C. GULF OF MAINE NORTHERN SHRIMP

Terms of Reference

1. Characterize the commercial and recreational catch including landings and discards.
2. Estimate fishing mortality, spawning stock biomass, and total stock biomass for the current year and characterize the uncertainty of those estimates.
3. Evaluate methodologies for the development of biological reference points for Northern Shrimp.

Introduction

1.0 Management

The Gulf of Maine fishery for northern shrimp (*Pandalus borealis*) is managed through interstate agreement among the states of Maine, New Hampshire and Massachusetts. The management unit is defined as the northern shrimp resource throughout the range of the species within U.S. waters of the northwest Atlantic Ocean from the shoreline to the seaward boundary of the EEZ. It is also recognized that the northern shrimp fishery, as defined here, is interstate and state-federal in nature, and that effective assessment and management can be enhanced through cooperative efforts with state and federal scientists and fishery managers. 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, which is the management body that establishes the annual fishing regulations. The management tools currently available to the Section include season length (within a time frame of December 1 through May 31) and gear restrictions.

1.1 Assessment

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 unified individual state port sampling programs in the early 1980s to better 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).

Beginning in 1997, the northern shrimp stock in the Gulf of Maine has been evaluated more quantitatively using three analytical models that incorporate much of the available data:

1. Collie-Sissenwine analysis that tracks removals of shrimp using summer survey indices of recruits and fully-recruited shrimp scaled to total catch in numbers (from dealers' reports and port sampling);
2. A surplus production analysis that models the biomass dynamics of the stock with a longer times series of total landings and three survey indices of stock abundance;
3. A yield-per-recruit (YPR) model and an eggs-per-recruit (EPR) model that simulate the life history of northern shrimp (including growth rates, transition rates, natural mortality, and fecundity) and fishing mortality on recruited shrimp. It uses estimates of trawl selectivity to estimate yield and egg production at various levels of fishing mortality, providing guidance on what levels of fishing are most productive and sustainable.

2.0 Life History

Northern shrimp (*Pandalus borealis*) are protandric (sequential) hermaphrodites, 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.

Several year classes in the last decade have shown some percentage of 2½ year old shrimp maturing as females instead of males. This presents both sexes in the same year class and may be a reaction to stress in the population as predicted by sex allocation theory (Charnov et al, 1978), or may be temperature or density driven (Apollonio et al, 1984, Koeller et al, 2000). In the 2001 year class, there is some evidence of early-maturing females appearing at 1½ years (Figure 12), which is unprecedented in the Gulf of Maine.

3.0 Fishery Description

Northern shrimp occur in boreal and sub-arctic waters throughout the North Atlantic and North Pacific, where they support important commercial fisheries. In the western North Atlantic, commercial concentrations occur off Greenland, Labrador, and Newfoundland, in the Gulf of St. Lawrence, and on the Scotian Shelf. The Gulf of Maine marks the southernmost extent of its Atlantic range. In the Gulf of Maine, primary concentrations occur in the western Gulf where bottom temperatures are coldest. In summer, adults are most common at depths of 90-180 meters.

The fishery has been seasonal in nature, peaking in late winter when egg-bearing females move into inshore waters and terminating in spring under regulatory closure. Northern shrimp has been an accessible and important resource to fishermen working inshore areas in smaller vessels who otherwise have few options due to seasonal changes in availability of groundfish, lobsters and other species.

The fishery formally began in 1938, and during the 1940s and 1950s almost all of the landings were by Maine vessels from Portland and smaller Maine ports further east. This was an inshore winter fishery, directed towards egg-bearing females in inshore waters (Scattergood 1952). New Hampshire vessels entered the fishery in 1966, but throughout the 1960s and 1970s New Hampshire landings were minor. Landings by Massachusetts' vessels were insignificant until 1969, but in the early 1970s the fishery developed rapidly, with MA landings increasing from 14% of the Gulf of Maine total in 1969 to over 40% in 1974-1975. In contrast to the historical wintertime Maine fishery, these vessels fished continually throughout the year and made significant catches during summer months

A wide variety of vessels have been used in the fishery (Bruce 1971; Wigley 1973). The predominant type during the 1960s and 1970s appears to have been side-rigged trawlers in the 14-23 m range. During the 1980s and 1990s, side trawlers either re-rigged to stern trawling, or retired from the fleet. Currently, the shrimp fleet is comprised of lobster vessels in the 9-14 m range that re-rig for shrimping, small to mid-sized stern trawlers in the 12-17 m range, and larger trawlers primarily in the 17-24 m range. The otter trawl remains the primary gear employed and is typically chain or roller rigged, depending on area and bottom fished. There has been a trend in recent years towards the use of heavier, larger roller and/or rockhopper gear. These innovations, in concert with substantial improvements in electronic equipment, have allowed for much more accurate positioning and towing in formerly unfishable grounds, thus greatly increasing the fishing power of the Gulf of Maine fleet.

