% confidence intervals.

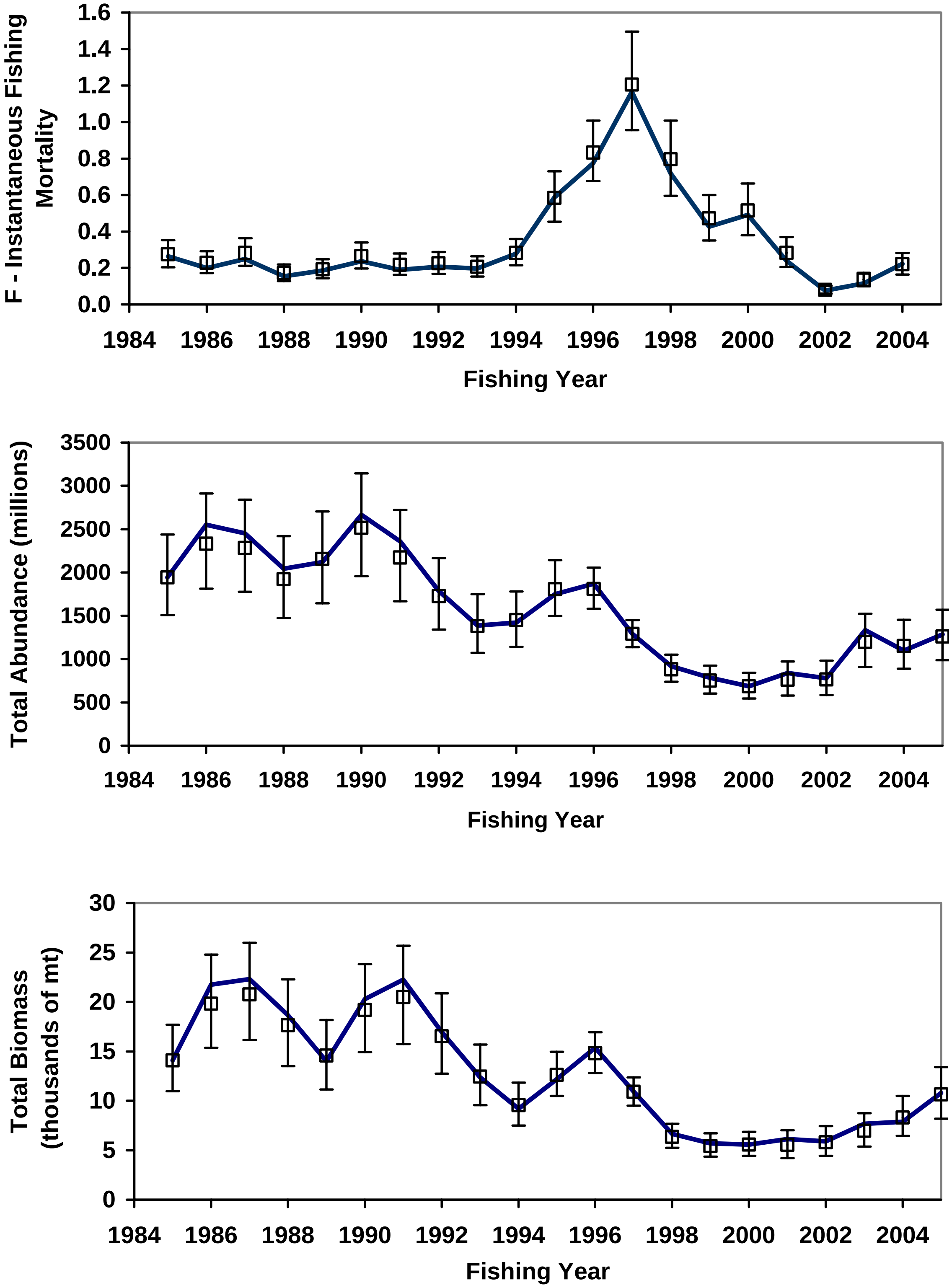


Figure 10. continued

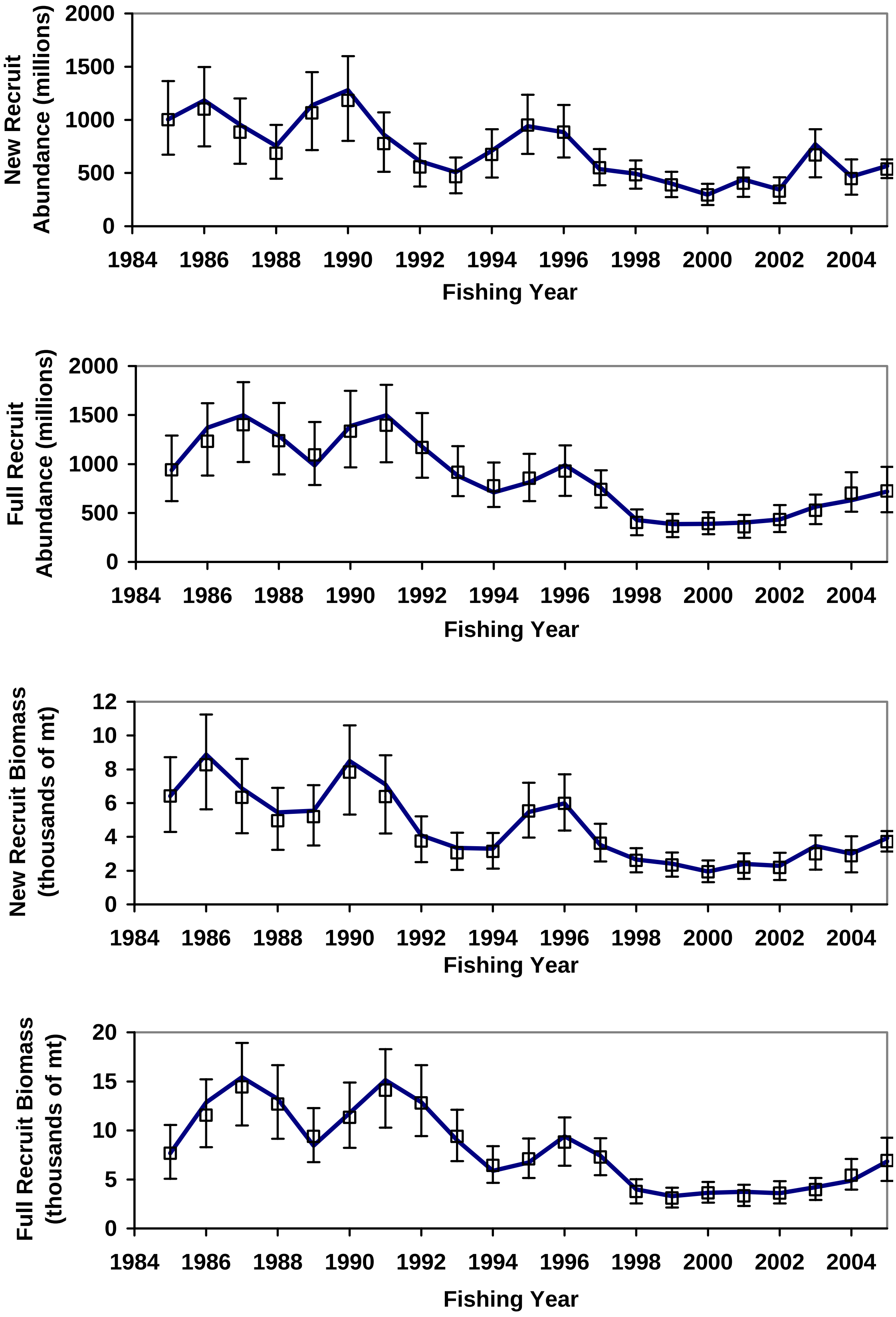


Figure 11. Catch - Survey Model (CSA) Input Data and Results

Input Data using Summer Survey

Survey Year*	Indices of Abundance: Recuits	Indices of Abundance: Full Recruits	Total Catch Millions*
1984	447.5580	479.0570	352.7930
1985	619.4560	925.4300	361.1710
1986	533.2920	848.5440	425.2940
1987	482.8980	766.9030	228.4340
1988	459.7550	387.7140	283.6470
1989	701.0930	817.9000	442.4290
1990	511.5210	907.5220	320.2900
1991	374.2770	612.0870	262.4340
1992	313.5950	444.3580	194.7880
1993	410.1960	320.7500	270.4060
1994	368.5900	364.3020	615.3180
1995	485.7860	653.3320	799.3680
1996	257.6520	348.6160	710.9720
1997	257.2980	267.1010	373.6800
1998	217.1340	226.6420	215.1220
1999	137.3900	174.6070	209.2790
2000	276.2810	288.1930	140.8820
2001	171.8090	196.3560	44.4000
2002	550.6000	372.9300	113.662
2003	222.9110	229.8540	172.174
2004	292.7240	405.8600	

