D. ASSESSMENT OF DEEP SEA RED CRAB

Report of the Invertebrate Working Group

1.0 TERMS OF REFERENCE

The terms-of-reference (TOR) for deep sea red crab were addressed in this assessment:

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 in those estimates. If possible, also include estimates for earlier years.*

3. *Either update or re-estimate biological reference points (BRPs), as appropriate.*

4. *Evaluate current stock status with respect to the existing BRPs, as well as with respect to new or re-estimated BRPs (from TOR 3).*

5. *Recommend what modeling approaches and data should be used for conducting single and multi-year projections, and for computing TACs or TALs.*

6. *If possible,*
    a. *Provide numerical examples of short term projections (2-3 years) of biomass and fishing mortality rate, and characterize their uncertainty, under various TAC/F strategies and*
    b. *Compare projected stock status to existing rebuilding or recovery schedules, as appropriate.*

7. *Review, evaluate and report on the status of the SARC/Working Group Research Recommendations offered in recent SARC- reviewed assessments.*

2.0 EXECUTIVE SUMMARY

TOR 1: (*Characterize the commercial and recreational catch including landings and discards.*)

Deep sea red crab fishing, which is done with large square or conical traps, occurs year round in deep water along the continental shelf edge from the southern part of Georges Bank south to Cape Hatteras. Deep sea red crabs have been fished commercially since the 1970s, and reported landings since 1982 (excluding 1994, when there was no targeted red crab fishing) varied from a low of 466 mt (1 million pounds) in 1996 to a high of 4,000 mt (8.9 million pounds) in 2001. The number of boats participating in the fishery has varied from 3 to 22. Since the Deep Sea Red Crab Fishery Management Plan was implemented in 2002, making it a limited access fishery, landings have been stable at around 2000 mt (4.4 million pounds) and there were 4 vessels fishing in 2005. A small percentage of annual landings are bycatch from the offshore lobster fishery (section 3.2). There is no recreational fishery for deep sea red crab.

The deep sea red crab fishery is male-only, so all females and undersized males (generally < 90 mm carapace width) are discarded. Reported discards from VTR logs (from 10 to 50% percent of the catch with a mean of 32-35%) are considered somewhat unreliable because they are reported irregularly and often in units that differ from landings, but they are consistent with a mean discard rate of 29% estimated from a comparison of sea-sampled catch and landed crabs. The survival rate of discarded crabs is unknown (Section 4.5).

TOR 2: (*Estimate fishing mortality, spawning stock biomass, and total stock biomass for the current year and characterize the uncertainty in those estimates. If possible, also include estimates for earlier years*)

The main sources of deep sea red crab abundance data have been two camera/trawl surveys specifically targeting red crabs. The first survey was conducted in 1974 by the NEFSC using sled-mounted camera gear to count the crabs on the bottom and an otter trawl to catch, measure and sex the crabs (Wigley et al. 1975). A second survey, using comparable gear, was conducted between 2003 and 2005 as a cooperative research project (section 5.1).

Based on the ratio of landings and fishable biomass from the most recent survey, average (± 1SE) fishing mortality is estimated to be 0.055 + 0.008 y^{-1} during 2003-2005. These estimates do not consider potential discard mortality, which may be substantial (section 7.2).

During 1974, male red crabs with a carapace width (CW) of 114+ mm were considered the minimum marketable size. Biomass of male red crabs over 114 mm was estimated to be 23,800 mt (52.5 million lbs) at that time. The biomass estimate for these large male crabs in 2003-2005 (13,800 ± 1,334 mt or 30.4 ± 2.9 million lbs) was 42% lower, but the current fishery lands smaller crabs, with a mean size of about 105 mm CW. Fishable male biomass (including all sizes available to the recent fishery) was estimated to be 34,300 mt (75.5 million lbs) during 1974. The estimate for 2003-2005 (36,300 ± 5,459 mt or 79.9 ± 12.0 million lbs) was 5% higher. The size structure of the red crab population has changed over time, probably in response to fishing. The average male crab is smaller in size while the average female is the same size as in 1974, and young crabs of both sexes are relatively abundant (section 5.1).

The current estimated biomass of sexually mature female red crabs (70+ mm CW) is 67,900 mt (149.7 million lbs), and the estimate for sexually mature males (75+ mm) is 47,800 mt (105.4 million lbs). These estimates suggest increases of 244% for females and 29% for males since 1974 (section 5.1).

The overfishing status of red crab is unknown because no reliable estimate of F_{MSY} or its proxy (MSY) exists. According to the Deep Sea Red Crab FMP, overfishing occurs if male landings exceed MSY. Landings during 2005 were 2013 mt, which is less than the preferred estimate of MSY=2830 mt (6.24 million lbs) in the FMP.

TOR 3: (*Either update or re-estimate biological reference points (BRPs), as appropriate*)

Because very little is known about deep sea red crab biology, it is a fairly new fishery, and there have only been two red crab surveys in thirty years, it has not been possible to estimate any reliable BRPs. Until the time series of reliable landings data lengthens, and more is known about red crab growth and natural mortality, BRPs are likely to be unreliable (section 8).

TOR 4: (*Evaluate current stock status with respect to the existing BRPs, as well as with respect to new or re-estimated BRPs (from TOR 3)*)

Stock status relative to a threshold for biomass was not evaluated because a reliable BRP was not available. However, the deep sea red crab stock currently appears to be at a biomass level comparable to estimates from 1974 (section 9).

TORs 5 and 6: (*Recommend what modeling approaches and data should be used for conducting single and multi-year projections, and for computing TACs or TALs*) (*If possible, provide numerical examples of short term projections (2-3 years) of biomass and fishing mortality rate, and characterize their uncertainty, under various TAC/F strategies and compare projected stock status to existing rebuilding or recovery schedules, as appropriate)*

Several model-based approaches, including length based catch curves and surplus production models, were examined for potential usefulness during this assessment. It was not possible, however, to use length based catch curves because of uncertainty about growth and longevity of red crab. Production models were not used because of insufficient surveys and commercial catch rate (LPUE) data. This is an important topic for future research (sections 6 and 7).

TOR 6: (*If possible, provide numerical examples of short term projections (2-3 years) of biomass and fishing mortality rate, and characterize their uncertainty, under various TAC/F strategies and compare projected stock status to existing rebuilding or recovery schedules, as appropriate)*

This TOR was not completed because of a lack of data on red crab growth, recruitment, and natural mortality which precludes quantitative projections (sections 6 and 7).

TOR 7: (*Review, evaluate and report on the status of the SARC/Working Group Research Recommendations offered in recent SARC- reviewed assessments*)

The previous deep sea red crab stock assessment, completed in 1977, did not include research recommendations.

3.0 INTRODUCTION

3.1 Biological characteristics

The deep-sea red crab (*Chaceon quinquedens*) is a deep-water species of brachyuran crab (family *Geryonidae*) that inhabits the edge of the continental shelf and slope off the Atlantic coast of the United States. The species is distributed between 200 and 1800 meters from Emerald Bank, Nova Scotia (and into the Gulf of Maine) and along the continental slope of the east coast of the U.S. into the Gulf of Mexico (Fig. D3.1; Pequegnat 1970; Williams and Wigley 1977; Elner et al. 1987, Duggan and Lawton 1997). Off the southeastern states and in the Gulf of Mexico the red crab co-occurs with its congener, the golden crab, *C. fenneri* (Weinberg et al. 2003). Genetic analysis suggests that the northern population of *C. quinquedens* is distinct from the Gulf of Mexico population (Weinberg et al. 2003), however the location of the boundary between these two stocks remains uncertain. Curiously, this analysis also suggests that the genetic differences between these two populations of *C. quinquedens* are greater than the differences between the two congeners, raising important questions about the designation of morphological species and the evolutionary history of these groups. For the purposes of this assessment red crab between Cape Hatteras and the Hague Line were considered a single stock.