A small pot fishery has also existed in mid-coastal Maine since the 1970s, where in many areas bottom topography provides favorable shrimp habitat yet is too rough or restricted for trawling. The trapped product is of good quality, as the traps target only female shrimp once they have migrated inshore. The trap fishery has landed as much as 9% of the landed total, but the annual average is usually around 5%. There is some indication that trap fishing for shrimp has grown in a few areas such as South Bristol (Lower mid-coast Maine). As the trap fishery is dependent on the availability of shrimp in a specific area, there is apparently a shorter season for traps than for draggers. The majority of the shrimp trappers also trap lobsters.

Management measures currently in place include season length (varying from year to year within a time frame of December 1 through May 31), gear restrictions, licensing, and mandatory reporting. Legal restrictions on trawl gear require a minimum 1.75 inch stretch mesh net and the use of a finfish separator device known as the “Nordmore grate” with a maximum grate spacing of 1 inch.

4.0 Habitat Description

Pandalus borealis has a discontinuous distribution throughout the North Atlantic, North Pacific, and Arctic Oceans. In the Gulf of Maine, northern shrimp populations comprise a single stock (Clark and Anthony 1981), which is concentrated in the southwestern region of the Gulf (Haynes and Wigley 1969; Clark et al 1999). Water temperature, depth, and substrate type have all been cited as important factors governing shrimp distribution in the Gulf of Maine (Haynes and Wigley 1969; Apollonio et al. 1986; Clark et al. 1999).

Temperature

The most common temperature range for this species is 0-5 °C (Shumway et al 1985). The Gulf of Maine marks the southern-most extent of this species’ range in the Atlantic Ocean, and seasonal water temperatures in many areas regularly exceed the upper physiological limit for northern shrimp. This environmental limitation restricts the amount of available habitat occupied by this species to the western region of the Gulf (west of 680 W) where bottom topography and oceanographic conditions create submarine basins protected from seasonal warming by thermal stratification. The deep basins act as cold water refuges for adult shrimp populations (Apollonio et al 1986). In the northeastern region of the Gulf, large shrimp populations do not persist because bottom waters are not protected from seasonal warming due to continual mixing from intense tidal currents nearer to the Bay of Fundy.

Depth

In the Gulf of Maine, northern shrimp are most frequently found from about 10 m to over 300 m (Haynes and Wigley 1969), with juveniles and immature males occupying shallower, inshore waters and mature males and females occupying cooler, deeper offshore waters for most of the year (Apollonio and Dunton 1969; Haynes and Wigley 1969, Apollonio et al 1986). During the summer months, adult shrimp inhabit water from 93-183 m (Clark et al. 1999); ovigerous female shrimp are found in shallower near-shore waters during the late winter and spring (Clark et al. 1999) when their eggs are hatching.

Substrate

Within its preferred temperature range, northern shrimp most commonly inhabit organic-rich, mud bottoms or near-bottom waters, where they prey on benthic invertebrates; however, the shrimp is not limited to this habitat and has been observed on rocky substrates (Schick 1991). Shrimp distribution in relation to substrate type determined by spring, summer, and autumn fisheries-independent trawl surveys clearly show northern shrimp primarily occupy areas with fine sediments (sand, silt, and clay). Shrimp are often associated with biotic or abiotic structures such as cerianthid anemone

(Langton and Uzmann 1989) and occasional boulders in these fine sediment habitats (Daniel Schick, Maine Department of Marine Resources, pers. comm.).

5.0 Data Sources

5.1 Commercial

5.1.1 Data Collection Methods

Commercial landings by state and month have been compiled by NMFS port agents from dealer reports. It is likely that catches sold to the small "peddler" market have been unreported, as well as some of those sold to those dealers (non-federally permitted) who are not required to report. These data were used for annual stock assessments until 2001, when vessel trip reports (VTRs) were found to be more complete. Small Maine vessels that did not have federal permits were not required to fill out VTRs until 2000. Landings have been calculated from VTRs for use in assessments in 2001 and 2002.