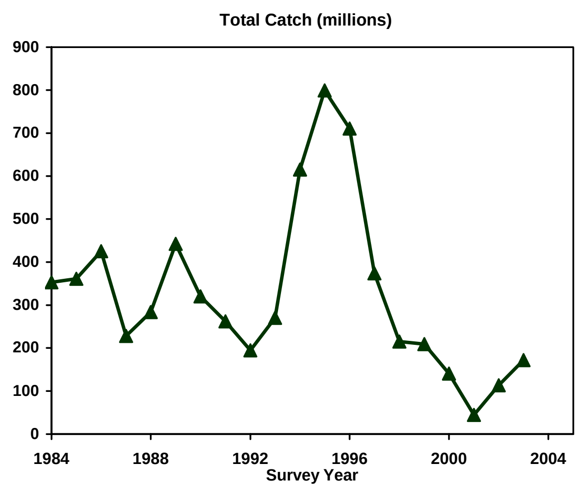
Results

Stock Size Estimates millions at time of Survey: Recruits	Stock Size Estimates millions at time of Survey: Full Recruits	Fishing Mortality All sizes	Total Mortality Z all sizes
1003.7	938.0	0.26	0.51
1183.6	1369.0	0.20	0.45
956.2	1497.1	0.25	0.50
754.5	1288.1	0.15	0.40
1137.0	983.8	0.19	0.44
1280.4	1386.0	0.24	0.49
862.0	1497.9	0.19	0.44
609.3	1176.3	0.21	0.46
509.2	879.5	0.20	0.45
710.6	710.9	0.28	0.53
938.9	812.3	0.59	0.84
883.3	987.8	0.77	1.02
535.6	756.4	1.17	1.42
492.0	427.5	0.72	0.97
400.5	386.1	0.43	0.68
295.9	388.5	0.49	0.74
438.5	401.4	0.24	0.49
344.5	432.9	0.08	0.33
770.9	562.8	0.12	0.37
467.5	629.3	0.22	0.47
567.8	717.8		

* Survey Year data are applied to the following Fishing Year

Input File Name	R2004NEW_BL.dat
Tuning Dataset	Survey
Time of Survey (yr)	0
Time of Catch (yr)	0.5
Natural Mortality Rate	0.25
Relative Catchability: Recruits to Full Recruits s_r	0.7 - 1.0
Catchability Estimate and CV	0.553 0.1473

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 2004



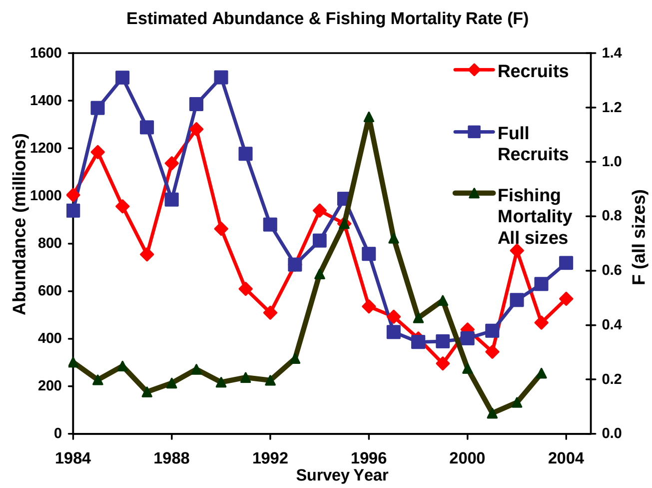


Figure 12. Estimates of fishing mortality (above) and stock biomass (below) for northern shrimp from Collie-Sissenwine analysis and surplus production modeling.