High numbers of red crab are found on mud, sand, and hard bottom between 320 and 914 meters, and water temperatures between 5-8° C (Wigley et al. 1975). Adult red crabs are somewhat segregated by sex; adult female crabs inhabit shallower zones than adult males. Furthermore, juvenile red crabs are found in deeper waters than the adults. From this pattern, Wigley et al. (1975) suggested a deep-to-shallow migration as crabs grow and mature.

As with other large-bodied decapods, red crabs are likely to grow quickly in their early years and then molt infrequently as they approach marketable size and sexual maturity. However, information on growth in the wild is scarce. In tagging studies currently under way since 2002, over 9000 crabs between 65 and 125 mm in size have been marked with tags that are retained through the molt. Of the 180 tag returns to date, only 11 crabs, mostly smaller ones, have shown any indication of growth. While these results are consistent with previous growth studies of this and other Geryonid crabs (Melville-Smith 1989), the data are insufficient at this time to parameterize a growth model for *C. quinquedens*. On the basis of very limited, mostly laboratory-based growth data, red crab are believed to require 5-6 years to attain a desired commercial size of 114 mm carapace width (4.5 inches; Van Heukelem 1983). Juvenile crabs grow faster in warmer water, and are estimated to require 18-20 molts over some 15 years before reaching their maximum size of 180 mm carapace width (Haefner 1978, Van Heukelem 1983). Red crabs are estimated to reach a maximum size of about 180 mm carapace width, and may live for 15 years or more (Serchuk and Wigley, 1982). Prior tagging studies, while documenting movement, provided almost no information on growth because the tags used were not retained through the molt (Lux et al. 1982). However, a few crabs were captured in that study that retained their tags for more than five years, underscoring the long intermolt periods.

Male red crabs are estimated to mature at about 75 mm carapace width and can reach a size of 180 mm, a weight of nearly 1.7 kg; females begin to mature at a somewhat smaller size, and do not grow as large, reaching a maximum carapace width of about 136 mm and 0.7 kg (McElman and Elner 1982). The reported size of ovigerous female crabs varies from 80-91 mm carapace width (Haefner 1977), 80-130 mm (Wigley et al. 1975; Haefner 1977) and some as small as 61 mm (Elner et al. 1987). It is possible spawning may not occur annually if mating only occurs during molting. Mature females are estimate to have intermolt periods as long of 5-7 years (Gerrior 1981; Lux et al. 1982). On the other hand, it is possible that females store sperm and are able to fertilize more than one clutch of eggs between molts, as has been observed in lobsters (Flight et al. 2004).

Mating behavior is typical of other crabs, where the larger male crab forms a protective "cage" around the female while she molts and becomes receptive to copulation. In red crabs this protective and copulatory period may last for as long as two to three weeks, substantially longer than most other brachyuran crabs (Elner et al. 1987). Where it has been possible from camera survey to measure the relative size of the male and female in mating pairs, the males have averaged about 50% larger than the females (Bergeron and Wahle in prep.). If males are only competent to mate when they are larger than females, recent evidence that the fishery may be depleting large males (Weinberg and Keith 2003) may be reason for concern over the potential for fishery impacts on the reproductive capability of the population.

Female deep-sea red crabs brood their eggs *en masse* under the abdominal flap for up to nine months, until the larvae hatch and are released into the water column (Haefner 1978). Egg bearing females are found year-round off New England with a peak in November. The large yolky eggs hatch between January and June. As in other decapods, the fecundity and reproductive output of red crab eggs scales with female body size (Hines 1988). However, red crabs are notable for their relatively heavy investment in egg production: clutch mass as a percent of female body mass is substantially greater than in other brachyuran crabs of comparable size (Hines 1988). Red crab eggs are also among the largest of brachyuran eggs; although there is a trade-off in fecundity as a consequence (Hines 1988).

Information on the biology and distribution of red crab larvae and postlarvae is scant. Laboratory rearing studies suggest that red crab larvae may require 23-125 days to settle (Kelly et al., 1982). Larval settlement is believed to occur near the base of the continental slope (Roff et al. 1986). Recruitment to the benthos is thought to be episodic with potentially long intervals between successful cohorts (Hines 1990 cited in Hastie 1995).

There is also very little information available on the red crab habitat requirements. Nonetheless, essential fish habitat (EFH) for red crab has been defined for each life stage of this species (eggs, larvae, juvenile, adult and spawning adult) (Steimle et al. 2001). Overall, both the water column and bottom habitats above the continental shelf between depths of 200 and 1800 meters have been defined as EFH for one or more life stages of red crab (Figure D3.1). Red crab EFH is not considered to be "vulnerable" to the effects of fishing gear, and the impacts of gear used in the red crab fishery on EFH of other species is considered to be minimal and temporary in nature.

3.2 Fishery characteristics

During the 1960s and 1970s, the deep-sea red crab resource was considered underutilized, and several vessels began experimenting in the early 1970s to develop a deep-sea red crab fishery in this region. The directed red crab fishery is entirely a trap fishery. The primary fishing zone for red crab is at a depth of 400-800 meters along the continental shelf north of Cape Hatteras, NC and south of the Hague Line. Fall River, MA is the primary port for all red crab landings and all red crab are currently processed at one facility in New Brunswick, Canada. Red crabs are sold by the processor to several large food chains, primarily as generic crabmeat and cocktail claws. Landings since the Red Crab Fishery Management Plan (FMP) and limited entry were implemented in 2002 have been stable at around 2000 mt (4.4 million pounds), with four vessels currently fishing.

On the basis of a comprehensive targeted camera and trawl survey conducted by the NEFSC in 1974 (Wigley et al. 1975), Serchuk (1977) provided preliminary estimates of maximum sustainable yield for red crab at approximately 2700 metric tons (5.9 million lbs.), about ten percent of the estimated standing biomass of commercial sized crabs (≥114 mm) at that time. Annual landings from the late 1990's to 2001, prior to implementation of the FMP, averaged around 3200 metric tons (7 million lbs.). If Serchuk's estimates are correct, the resource would be fully exploited at that level of fishing effort. However, these estimates are based on standing stock estimates nearly three decades old. The present stock assessment utilizes the results of comparable series of surveys conducted between 2003 and 2005 as part of a cooperative research project supported by the Northeast Consortium.

Since implementation of the FMP in October 2002, reporting of red crab landings has improved, and all vessels that land red crab are now required to report total landings by trip. Ex-vessel revenues are estimated to be about $4-5 million dollars a year, and the four vessels involved in this fishery have a very high dependence on the red crab resource.

The average length of vessels prior to the FMP was 105 feet, ranging from 72 to 150 feet in length. Since implementation of the FMP none of the vessels have upgraded length, tonnage or horsepower. One of the four active vessels uses a rectangular wooden trap, and the other three vessels use a conical trap.

3.3 Relevant fishery management measures

The limited access program for the directed red crab fishery currently operates with a target TAC of 2688 mt (5.928 million pounds) and a 780 days-at-sea allocation. Other management measures include trip limits, limits on the number of traps permitted per vessel, a prohibition against harvesting female crabs, and other measures.

4.0 FISHERY DATA

4.1 Commercial landings

Red crab landings from dealer reports during 1982 to 2005 have varied without trend, from a low of 450 mt (1 million pounds) in 1996 to a high of 3990 mt (8.8 million pounds) in 2001 (Table D4.1). Dealers reported only 250 kg (560 pounds) of landings in 1994, however, and current industry members report that targeting red crabs temporarily stopped in 1994. Landings in 2003-2005 were between 2040 and 1900 mt (4.2 and 4.5 million pounds). Red crab landings are primarily from specially designed crab traps (Table D4.2), although some landings occur as incidental catch in offshore lobster traps. Unadjusted ex-vessel prices have risen from $0.44-0.57 in 1982-1999 to $0.90 in 2005.