A port sampling program was established in the early 1980s to characterize catch at length and developmental stage, as well as to collect effort and fishing depth and location data. Samplers strive to achieve representative sampling by maintaining up-to-date lists of active buyers and visiting ports in proportion to their landings activity. Sampling consists of interviewing boat captains and collecting a 1 kg sample of shrimp from each catch. The samples are separated and weighed back at the lab by species, sex and development stage. Measurements are made of all shrimp dorsal carapace lengths to the nearest half mm. The numbers of shrimp measured, and a calculation of sampling intensity are shown in Tables 2 and 3.

5.1.2 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; Table 1a). 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 1a&b). 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. Landings declined between 1996 and 1999 to 1,900 mt. This was followed by a slight increase to 2,400 mt in the 2000 season. Landings dropped during 2001 to 1,400 mt and in 2002 to a low of 400 mt for the 25-day 2002 season. The 2002 landings were the lowest northern shrimp landings since the fishery was closed in 1978 (Table 1a, Figure 1).

Maine landings comprised 75% of season totals during 1984-1996. The proportional distribution of landings among the states has shifted gradually since the 1980's when Massachusetts accounted for about 30% of the catch. In 2001 and 2002, the proportional distribution of landings was still greatest for Maine but was then followed by NH with 18% (2001) and 13% (2002). Massachusett's landings made up 5% of the 2001 landings and 1.5% of the landings in 2002 (Tables 1a&b). The majority of landings generally occur in January and February (Table 1b, Figure 2). Since the 1999 season, there has been a reduction in the number of months fished.

Size composition data (Figures 3, 4a&b), 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 were supported in large part by mature females (assumed age 5) from the 1982 year class. Landings declined sharply in 1988 with the passage of the 1982 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 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 from the 1996 yearclass 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. 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 yearclass) were generally absent, but a noticeable quantity of 1-year-old shrimp (2001 yearclass) were caught (Figures 3, 4a).

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 4b). 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 1b) 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 at 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.

5.1.3 Commercial Discards and Bycatch

Sea sampling observations on shrimp otter trawl trips from 1984 to 1996 indicate that weight of discards is less that 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 Jeffreys 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 Jeffreys 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.

5.1.4 Commercial Catch Rates and Fishing Effort

Maine trapping operations accounted for 4% to 8% of the state's total number of trips from 1987 to 1994, and for 15.9, 16.9, and 18.0% in 2000, 2001, and 2002 respectively, according to 2000-2002 Vessel Trip Report (VTR) data.

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 6, 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, 3,527 in 2001, and 870 in 2002.

Approximately 310 vessels participated in the shrimp fishery in 1997, 260 in 1998, and about 238 in 1999. In 1999, the majority (181) were from Maine, while the number of vessels from New Hampshire ports remained at about 30, and the numbers from Massachusetts declined from 33 vessels in 1998 to 27 in 1999. In 2000 and 2001 there were 285 and 274 vessels participating, respectively. In 2002, there were 133 vessels from Maine, 6 from Massachusetts, and 21 from New Hampshire, for a total of 160 vessels that reported shrimp trips.

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 2002 are still being received. 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.

Catch per unit effort (CPUE) indices have been developed from NMFS interview data (1983-1994) and logbook data (1995-2002) and are measures of resource abundance and availability (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 (Figure 5) 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 1,050 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 756 pounds per trip, the lowest since 1993. In 2002, the catch per trip was 872 pounds (Figure 5).

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 and New Hampshire's port sampling programs, and agree well with the (less precise) catch per trip data from logbooks (see text table below and Figure 5). Inshore CPUE for 2002 was 223 lbs/hr, offshore was 91, and the season average was 194 lbs/hr, (see table below.)

Higher catch rates (per hour) 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. Higher catch rates (per trip) may indicate a higher than average incidence of multiple-day trips. For these reasons, attempting to interpret catch rate data is not for the faint of heart.

ME/NH CPUE in lbs./hour towed, from port sampling. Catch in lbs./trip is from NMFS weighout and logbook data.

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	1,067
2000	288	337	292	1,444
2001	100	135	109	756
2002	223	91	194	872

5.1.6 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):

$$P = 1/(1+e^{-(a\mathrm{CL}+b)}) \tag{1}$$

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.

5.2 Recreational

A very limited recreational fishery exists for northern shrimp. This fishery, using traps, has been for personal use and has not been licensed.

5.3 Fishery-Independent Survey Data

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 jointly by the NSTC and NEFSC (Figure 6).