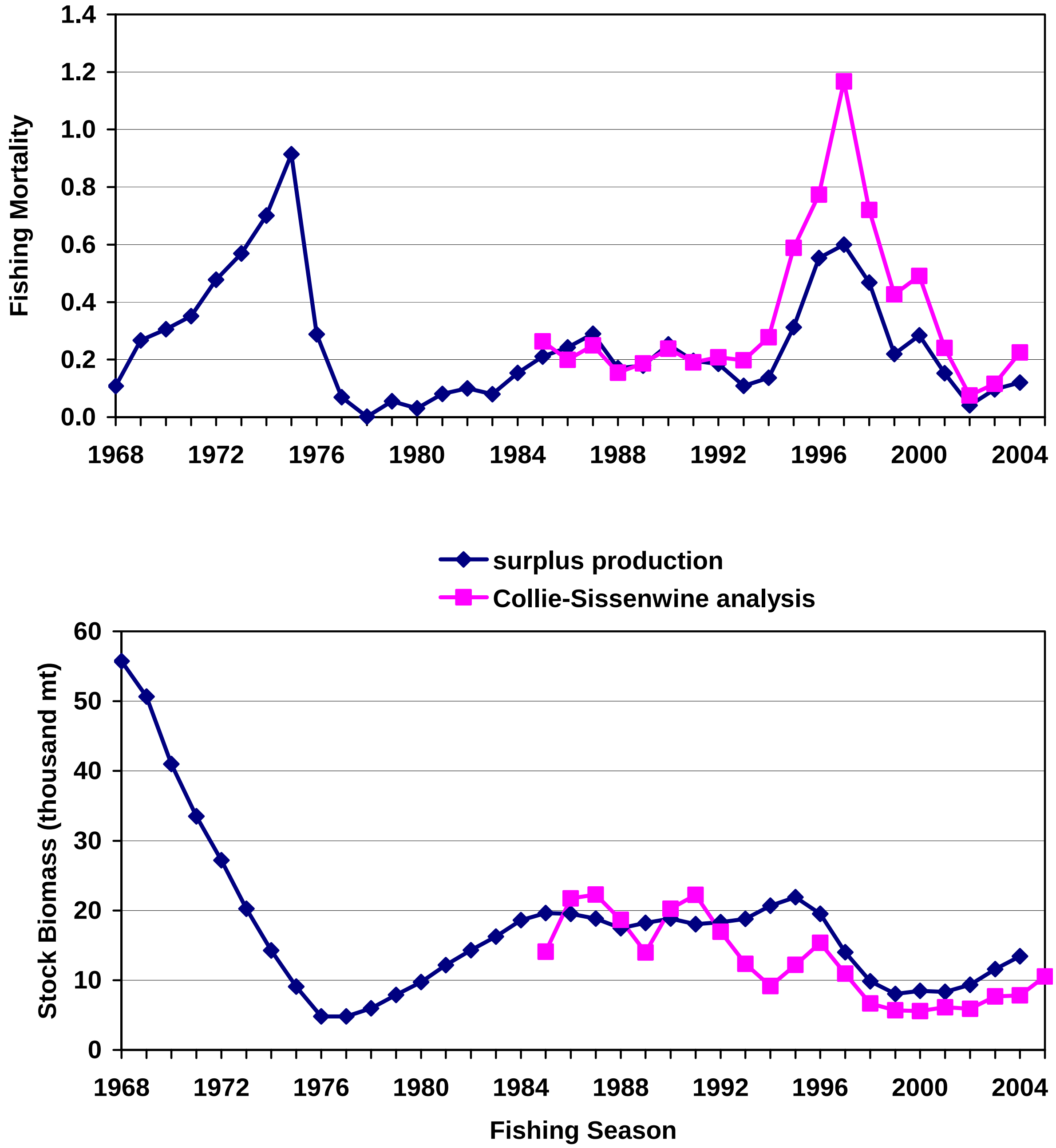
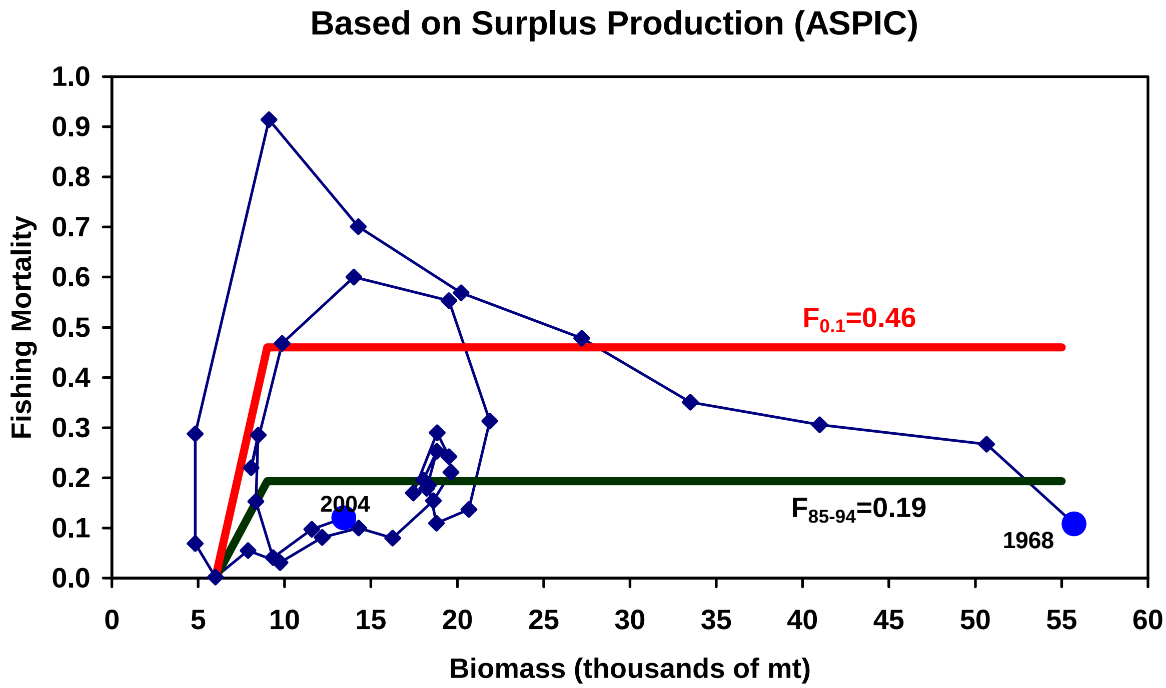