According to dealer reports (Table D4.1), 50-150 trips landed red crab each year prior to 2003. After 2003, the number of trips declined to 63-77. Average landings per trip were between 40 and 84 thousand lbs. (18-38 mt) during 1982-1991 (Table D4.1), declined to between 7 and 22 mt (15,000 and 48,000 pounds) during 1992-1997, and varied without trend during 1998-2005 between 23 and 30 mt (51 and 67 thousand pounds). Landings since the 2002 FMP was approved are constrained to 34 mt (75,000 pounds) per trip, averaging from 25to 32 mt (56 to 70 thousand pounds), including a few trips landing red crab as incidental catch.

Vessel Trip Report (VTR) logbooks are an important source of information about the commercial fishery during 1994-2005 (Table D4.3). A small fraction of total landings was reported via VTR logbooks prior to 2002. VTR data coverage has been gradually improving, however, and included 82-85% of landings in 2004 and 2005 (Table D4.3).

Canadian landings are low compared to those in the US. Landings of 623,000 lbs (283 mt) in 1996 declined to 11 mt (25,000 pounds) by 1998, increased to 57 mt (126,000 pounds) in 2001 and then declined to 24 mt (53,000 pounds) in 2004 and 21 mt (47,000 pounds) in 2005 (D. Pezzack, Canadian Department of Fisheries and Oceans, pers. comm.).

4.2 Spatial distribution of landings

Survey strata defined by Wigley (1975) are the primary spatial unit used in this stock assessment (stratum A in the south to stratum D in the north, Figure D4.1). Most recent landings originated from the four limited access vessels that report landings via VTR logs. They include the average latitude and longitude of the area fished during each trip. Each red crab trip generally occurs in a relatively confined area, with the vessel setting roughly six trawls of around 100 traps per string. Reported latitude and longitude (with the exception of reporting mistakes) are useful for assigning landings to survey strata. Industry members report that fishing locations outside the survey strata are errors, rather than real fishing locations. Trips with mis-reported locations were assigned to the closest stratum for further use in the assessment.

US landings in 2003 and 2004 from the four limited access vessels using the VTR system are assigned to survey strata in Table D4.4. These data accounted for 55 trips in 2003 and 64 trips in 2004 (some trips had no latitude or longitude values), accounting for 1400 and 1540 mt (3.1 and 3.4 million pounds) of landings, respectively. Half of the landings on these trips were caught in Stratum C. Stratum D had the next highest reported catch and 14 trips.

Since 2001, trips were generally well distributed along the shelf break and in all four survey strata (Figure D4.1). During 2001-2005, trips in stratum D were concentrated along the southern edge of Georges Bank but fishing also occurred further east along the SE edge of Georges Bank during the late 1990s (Figure D4.2).

The names of vessels harvesting red crab are replaced in this report by codes (B-E for the four boats currently active) to enhance confidentiality. The four currently active vessels tend to fish in relatively discrete offshore areas, along a relatively narrow strip along the outer edge of the continental shelf (Figure D4.2).

Trips by Canadian vessels are generally fished on the SE part of Georges Bank, east of the Hague Line and on the southern portion of the Scotian Shelf, west of 62°30’ W longitude along the 200m isobath (D. Pezzack, Canadian Department of Fisheries and Oceans, pers. comm.).

4.3 Fishing effort

Dealers provide the longest time series of fishing effort data, but it is only useful for examining the catch per trip, since the reporting of days absent by port agents was discontinued in 1994. More importantly, different sets of vessels were present in the fishery before 1994 (Figure D4.3). Changes in technology and regulations, as well as changes in vessel ownership and fishing behavior (reported to have occurred by industry members), may have also have affected catches and trip length. Industry members saw signs of these changes in vessel ownership and operation in the VTR-based LPUE data from the early to mid 1990s.

Excluding vessels that appeared to be landing red crab as incidental catch, the average catch per trip was 23-68 mt (50,000 to 150,000 pounds), depending on vessel and year. After 1994, the average catch per trip for a vessel was 23-45 mt (50,000 to 100,000 pounds) and since 2002 has averaged about 23-27 mt (50,000 to 60,000 pounds). Since the FMP implementation in 2002, the catch is limited to 34 mt (75,000 pounds) per trip by regulation, except for one vessel that qualified for a 57 mt (125,000 pound) live weight trip limit.

Although the time series is shorter than the dealer reported landings data, VTRs provide a more reliable measure of trends in LPUE. Catch per day at sea (DAS) can be derived by computing the difference between the date sailed and the date landed, which usually corresponds to when the vessel leaves the dock and when it arrives in port. Trends in landings per DAS by trip since 1995 for the four limited access vessels are shown in Figure D4.3.

Vessels also report the amount of gear fished via VTRs. The four limited access vessels in the LPUE time series typically fish 100 traps per string (trawl) and six strings per day. Some fish about 180 traps on three strings.

The VTR data were carefully reviewed to determine what gear information had been reported on each trip to calculate the number of trap hauls on a trip. VTRs contain three fields which indicate the amount of gear a vessel fishes on a trip, GEARQTY, GEARSIZE, and NHAUL. These fields can be difficult to interpret because the vessels do not report these variables in the same way and some have even changed what they report during the time series. Applying knowledge about how the vessels fish allows proper interpretation of the data and corrections where necessary. Typically, GEARQTY is reported as the number of traps on a string, but sometimes represents the total number of traps fished in a day. GEARSIZE is typically the number of strings (trawls) fished in a day. NHAULS is usually the total number of strings fished in a trip, but is sometimes reported as the number of traps fished per day. The data in these fields, while reported inconsistently, are easy to interpret for calculating the total number of trap hauls, once the type of information being reported is understood. The current vessels in the fishery typically make daily hauls of their trap strings and generally make about 2500 to 4500 individual trap hauls per trip, except for broken trips that can be identified by low landings.

4.4 Trends in nominal and standardized LPUE

Nominal LPUE

Prior to plotting trends, to enhance confidentiality, nominal landings per unit effort (LPUE) for individual vessels (either landings per DAS or landings per trap haul) were normalized to mean zero and unit standard deviation. Normalized trends in landing per DAS for each vessel were computed using data for quarters 3 (Jul – Sep) and 4 (Oct – Dec). Quarters 3 and 4 were chosen to standardize the data, because this is when the catch rates were highest and when most of the vessels targeted red crab. Vessel C tends to fish year around and has a substantial number of trips in quarters 1 and 2. The LPUE data for this vessel was standardized to the mean catch over the entire year. Outliers in the data were corrected for obvious errors or omitted if they could not be corrected and were substantially outside the normal range.

Trends in catch per DAS are shown by vessel in Figure D4.4. Catch rates per DAS in quarters 3 and 4 (the peaks in catch per DAS for vessels B, D, and E) appear to be declining slowly from 2001 to 2005. Catch per trap haul, on the other hand, declined in 2003, but then increased in 2004 and 2005 (Figure D4.5). These trends however may be deceptive if the geographic distribution of trips changes and the catch rates are more representative of localized availability than of trends in exploitable biomass.

The geographical distribution of landings per trap haul for each vessel is shown in Figure D4.6. The geographical distribution of catch per trap haul by quarter is shown in Figure D4.7. Most of the catch in strata A, B, and C is taken in quarters 3 and 4, but a large fraction is also taken in quarters 1 and 2 in Stratum D. For this reason, trends in average normalized catch rates are compared for all quarters in Stratum D, but only quarters 3 and 4 in the other strata.

The catch rates in Stratum A have generally declined since 2001 (Figure D4.8). Vessel E was the primary vessel fishing with reported trips in the stratum. Catch per DAS was lowest in 2004 and increased in 2005, whereas catch per trap haul has declined continuously from 2003 to 2005.

The catch rates in Stratum B were highest in 2002 and lowest in 2003 (Figure D4.8). The average catch rates increased in 2004 and 2005. The trends for Stratum B are based on a low number of trips, however. Vessel E reported 4 trips in 2002-2004 and Vessel B reported 6 trips in 2005.

Most trips in Stratum C are reported by Vessel D. Catch rates were lowest in 2001, reached a peak in 2002 and have since declined in 2003 and 2004. Catch rates increased in 2005.