<u>Maine Survey</u>
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).

<u>Groundfish Surveys</u>
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 and early 1970'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).

<u>NSTC Shrimp Survey</u>
The NSTC shrimp survey has been conducted each summer since 1983 aboard the R/V Gloria Michelle 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.

5.3.4 Biomass Indices

Biomass indices for the three surveys are presented in Figures 6 and 11 and Table 10.

The statistical distribution of the summer 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 (Table 7, Figure 10). 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 summer survey catches by length and developmental stage (Figure 12) reflect the predominance of the strong 1982, 1987, 1992, and 2001 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 13). 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:

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

where CL_∞=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

6.0 Methods

6.1 Models

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 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. This modified DeLury model was applied to the Gulf of Maine northern shrimp fishery:

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

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):

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

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:

$$n_t' = q_n N_t\, e^{\eta t} \tag{5}$$

and

$$r_t' = q_r R_t\, e^{\delta t} \tag{6}$$

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 ($e^{\varepsilon t}$):

$$\boldsymbol{n}_{t+1} = [(\boldsymbol{n}_t + \boldsymbol{r_t}/\mathbf{s_r})e^{-0.5M} - \boldsymbol{q}_\mathbf{n} C_t]\, e^{-0.5M} \quad \boldsymbol{e}^{\boldsymbol{\varepsilon}\mathbf{t}} \tag{7}$$

where

$$s_r = q_r / q_n \tag{8}$$

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 12). 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_r 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:

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

and

$$F_{R+N,t} = Z_{R+N,t} - M \tag{10}$$

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

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

and

$$F_{R,t} = p\ F_{N,t} \tag{12}$$

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

CSA results are summarized in Tables 8 & 9 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 18% to 25%, estimates of recruitment were slightly less precise (CV=23% to 26%), and q_n was estimated with moderate precision (CV=16%). Defining correlation between parameters (Appendix A) as:

$$r_{ij} = CV_{ij}/(CV_{ii}*CV_{jj})^{0.5} \tag{13}$$

there were no large correlations among the 38 parameter estimates (all r's < 0.4). Residuals ranged from –0.33 to 0.35 without significant annual patterns, indicating that the data fit the model well (Figures 14, 15).

Estimates of recruitment to the fishery averaged 0.8 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 1 billion prior to the next scheduled fishing year (2003). Fully-recruited abundance averaged 1.0 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 0.6 billion in the current year. Total stock biomass estimates averaged about 13,200 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 the last three years to its current value of 9,200 mt (Tables 8a&b, Figure 14).

Annual estimates of fishing mortality (F) averaged 0.34 (26% exploitation) for the 1985 to 1995 fishing seasons, peaked at 0.87 (52% exploitation) in the 1997 season and decreased to 0.28 (22% exploitation) in the 2000 season (Table 8a, Figure 14). In 2001, F rose to 0.40 (29% exploitation). In the most recent fishing year (2002) the short season and poor stock condition (in terms of exploitable shrimp) along with an exceptional recruitment pulse resulted in F estimates for the terminal year (2002) of –0.01. While the removal of at least 375 mt of shrimp by the fishery indicate some level of F, the slightly negative value is analytically plausible. In addition to the relative lack of precision in estimating the terminal year F, there is the possibility that either M is not the constant 0.25 assumed, and/or catch is not measured precisely. The three year (2000 - 2002) average is 0.22 (18% exploitation). The recent pattern in F reflects the pattern in nominal fishing effort (Figure 5). Estimates of mortality in the first and last years are the least reliable in CSA analysis, because they are linked to one adjacent year rather than two. Averages of terminal mortality estimates (e.g., F_{00-01}=0.65 or F_{99-01}=0.54) are less sensitive to measurement error in the 2002 survey observation of fully-recruited shrimp or reporting of catch in 2002. However, averaging F_{01} with previous years may be inappropriate because of the apparently significant decrease in effort and exploitable shrimp stock. 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 thousand 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 the final year (F_{01}) was –0.01 with an 80% confidence interval of -.0.12 to 0.21 (Figure 15). Two approaches were examined to define a multiple year "average" F. The first examined the distribution of bootstrap estimates from all applicable years as if they all represented estimates of the current fishing mortality (Figure 16a). The second approach was to average the estimates for each bootstrap iteration, and examine the resultant distribution (Figure 16b). From this, while the medians of the two approaches agree, it is clear there is a loss of precision of the second due to the reduction of the tails through averaging (Figure 16c). The result for both approaches using a two and three year average are shown below:

	1999-2001 Average	1999-2001 All	2000-2001 Average	2000-2001 All
10th Pctl	0.15	-0.03	0.05	-0.07
Median	0.25	0.26	0.17	0.17
90th Pctl	0.35	0.48	0.28	0.39

Abundance estimates were not bias-corrected, because estimates of bias were not substantial (<10% in most years).