Figure 13. Biomass dynamics of the Gulf of Maine northern shrimp fishery, from surplus production (above) and Collie-Sissenwine (below) analyses, with possible fishing mortality and biomass reference points.



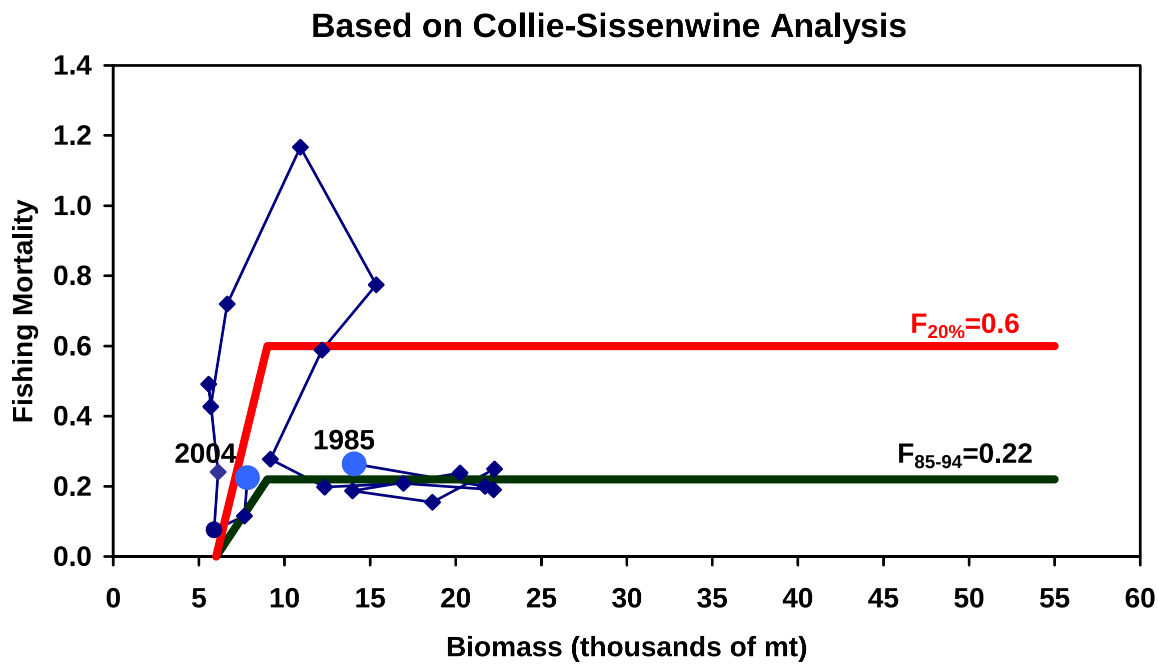
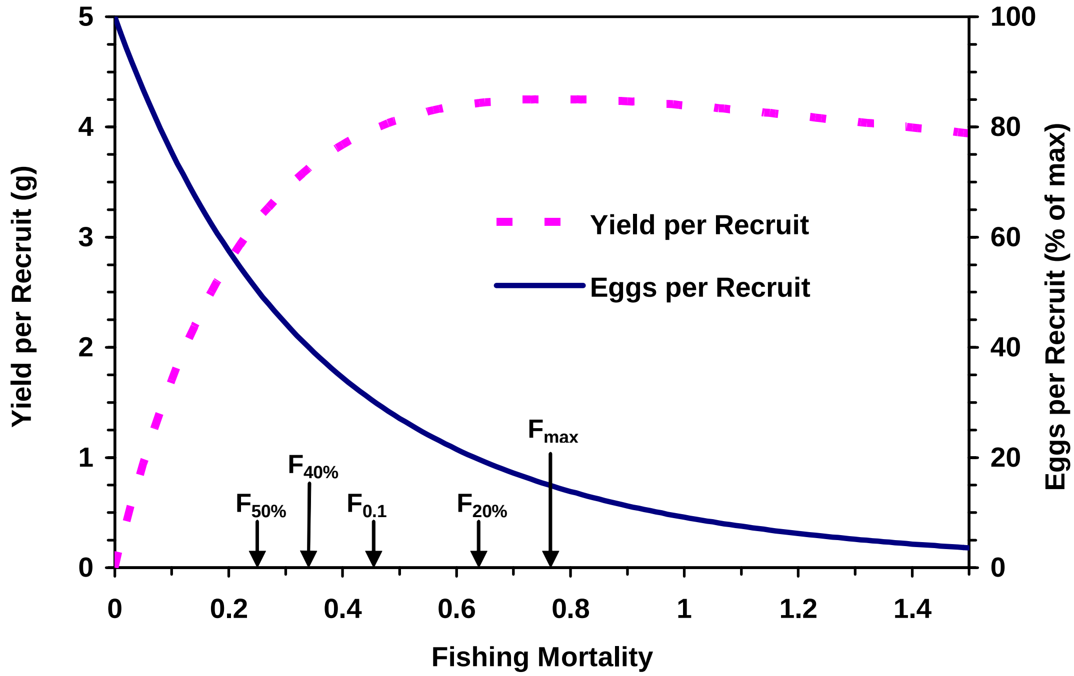