Vessel C fished most frequently in Stratum D and has the longest time series of VTRs. Catch rates in the mid 1990s were relatively high, dropped to a low level in 2000, reached a peak in 2002 and then declined through 2004 (Figure D4.8). A small increase in catch rates was observed in 2005.

In all four strata, catch rates were generally highest in 2001 or 2002, declined in 2003 and 2004, then recovered a bit in 2005.

Standardized LPUE
Generalized Linear Model (GLM) analysis was used to standardize LPUE from VTR data for 2001-2005 because data for 2001-2005 are most complete and reliable. Log-transformed LPUE (calculated from the days absent and catch per trip information provided in the Vessel Trip Reports) were standardized in a Generalized Linear Model (GLM) using year, vessel, quarter, statistical area and quarter-vessel interaction effects. All these effects were significant (Appendix D2). The most influential variables were quarter, vessel, and year (Figure D4.9). Residual analysis (Figure D4.11) suggests good model fit.

Standardized LPUE data show some evidence of declining catch rates during 2001-2005 (starting with 2001, the average standardized catches per haul were 8.1, 9.4, 6.8, 6.3, and 7.5 kg, figure D4.10) but the time series is too short to measure trends with confidence. In subsequent years, as the time series lengthens, the standardized LPUE will become a better indicator of the stock status.

4.5 Discards

Discards reported in VTRs
Vessels generally discard female and unmarketable size male crabs. Some vessels report the amount of discards on their VTRs. The amount of discards as a proportion of the total reported catch varies greatly from vessel to vessel, and even between trips for one vessel. Some vessels report no discards in a fishery where discarding of crabs is commonly practiced. The total reported discards in Table 4.6 from VTR logs are therefore considered unreliable but may represent a minimum estimate of total discards.

Three of the limited access vessels appear to report discards fairly consistently. Based on data from these vessels, discards in the second quarter of the year appear to be somewhat higher than at other times of the year (Figure D4.12). Discards as a fraction of the catch for vessels B and C, were about 20 to 50% during the first and third quarters, with a mean value of about 32 to 35%. The proportion discarded by vessel C was about the same in quarter 4, but was only 10-30% for vessel B. This may reflect differences in discrete areas fished by individual limited access vessels (see discussion below). The proportion of crabs discarded by vessel D was lower than either vessels B and C, except during quarter 2, which may be anomalous because discards were reported on only two trips, or because discards are reported in different units than landings.

Discards based on sea- and port-sampling
Size (CW) composition data from sea samples and port samples were compared to evaluate potential discard of female and undersize male red crabs in the fishery during 2004-2005. Sea sample data were collected by a crew member on board one red crab fishing vessel that participated in a pilot program during 2004-2005. Sea samples were records of all red crabs in roughly one pot per trawl that were sexed and measured (carapace width to the nearest mm) at sea before any discard took place.

Port sample data (sex and size of landed red crabs) were collected from landings by port agents. Port samples from both years were assigned to a survey stratum based on the statistical area reported by the vessel for the location of the catch. Port sample records for statistical areas that were not from strata where sea samples were taken were excluded from the analysis.

During 2004, there were sea sample data from eight commercial trips in survey strata C and D. During 2005, there were sea sample data from six commercial trips from survey strata A, C and D. Sea sample data for 2004 were from quarters 3 and 4. Sea sample data for 2005 were from quarters 1 and 4. Port samples were from all 4 quarters in both years.

Size frequencies of all male red crabs from both sea and port samples were plotted together for comparison. Female size composition data were plotted separately (Figure D4.13). The data show that proportions of small male red crabs were higher in sea samples than in landings.

Based on visual inspection of the size composition data, male crabs smaller than 90 mm were assumed to be discarded. From 90 mm to 95 mm, half of the males in sea sample size composition data were assumed discarded. All females were assumed discarded. The potentially discarded and kept portions of the sea sample catch were converted from numbers to weight using sex-specific size-weight relationships (Farlow, 1980 cited in Steimle et al. 2001) so that discard ratios could be calculated in terms of numbers and weight. The potential discard ratios (Table D4.5) were calculated as discard divided by the total catch (males plus females).

The high level of potential discards for stratum C in 2005 is due to the large percentage of females caught there. The previous year in the same sector many unmarketable small males were caught. These data seem to illustrate the seasonality and variation in discards.

4.6 Trends in commercial size-frequency

Port agents sampled 71 trips and measured 5,954 red crabs during 2001-2005 (Table D4.6). In contrast to VTR data, port agents assigned sampled trips to three-digit statistical areas, instead of latitude and longitude. In this analysis, statistical areas for port sample data were linked to survey strata according to the following table:

Statistical areas	**Survey stratum**
622, 627	A
538, 616	B
526, 537	C
525, 562	D

Most of the trips and crabs sampled were caught in statistical areas associated with strata C and D. Only three trips were sampled in 2004 and 2005 from stratum A. Nine trips were sampled in 2004 and 2005 from stratum B, plus one trip sampled in 2001.

Cumulative size distributions for all areas combined (Figure D4.14), show a trend towards landing smaller red crab during 2001-2005. With the exception of 2004, crabs landed each year were generally smaller than during the year before. The apparent trend for all areas combined may have been driven by relatively few samples in the Mid-Atlantic region because no trend is evident in samples from the Georges Bank region (Figure D4.14). Changes in culling, landings of female crabs, changes in location fished, or sampling bias may also be responsible. Plots of mean size by year for each survey strata do not show trends over time during 2001-2005 (Figure D4.15).

In summary, the data provided by the fishery is extremely valuable when it comes to the management and assessment of red crab, and provides several ways of monitoring the condition of the population. Spatial distribution of fishing effort, landed crab size frequencies and LPUE are all possible to analyze on an ongoing basis through the data provided by the VTR and port sampling programs.

5.0 FISHERY INDEPENDENT DATA

This section summarizes all available fishery independent survey data for red crab. Survey data useful for red crab included those specifically targeting red crab, as well as groundfish and shrimp surveys that caught red crab incidentally.

Targeted surveys were first conducted in 1974 by NEFSC using sled-mounted camera gear and an otter trawl (Wigley et al. 1975). A comparable survey was conducted between 2003 and 2005 in a cooperative research project supported by the Northeast Consortium and led by industry-scientist partners, Jon Williams (Benthic Fishing Corp.) and Richard Wahle (Bigelow Laboratory for Ocean Sciences). The more recent surveys were conducted for the express purpose of assessing changes in crab abundance on the fishing grounds after approximately three decades of harvesting.

Non-targeted surveys include, (1) the winter, spring and fall NEFSC groundfish bottom trawl surveys, (2) the NEFSC shrimp survey, (3) the NEFSC Cooperative Monkfish survey, and (4) the Rutgers Supplemental Finfish (transect) survey.

The information presented from these surveys includes, where applicable, location of survey catches, crab densities per unit area, catch per tow, proportions of positive, and size frequency distributions. Where it is relevant to the assessment, data are presented by survey, season and sex.

5.1 Camera/otter trawl surveys

The camera and otter trawl surveys originally conducted in 1974 and repeated in 2003, 2004, and 2005 provide an opportunity to compare the red crab population before and after a period of sustained targeted exploitation for more than two decades. As much as possible an effort was made to pair camera and net tows at each survey site. Camera surveys provided estimates of population density and otter trawls provided data on sex, size, and maturity.

The 1974 surveys were conducted from the R/V *Albatross IV*, a 57 m (187 ft) research vessel operated by the National Marine Fisheries Service, Northeast Science Center. The more recent surveys were conducted from two different fishing vessels, the 96 foot F/V *Hannah Boden* and the 90 foot F/V *Krystle James*, both of which are engaged in the deep sea red crab fishery.

The locations of the camera and net tows conducted. in 1974 and in 2003-2005 are shown in Figure D5.1. The overall sampling effort spanned a segment of the continental shelf break from offshore Maryland to the eastern end of Georges Bank. Survey results are partitioned into seven depth intervals and four geographic sectors originally established by Wigley et al. (1975). The distribution of camera tow and otter trawl sampling effort by depth and sector is tabulated for all years (Table D5.1).