Retrospective Analysis

Comparison of results from 10 retrospective CSA runs 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 deleting the last year of survey and catch data (for five years) to create a retrospective series of CSA estimates as well as runs that similarly truncated the first year (Table 9, Figure 17a-d). Terminal mortality estimates (both initial and final year) were quite stable in most years with minimal retrospective differences in F (Figure 17a). Similar stability was seen in estimates of abundance and biomass (Figures 17b-c). The NLSS estimate of q was also very stable for the series of retrospective analyses (Figure 17d).

Confirmatory Analysis

An alternative method of estimating stock size and F was explored to corroborate results from CSA. A nonequilibrium surplus production model (Prager 1994, 1995) was fit to seasonal catch and survey biomass indices from 1968 to 1996 (summarized in Table 10, 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):

$$dB_t/dt = rB_t - (r/K)B^2_t \tag{14}$$

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:

$$dB_t/dt = (r\text{-}F_t)B_t - (r/K)B_t^2 \tag{15}$$

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

$$B_{t+1} = B_t + (r\text{-}F_t)B_t - (r/K)B_t^2 \tag{16}$$

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). A fair portion of the variance in the fall and Maine surveys was explained by the model (R^2=0.5 an 0.6, respectively), but much of the variation in the summer shrimp survey was not resolved (R^2=0.3). 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 CSA model; F_{02} was the lowest value since 1983 (Figure 19). Recruitment of the strong 1982, 1987, 1992, and 2001 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 CSA. The biomass dynamics model suggests that a maximum sustainable yield (MSY) of 5,000 mt can be produced when stock biomass is approximately 29,900 mt (B_{MSY}) and F is approximately 0.17 (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 1000 times to estimate precision and model bias. Bootstrap results suggest that r, MSY and F_{MSY} were relatively well estimated(relative interquartile ranges were <16%, and bias was <4%). Estimates of K, B_{MSY}, and q's were moderately precise (relative IQs were 20-32%, bias was <8%), and B_1 was not as precisely estimated (relative IQ=43%). The ratio of F/F_{MSY} in 2002 was estimated with moderate precision(relative IQ = 30%, bias = -3.44%.). Similarly, $B \backslash B_{MSY}$ in 2002 was estimated with moderate precision. (relative IQ =36%, bias = -9.12%)

8.0 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 11, 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_{∞}=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 11). 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 Fs well below 0.6.

The survey index of age-1.5 shrimp biomass appears to be correlated to the biomass index of females from two years previous (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. Prior to 2001, 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 last three years average spawning stock index was 2.5 kg/tow. Prior to 2001 all cohorts produced by spawning indices of 3kg/tow or less were below average. However in 2001, the below average SSB of 2.8 kg/tow produced an exceptionally high recruitment index. Based on this it is currently difficult to estimate a SSB/R relationship that is representative of this stock (see SARC36 Working Paper C3).

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.

As noted above, reference points based on SSB/R are problematic, as are extensions to MSY based metrics. The use of proxies (such as periods of "stability") are being examined in the development of control rules (see SARC36 Working Paper C2 and Figure 20a). However, it is apparent that the choice of the stable period (and the stock status during that time) influence what becomes the M (maximum) of MSY based reference points. Additionally, if the stock has been reduced far enough below a sustainable level, there may need to be an extended period of time for recovery to allow any level of future stability. Further discussion on this point can be found in (see SARC36 Working Paper C3).

9.0 Recommendations and Findings

9.1 Evaluation of current status

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, and 1998 year classes.

In 2003, the 1997 year class will have passed out of the fishery, and the very weak 1998 year class (assumed 5-year old females), moderate 1999 year class (assumed 4-year-old females), virtually absent 2000 year class (assumed 3-year-old males, transitionals, and early-maturing females), very strong 2001 year class (assumed 2-year-old males, transitionals, and early-maturing females), and unknown 2002 year class (juveniles) will remain.