Figure 14. Yield and egg production per recruit.



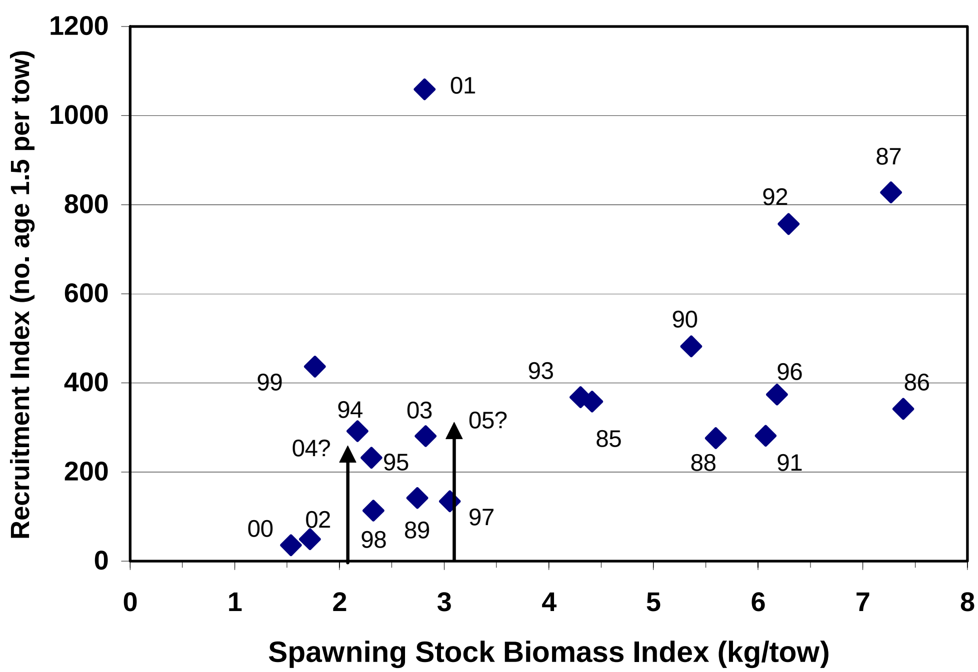


Figure 15. Relationship between summer survey index of Gulf of Maine female shrimp biomass the summer before spawning to age 1.5 abundance two years later. Two-digit numbers indicate the assumed age 1.5 year class.