Specifications of the camera-sled systems and otter trawls employed in the two surveys are summarized in Table D5.2 and details of the methodology follow.

Camera-Sled System

Photographs were used to determine the density (numbers per unit area) of red crabs and associated fauna. The photographic system in both surveys was mounted on a benthic sled. The sled used in the more recent survey was somewhat smaller than that used in 1974 primarily because of constraints imposed by the smaller size of the vessels. As a result there were some unavoidable differences in the area of sea bed sampled by the two systems (Table D5.1). In both cases during preliminary trials in shallow water, a grid with known intervals was placed level on the sea floor in front of the camera to determine the area of illumination in the image. During image analysis only the best-lighted and unobscured areas of the photograph were used, and crab densities calculated for individual images were thus corrected accordingly.

The camera system used in 1974 consisted of a 70 mm Nikon film camera and stroboscopic light (see Theroux 1976, Wigley et al. 1975 for details). The camera was aimed perpendicular to the sled at a height of 1.75 m and a downward angle of 16 degrees from horizontal. In that position the camera viewed a total area of 148 m^2 although the effective area sampled (illuminated) was 31.8 m^2 (Theroux 1976, Patil et al. 1979). The system was programmed to take photographs every 10 sec; at a speed of 2 knots a photograph would be taken approximately every 10m and a 30 minute tow provided approximately 180 images.

The system used in the 2003-2005 surveys consisted of a Nikon Coolpix 990 digital still camera modified with a programmable intervalometer and computer interface software designed by Engage Technologies. The camera was housed in a deep-sea titanium housing and was coupled to a Benthos model 382 strobe (on loan from the National Undersea Research Center at the University of Connecticut). The camera was aimed perpendicular to the sled at a height of 1m with a downward angle of 35 degrees. In that position the camera viewed a total area of 10 m^2 and an effective illuminated area determined to be 6.6 m^2. This was determined using a grid subdivided into 0.01 m^2 squares placed horizontally on the sea bed in front of the camera. The system was programmed to take photographs every 15 sec; at a speed of 2 knots a photograph was taken approximately every 14m, a 30 minute tow resulting in about 120 images.

For surveys in both 1974 and 2003-2005, it was important to determine if the oblique orientation of the camera relative to the sea bed may have resulted in under-estimates of abundance because of crabs avoiding the sled in the foreground or not being detected in the background. It was only possible to evaluate this question for the 2003-2005 surveys because the photographs from the 1974 were not available. In the case of the 2003-2005 surveys, it was possible to determine if crabs were more abundant in the foreground or background areas of the photograph. A subset of 141 randomly selected photographs from the 2005 surveys was examined, all photographs containing one or more crabs. The 6.6 m^2 illuminated area of each photograph was divided into equal 3.3 m^2 foreground and background sub-areas in which crabs were counted. The null hypothesis that crabs were as likely to be present in the foreground as the background areas was tested with a simple χ^2 statistic. Crabs occurred with significantly greater frequency in the background (79% of the time) than the foreground sub-areas (34% of the time; χ^2 contingency analysis: $\chi^2 = 49.06$, df = 1, $p < 0.0001$). This result suggests crabs may have been avoiding the oncoming sled, and that the resultant density estimates may be too low.

It is possible that population estimates from the 1974 survey would be subject to the same bias, although perhaps to a lesser extent given the larger area photographed. However, it is also possible that the larger area sampled in the 1974 photographs (31.8 m^2 versus 6.6 m^2 in 2003-2005) might cause smaller red crabs to escape detection at the margins, and in turn, result in underestimates of abundance. Unfortunately, materials from the 1974 survey that might be used to evaluate this hypothesis were lost. NEFSC staff searched files and storage facilities for information about calculation of red crab densities during the 1974 camera/bottom trawl survey. Some related materials (originally the property of Roger B.Theroux) were found but no survey photos or information about processing of photo images was recovered.

Otter trawl

Net trawls were used in both surveys to collect crabs for the purpose of determining size, sex and shell condition. The nets used in the two surveys were virtually identical; specifications are listed in Table D5.2. Once the net was deployed, it was towed at 1.5- 2.0 knots for 30-45 min. The scope (wire length to depth ratio) used during the 2003-2005 surveys was consistent with that employed during the 1974 surveys (Theroux pers. comm.): it varied between 1.5 and 3 depending on depth and conditions. In the more recent surveys no net tows were conducted at depths greater than 500 fathoms (914 m) because of insufficient wire to tow successfully at those depths.

Catch numbers were standardized to catch-per-30-minute-tow. Catch-per-tow was not found to correlate strongly with the density estimate from the camera tows at the same sites ($r^2 = 0.06$); therefore catch per tow was not regarded as a reliable indicator of abundance. Otter trawl data, however, were a valuable source of information on crab size and sex composition. The sex and size composition data were used to parse density estimates from the camera survey.

Differences in results among the four surveys carried out during 2003-2005 (June, August 2003, June 2004, and June 2005) may have been due primarily to sampling errors. For use in computing recent abundance and fishing mortality, data from surveys during 2003-2005 were combined by averaging the stratum and depth specific estimates available from each individual survey. Standard errors were computed based on the four survey-specific estimates. This approach treats the individual survey estimates (rather than individual camera sled tows) as the experimental unit. Standard errors and CV's for biomass and abundance estimates calculated in this way will be relatively high because the number of observations (4) is lower than the number of camera sled tows.

Density and Abundance Estimates by Sex and Size

Figure D5.2 provides an overview of the approach whereby crab densities from camera tows and sex and size composition from net tows enabled estimates of numerical abundance and biomass. Biomass density was determined slightly differently in the two surveys. In Wigley et al. (1975), biomass density was determined by dividing the total weight of the otter trawl catch by the number of crabs in the catch to give an average weight per crab. Biomass density for a given geographic stratum is the product of numerical density and the average weight of crab in the catch.

In the 1974 survey, commercial crabs were defined as crabs of both sexes $\geq$114 mm carapace width, the marketable size at the time. Wigley et al. (1975) did not make a distinction between male and female crabs in estimating standing crop biomass. However, detailed data from otter trawl tows in the 1974 survey were available (Murray 1974) and it was possible to use the otter trawl size and sex data to prorate total abundance and biomass by size and sex.

Sex-specific size-weight relationships (Farlow 1980 cited in Steimle et al. 2001) were used in calculating biomass in the 1974 and 2003-2005 surveys:

$$\text{Males:} \quad \log W = 3.0997 \log(L) - 0.59763$$

$$\text{Females:} \quad \log W = 2.75225 \log(L) - 0.34986$$

where L is carapace width in cm and W is body weight in grams. Using these relationships, it was possible to convert numerical densities for any size group of crabs to biomass density.

To calculate numerical and biomass standing crop, densities were multiplied by estimates of the area of sea floor in each stratum at and depth interval. These areas in hectares (ha) were deduced from Wigley et al. (1975) by dividing the reported abundance estimate by the density estimate for each depth-sector stratum (Table D5.3).

The depth range over which densities and standing crop are estimated is 125-500 fathoms (229-914m). At greater depths net tows were unreliable and no harvestable crabs were found either in 1974 or in the more recent surveys. In strata where no tow data were available the mean value for that depth was used as a proxy value from which to calculate standing crop.

Size and Sex Composition

In 1974 a total of 795 female and 641 male crabs were collected by otter trawl. Between 2003 and 2005, 4602 female and 2209 male crabs were collected. The overall size compositions for the 1974 and 2003-2005 surveys are presented by sex in Figure D5.3. Size and sex composition differed in the two surveys in important ways. Although the overall size range and catch-per-tow of crabs from the two surveys was similar, the number of large male crabs was substantially lower in the more recent surveys than in 1974. The size composition of females differed much less dramatically, with the current size mode of female abundance falling within the same range is it did in 1974. Also apparent in the 2003-2005 size distribution is a greater proportion of crabs of both sexes in the 50 to 80 mm size range. The apparently higher abundance of these small crabs may have been due to good recruitment. It is unlikely the differences in the size composition of crabs between the earlier and more recent surveys were due to differences in the selectivity of the nets. The nets in the two surveys were virtually identical and they were towed in the same manner. Appendix D3 contains proportions at size and sex for each depth-sector stratum that contributed to estimation of density and standing crop.