Exploitable biomass as estimated from CSA declined from 15,500 mt in 1995 to a time series low of 5,700 in 1999. Since then the biomass estimate has risen to 9,200 mt in 2002, as a result of the appearance of the moderate 1999 year class and the strong 2001 year class. This estimate is still well below the time-series average of 13,000 mt, and below the average of the 1985-1995 period of 17,000 mt (Table 8a). The estimate of spawning stock biomass (Figure 22a, arrow labeled “03”) is also still well below the time-series mean.

9.2 Research Recommendations

- The potential for improving estimates of mortality, abundance, and biomass from historical fishery and survey data from the 1960’s should be investigated for further guidance on appropriate biological reference points.
- Development of a time series of standardized effort would help to corroborate patterns of estimated F. Such analyses depend on completion of audits, processing of vessel logbook data, and estimation of data not included in logbooks (Maine small vessel fleet before 2000).
- Methods for age determination from length and ontogenetic stage information should be investigated to develop the possibility of using age-based assessment methods.
- A standard set of non-random stations have been sampled during the northern shrimp survey since 1994. When an adequate time series is achieved, catch data from these stations should be incorporated into survey indices of abundance and biomass.
- Estimates of fecundity at length should be updated, and the potential for annual variability should be explored.
- NEFSC fall trawl survey data should be segregated by day/night and analyzed for differences.
- The appropriate weighting of port sample data for estimates of mean weight should be investigated.
- Growth, survival, sex transition, fecundity, and migration in response to environmental conditions and population density should be evaluated.
- A better understanding of juvenile life history is needed.
- The implications of low male abundance should be investigated.
- Models that incorporate environmental variables and changes in life history parameters would be especially useful, if those signals are ever characterized better than they are currently.

ACKNOWLEDGMENTS

The Northern Shrimp Technical Committee thanks all those people who 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. In particular, we would like to thank the 1997-98 technical committee – Steven Cadrin, Daniel Schick, David McCarron, Stephen Clark, Michael Armstrong, Bruce Smith, and J. Brian O’Gorman. Much of the work presented here was developed by them (Cadrin et al, 1998).

10.0 SARC Comments

The CSA-estimated biomass of 9,200 mt is above the proposed biomass threshold of 9,000 mt, i.e. 50% of B_{MSY}. However, management advice based on the results of biomass dynamics models may not provide sufficient detail relative to the unique life history characteristics of the species. The SARC questioned the usefulness of a single reference point estimate when simple interpretation of empirical data (fishery-independent indices) may provide more reliable management advice. Progress was made in assessing stock status with models, but further work to develop objective decision criteria is needed.

The SARC was concerned that the natural mortality estimate (M = 0.25) used in the CSA approach is uncharacteristically low for a short-lived shrimp species. It was noted that the regression method estimate of M = 0.25 and the Z-based estimate of M = 0.17 derived when the fishery was closed in 1978 are less than or equal to the value currently being used. The calculated Z in 2002, a year of minimal fishing effort, is 0.25. The SARC suggested investigating alternative methods of estimating M, such as maximum expected lifespan, size-dependent mortality, life-history based approaches, and deriving Z from the ratio of female 2 to females 1 and female 2 in the previous year.

Although biomass estimates from the current assessment do not match historical estimates, this discrepancy was attributable to changes in empirical data, including correction of the 1987 summer trawl survey indices, and updating of the time series of catch data. Revisions were also made to partitioning of recruits and fully recruited shrimp. The SARC recommended that any changes made since SARC 25 need to be documented.

The SARC discussed the appropriateness of the method of determining F from the CSA harvest rate. The F generated by this method is a more precise approximation than the log-ratio method.

10.1 Sources of Uncertainty

- Natural mortality is poorly defined.
- Catch reporting is often late and incomplete.
- Northern shrimp are not consistently available to the NEFSC Autumn survey because of:
  a.) diurnal variation
  b.) migration patterns
  c.) egg-bearing females may have a more limited vertical migration pattern
- Growth, upon which YPR and EPR are based, is poorly estimated.

10.2 SARC Research Recommendations

- Further exploration of natural mortality assumption.
- Investigation of growth for improved calculation of YPR and SPR.
- Consider alternative estimators of F.

- Consider a two- rather than a one-stage control rule.
- Investigate survey selectivity.
- Explore alternative assessment models especially, statistical catch-at-length methods.
- Consider the potential for using length-frequency distributions for developing management advice.
- Explore utilizing the ratio of stage 2 to stage 1 females for estimating total mortality.
- Investigate the appropriate weighting of port sample data for estimates of mean weight.

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