Density and Abundance Estimates

Estimates of red crab biomass from the 2003-2005 surveys were compared to estimates from earlier surveys conducted in 1974. Biomass estimates are given for the following groupings of crabs: all crabs, male crabs ≥114 mm (commercial by 1974 standards), fishable crabs by current standards, as well as sexually mature crabs of both sexes. Tables provided in Appendix D4 summarize the data from which the following analysis was derived; they give numerical density, biomass density, numerical abundance, and total biomass by depth and sector for the different size and sex categories of crabs.

Total red crab biomass is estimated to have increased by two-and-a-half fold since 1974, most likely because of the larger numbers of small crabs (Figure D5.4). Despite the overall increase in crab abundance, the biomass of crabs of both sexes ≥114 mm is estimated to be down by 27% (Figure D5.4), and this decline is primarily the result of a 42% decline in large males ≥114 mm (Figure D5.4).

The red crab fishery currently harvests crabs substantially smaller than what was considered marketable in 1974 (114+ mm). Therefore estimates of the biomass of crabs 114+ mm were compared to the estimated biomass of crabs currently vulnerable to the fishery based on fishery selectivity during 2003-2005 (in Section 7 of this report). Despite the estimated decline in very large males, under the current fishery, the biomass of fishable crabs is estimated to be about 5% higher than it was in 1974, although this value falls within 1 SE of the 2003-2005 mean (Figure D5.4).

The depth distribution of red crabs during the 2003-2005 surveys (all sectors combined) was considerably different than in 1974 (Figure D5.5). In the 2003-2005 surveys, crabs of all sizes were estimated to be somewhat less abundant in the shallow zones, but considerably more abundant in the deeper zones (Figure D5.5, top). Commercially harvestable males, both by the 1974 standard (114+ mm) and currently fishable standard, were estimated to be considerably less abundant in the shallower zones while their biomass was higher in deeper zones (Figure D5.5, middle & bottom panels).

Red crab distributions by sector, combining all depths, were also somewhat different than in 1974 (Figure D5.6). In the recent surveys total crab biomass was estimated to be considerably higher in all sectors except B, relative to 1974 levels (Figure D5.6 top). The biomass of fishable males was about twice the 1974 levels in sectors A and D, but fell below 1974 levels in sectors B and C (Figure D5.6 middle). The biomass of the larger males (114+ mm) was estimated to be below 1974 levels in all sectors except in D (Figure D5.6 bottom).

The biomass and distribution of reproductive male and female red crabs also appears to have changed since 1974 (Figure D5.7). For the purposes of this assessment the size of spawning females was defined as females equal to or larger than 70 mm CW based on observations of the smallest ovigerous females. In separate surveys the minimum size of ovigerous females has ranged from 61 to 80 mm (Wigley et al. 1975, Haefner 1977, Elner et al. 1987). Male red crabs may be physiologically mature at sizes less than 40 mm (Haefner 1977), but in camera surveys males observed in copulatory embrace have averaged about 50% larger in carapace width than females. This suggests males must be considerably larger than females to mate successfully. A previous report set the size of reproductive males at 75 mm (McElman & Elner 1982). This size designation seemed reasonable for the purposes of this stock assessment because it balances the uncertainty between physiological and functional maturity and is somewhat larger than the minimum spawning size used here for females.

The depth-wise pattern of spawning male and female red crabs (all sectors combined) has changed from the 1974 pattern in similar ways (Figure D5.7). Although the biomass of spawning female and male red crabs is estimated to have declined from 1974 levels in the 175-225 fathom depth stratum, the biomass of spawning females is currently estimated to be substantially higher at greater depths (Figure D5.7).

Reproductive crabs were also compared across sectors by combining data from all depths (Figure D5.7 bottom panels). In all sectors the biomass of spawning females was estimated to be more than twice as high in 2003-2005 as it was in 1974. Differences in mature male biomass among sectors (Figure D5.7 bottom right) were similar to that for harvestable males (Figure D5.6 bottom): it was estimated to be lower than in 1974 in sectors B and C, but about twice as high in sectors A and B.

Taken together, while the targeted surveys indicate that the population of red crabs in the entire survey area is substantially greater than it was in 1974, there is evidence of depletion of large commercial size males, especially in the shallow strata and geographic sectors B and C which may be subject to most intensive harvesting.

5.2 Non-targeted surveys

Table D5.4 shows sampling intensity of the four non-targeted surveys within the red crab survey strata defined by Wigley et al. (1975). Crabs in NEFSC/NMFS trawl surveys were not reliably identified to species prior to 1999; therefore only data collected since 1999 are presented. The Cooperative Monkfish surveys and the Rutgers Supplemental Finfish surveys began after the year 2000. Crab carapace width was measured to the nearest centimeter in these surveys.

NEFSC Groundfish and Shrimp Surveys

The winter groundfish bottom trawl survey and the summer shrimp survey in the Gulf of Maine, show the most promise for tracking trends in red crab abundance along the shallow edge of the species depth range. Because of the rarity of red crabs in the catch, indices based on proportion positive tows may be more useful than indices based on numbers caught (Figures D5.8 and D5.9). Other bottom trawl surveys provide information on red crab distribution and sizes but are not likely to be useful in tracking abundance.

The winter groundfish survey covers the shelf waters of Mid-Atlantic Bight and the southern part of Georges Bank, and the spring and fall surveys cover the entirety of Georges Bank and the Gulf of Maine as well (Figure D5.10). The spring and fall surveys complete over 300 stations a year. The first survey was in 1963, and the first recorded red crab catch was in 1967. A total of 2841 red crabs were captured during NEFSC groundfish surveys during 1967-2005. Total catch (combining surveys from all seasons) averaged 36 crabs per year with the occasional larger catch mostly attributable to one or two tows. After 2000, winter survey catches increased, which may be due to an increase in sampling intensity in deeper strata initiated in 2000 (Figure D5.9).

The northern shrimp survey has taken place once a year in the summer since 1983, and covers the Gulf of Maine, using a 4-seam commercial shrimp trawl. A total of 823 red crabs (an average of 36 a year) have been identified during shrimp surveys, which generally complete between 50 and 70 stations yearly.

- ***Proportion of positive tows:*** The proportion of positive tows (tows containing red crab) in a survey can be useful for detecting trends over time for an infrequently caught species like red crab (Mangel and Smith, 1990). Sampling has been consistent in NEFSC groundfish surveys since 2001, so positive-tow data from the same survey season in different years are directly comparable. Over the last five years the proportion of positive tows for red crab from the spring and fall surveys has stayed fairly stable or decreased slightly, while positive tows have increased in the winter surveys. The number of shrimp survey tows containing red crab has been stable except for a dip in 2004 (Figure D5.9).

Independent of season, red crabs are generally taken along the Mid-Atlantic Bight and southern New England shelf break as well as in the basins of the GOM (Figures D5.11-D5.14). The largest red crabs are generally found in the southern part of the survey, while some of the smallest are found in the GOM. Males and females are caught in the same places, but females predominate numerically comprising 70% of all NEFSC crabs that were sexed.

- ***Length frequencies:*** Length frequencies of all red crabs in the NMFS database suggest a reduction in the proportion of large males resulting in a decrease in their mean size, but little change in the size of females between 1996-2000 and 2001-05 (Figures D5.15 and D5.16). Survey length data for 1991-1995 may show a recruitment event. Females caught during the winter bottom trawl survey far surpassed any other catches in number, and it appears slightly larger crabs of both sexes may be caught during the winter.

NMFS Cooperative Monkfish Surveys

The area covered by the Cooperative monkfish surveys is much the same as the spring and fall NMFS ground fish surveys, but the catches of red crab are larger and more frequent largely because the monkfish survey was designed to sample deeper areas where the heaviest commercial fishing for monkfish occurs. The shelf drops off fairly quickly, so a tow a small distance further out can be in significantly deeper water.

Two monkfish surveys were conducted in early spring (Feb/Mar to May/Jun), one in 2001 and a second in 2004. They covered all of the Gulf of Maine, Georges Bank and the mid-Atlantic Bight (Figure D5.17). Data were available for the 2001 survey from 80 stations for which data had been processed to date for an area between Delaware Bay and the Great South channel. This represents a substantially smaller area than the 304 stations for which data were available from the 2004 survey.

The mean depth of tows in which more than one red crab was caught during the 2001 monkfish surveys was 428 m, considerably deeper than the mean depth for all NMFS groundfish surveys (290 m). The shelf break north of Hudson canyon to the Great South Channel is an area where the monkfish survey tows are noticeably denser and further offshore, and the large red crab catches there contrast with the sparse catches in the same area by the bottom trawl survey (Figure D5.17). Maps of the monkfish survey red crab catch by year, size category and sex (Figures D5.17-D5.21) are similar to maps of red crab catch by NEFSC bottom trawl surveys. In particular, females outnumber males, and larger females are found in the south. Size frequencies from the 2001and 2004 Monkfish surveys (Figure D5.22) show smaller red crabs in the Gulf of Maine.

Rutgers Supplemental Finfish (Transect) Survey

These surveys sample along a transect line moving from shallower to deeper water near four offshore canyons in the Mid-Atlantic Bight, generally completing 20-30 stations per cruise. Supplementary survey data are available from eight cruises, the first March 2003 and the most recent in March 2005. All cruises took place in January, March, May or November. The surveys are meant to track the seasonal offshore, onshore and along shore movement of finfish. Since red crabs are only recorded in kilograms per tow the data are limited, but the recurring sampling in the same locations makes these surveys potentially useful for looking at trends over time. Between 2003 and 2005 the weight of crabs per haul was greatest in the deeper tows and varied without trend (Table D5.5).

In summary, although the non-targeted surveys sample red crabs at the fringe of their depth range, they have the potential to act as an index of abundance, especially those surveys with a long time series of annual catch data.

6.0 NEW ESTIMATES OF BIOLOGICAL PARAMETERS

No new estimates of growth, maturity or natural mortality were developed in this assessment. Various length based approaches were applied to survey size data for red crab to estimate growth and maturity parameters. Results were uncertain and this area is an important topic for future research.

7.0 ABUNDANCE AND MORTALITY INFORMATION AND ESTIMATES

Camera/bottom trawl estimates of fishable biomass and landings data were used to estimate fishing mortality for male red crab in this assessment. Several more sophisticated model-based approaches, including length based catch curves and surplus production models, were examined also. It was not possible, however, to use length based catch curves because of uncertainty about growth and longevity of red crab. Production models were not used because of insufficient survey and commercial catch rate (LPUE) data.

7.1 Fishery selectivity

Fishery selectivity curves estimated in this assessment measure the relative probability that red crabs of different sizes will be taken in the fishery and landed. Fishery selectivity should be low for small red crab and should increase with size because small individuals are not marketable.

Fishery selectivity curves for deep-sea red crab were estimated in this assessment by comparing length composition data from port samples during 2004-2005 to length composition data from the camera sled/bottom trawl survey during the same years. In effect, the survey length composition data were used as length composition data for the population. The survey bottom trawl had a small mesh liner that increased retention of small individual red crabs so that they might occur more frequently in survey bottom trawl catches.

Fishery length data were originally in numbers of individuals measured per 1 mm size group by trip. Fishery length data from all trips in each statistical area and year were combined by addition. Survey length data were originally in numbers caught per standard 30 minute tow and 1 mm size group. Survey length data from all tows in each survey stratum and year were combined by addition. Commercial and survey length data were then aggregated by 5 mm size groups for subsequent analyses. Five millimeters is likely the range of measurement error in commercial length data for red crab.

Survey and commercial length composition data indicate that red crabs in the north are larger than in the south. There were differences in survey length composition data for 2004 and 2005, probably due to sampling error arising from relatively few survey stations. Based on preliminary analyses, survey and commercial length data were assigned to northern and southern regions and data for 2004 and 2005 were combined. The resulting length composition data were converted to proportions at length for further analysis.

For survey data, the southern region included strata A and B while the northern region included strata C and D. Regions for commercial data were based on statistical areas used to report landings. In particular, the southern region included statistical areas 533, 613, 615, 616, 621, 622, 623, 625, 626, 627, 631, 632, 635, and 636 while the northern region included statistical areas 522, 525, 526, 534, 537, 541, 543 and 562.

The approach to estimating fishery selectivity curves for red crab was a method for limited data first used by NEFSC (2004) for ocean quahog. Fishery selectivity was modeled using ascending logistic curves:

$$\hat{s}_L = \frac{1}{1+e^{\alpha+\beta L}}$$

where $\hat{s}_L$ is predicted commercial selectivity at size L (mm, $0 < s_L < 1$), and α and β are parameters estimated in Excel by nonlinear regression and least-squares. The lengths used in the regression analysis were the midpoints of the 5 mm length groups (e.g. 92.5 for the 90-94 mm size group). Residuals minimized by least-squares were:

$$r_L = L(s_L) - L(\hat{s}_L)$$

where $L(p)=\ln(p)/\ln(1-p)$ is the logit transformation for the proportion p. The logit transformation is commonly used in regression analyses with proportions. Only size groups with both survey and commercial data were used in the regression analysis.

The estimated selectivity curves for both areas were similar and it would be reasonable to use a single curve estimated with data from the southern and northern regions combined in analyses for the whole stock (Figure D7.1, and see below). Fishery selectivity for red crab in all regions during 2004-2005 is near 0% at sizes less than 80 mm. After 80 mm, fishery selectivity increases rapidly and is nearly 100% by 120 mm. Red crabs reach 50% selectivity at about 90-94 mm (see below). The steep ascending part of the selectivity curve occurs at the same lengths as the steep left-hand side of the fishery length composition data (Figure D7.1).

Fishery selectivity parameters for deep-sea red crab during 2004-2005.

Estimate	South	North	Combined
α	26.95	32.37	26.86
β	-0.2991	-0.3461	-0.2905
$L_{50\%}$ (mm)	90	94	92

7.2 Biomass and fishing mortality during 2003-2005

Fishable biomass for red crab is the portion of total stock biomass that is fully available to the commercial fishery. Fishable biomass is important because it can be used to calculate exploitation and fishing mortality rates. In particular, if C is catch in weight and B is average fishable biomass during the year, then the annual fishing mortality rate is $F=C/B$ (Ricker 1975). Biomass estimates for male red crab approximate average annual biomass because they are from camera/trawl surveys conducted during summer (i.e. midyear). For red crab, landings data (assumed to be 100% male) are used instead of catch data because estimates of mortality due to discard at sea are not available.

Average fishable biomass for male red crab during 2003-2005 was estimated based on fishery selectivity and average abundance at length in video/trawl surveys during the same years. Fishable biomass was calculated:

$$B = \sum_{L=1}^{150} B_L s_L$$

where B_L is average fishable biomass of red crab of size L, and s_L is commercial selectivity at size calculated using parameters for the northern and southern regions combined. Fishable biomass during 1974 was calculated for comparison based on the same fishery selectivity curve. It was not possible to compute fishing mortality during 1974, however, because the fishery in 1974 selected larger (114+ mm CW) individuals (Serchuk 1977).

Fishable biomass of male deep-sea red crabs averaged ($\pm$1SE) 36,250 $\pm$ 5,460 mt (80 million lbs) during 2003-2005, while landings averaged about 2000 mt (4.4 million lbs) per year (Table D7.1). In contrast, and based on the selectivity curve for the recent fishery, fishable biomass was about 34,000 mt (76 million lbs) during 1974 (Table D7.2). According to Serchuk (1977) landings during 1974 were about 503 mt (1.1 million lbs). Fishing mortality rates for deep sea red crab averaged 0.057, 0.031, 0.100, 0.030 in survey strata A-D, and 0.055 $\pm$ 0.008 y^{-1} for the stock as a whole during 2003-2005. The Standard Error term for fishing mortality SE_F was calculated assuming that the coefficient of variation for fishing mortality ($CV_F = SE_F/F$) is equal to the CV for recruited biomass ($CV_B = SE_B/B$). Thus $CV_B = 5459/35{,}253 = 0.15$, and $SE_F = F(CV_B) = 0.055(0.15) = 0.008$. This further assumes no error in landings data and that the average biomass estimate is log-normally distributed. Thus, $SE_F = F\ (SE_B) = 0.55\ (0.15) = 0.008$. More detailed information about the calculation of confidence intervals for estimates of fishable biomass during 1974 and 2003-2005, and fishing mortality during 2004-2005, can be found in appendix D5.

Substantial discards of male and female red crab likely occur in the red crab fishery. Mortality due to discarding is unknown. If discards are substantial and discarded red crab often die, then fishing mortality estimates for male red crab based on landings underestimate mortality rates due to fishing. Fishing mortality rates for females are assumed to be zero in this assessment because females are relatively uncommon in landings. However, mortality of discarded females due to fishing may be substantial if discard mortality is high.

8.0 BIOLOGICAL REFERENCE POINTS

Lack of data about growth, longevity, and trends in abundance precluded estimation of new reference points in this assessment. Based on the previous assessment, MSY for deep sea red crabs 114+ mm (males only) is 1/2 M B_o = 2,494 mt (5.5 million lbs.). This estimate assumes that the natural mortality rate M is 0.2 y^{-1}, the minimum market size is 114mm, and that the estimate of exploitable biomass from the 1974 survey was made when the stock was near the virgin level (B_o). The 2002 FMP includes a preferred estimate of MSY=2,830 mt (6.24 million lbs) which was calculated using the same model but assuming a natural mortality of M=0.15, a minimum market size of 4 inches (101mm) and an expanded fishing area. Due to uncertainty about biological parameters and the model used to calculate MSY, these estimates are considered invalid. More accurate estimates were precluded in this assessment by lack of information about growth, longevity and trends in abundance.

9.0 CONCLUSIONS ABOUT STOCK STATUS

The deep sea red crab population and fishery appear to be at sustainable levels. The red crab fishery has had a noticeable impact on the stock of large male red crabs $\geq$114 mm carapace width which were considered marketable in 1974. Since 1974 the abundance of large males has decreased by 42%, probably in response to fishing. However, the biomass of currently marketable male crabs which includes smaller individuals has increased by 5%. Small red crabs less than about 60 mm appear to be abundant relative to 1974. Current landings during 2002-2005 averaged approximately 2000 mt (4.4 million lbs), and were comparable to average landings of about 2300 mt (5 million lbs) during 1982-2001 as the population was being fished down from the virgin state. Results of this stock assessment are consistent with the hypothesis that the red crab population has been fished down from a virgin state over the past 30 years and is currently at a productive biomass level. There are, however, several key issues that contribute uncertainty to this conclusion (i.e. lack of biological information about growth and longevity that could be used to estimate stock productivity and information about discard mortality, see below).

Camera/bottom trawl surveys directed at red crab and carried out during 1974 and 2003-2005 are the main source of information about biomass. Biomass of female red crab increased during 1974 to 2003-2005. Total biomass of male and female red crab 114+ mm CW was 25,900 mt during 1974 and declined by 27% to 18,990 $\pm$ 2160 (1SE) mt during 2003-2005. Average biomass of male red crab large enough to contribute to the fishery during 2003-2005 was more than one-half of the level observed in 1974. Biomass of male red crab 114+ mm was 23,794 mt during 1974 and declined by 42% to 13,769 $\pm$ 1334 during 2003-2005. Fishable male biomass (which includes all sizes available to the recent fishery) was 34,264 mt during 1974 and increased by 5% to 36,253 $\pm$ 5459 mt during 2003-2005. Biomass of red crab $\geq$ 114 mm CW decreased while fishable biomass increased because small red crabs which contribute to fishable biomass were abundant during 2003-2005. Small red crabs are abundant suggesting good recruitment, although this may be due to higher probability of detection for small red crabs in the 2003-2005 surveys.

LPUE and fishing effort were stable during 2001-2005. Landings fluctuated without trend during 1982-2005 and were stable during 2001-2005. Regulations preclude landing female red crabs but discard mortality may occur. Fishery size data show declines in the proportion of large male red crabs which are targeted by the fishery.

The fishery during 2003-2005 targeted smaller red crabs than during the 1970's when most of the landings consisted of red crabs 114+ mm CW. During 2003-2005, 50% of male red crabs were fully available to the fishery at 92 mm CW.

Fishing effort (number of vessels and total days fished) is effectively controlled by a limited entry program but latent effort exists because current days at sea allocations (DAS) have not been fully utilized. The fishery is managed under a target TAC that has not been reached in recent years.

Red crab catches have been fairly stable in bottom trawl surveys directed at groundfish and shrimp. Survey size data show evidence of reductions in the relative abundance of large male red crab.

Based on the ratio of landings and fishable biomass, average ($\underline{+}$ 1SE) fishing mortality is estimated to be $0.055 + 0.008\ y^{-1}$ during 2003-2005. These estimates do not consider potential mortality due to discard of undersized male or female red crabs, which are protected by regulations. Discard of undersized males and females are likely substantial but discard mortality rates are uncertain.

Discards consist of female crabs (which are not landed by regulation) and male crabs too small to sell. Comparison of port sample data and sea sample data from one vessel during 2004-2005 suggests that discard levels for males and female red crab average about 29% of total catch weight. VTR data are harder to interpret but indicate discard levels of 32 to 35%. Mortality rates for discarded red crab are unknown.

As currently defined in the FMP, overfishing is not occurring because landings of male red crab during 2003-2005 were 2013 mt, which is less than an estimate of MSY (2670 mt) from the last assessment (Serchuk 1977), and less than the FMP preferred MSY of 2830 mt. However, these MSY estimates are based on the assumption that the natural mortality rate is either 2.0 (Serchuk) or $1.5y^{-1}$ (FMP), which is probably unrealistic, and a stock assessment method which is more applicable to short-lived productive fish stocks. If red crabs are long-lived, then the estimated MSY level may be misleading and the stock is likely to be less productive than expected.

Stock status relative to biomass thresholds and targets is unknown because biological reference points have not been defined.

10.0 RESEARCH RECOMMENDATIONS

10.1 Commercial fishery data:

- Investigate seasonal patterns and magnitude of red crab discarding through sea sampling, and compare sea-sampled discard rates with VTR reported discard rates.

- Look into a possible industry-based sampling program for assessing size and sex of discards.

- Assess survival of discarded red crabs.

- Document in detail the configuration and features of the traps currently used by vessels in the fishery, and investigate changes in trap design that would reduce catch of unmarketable (small) red crabs.

- Consider whether there may be a way of reporting trip data that would be more readily translatable to LPUE.

10.2 Biological data:

- Develop a better understanding of the reproductive cycle, maturity schedule, fecundity of the deep sea red crab, and the potential reproductive consequences of removing large males from the population.

- Develop a better understanding of the growth rate and molt cycle of red crab.

- Examine red crab sex ratios: can they be standardized by depth so that comparisons can be made from year to year and changes in the ratio tracked?

- Information on larval supply, transport, settlement and early juvenile distributions and abundance would contribute to an understanding of recruitment processes.

- More detailed bathymetry of the continental slope would be beneficial to an understanding of this and other deepwater species.

10.3 Assessment methods:

- Evaluate the use of a size-structured and sex-specific stock assessment model compatible with the data available.

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