Appendix 3

Stock Status of the Northern Red Drum Stock

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Executive Summary

The current red drum assessment indicates that F has decreased and escapement and static SPR have increased for the red drum northern stocks during the current (late) management period. The results from the 2000 stock assessment indicated that overfishing was occurring, with static SPR values well below the threshold SPR. The current model estimates are all above 30% static SPR and, therefore, indicate that overfishing is not occurring. It appears that the condition of the northern red drum stock has improved and that the more restrictive management measures implemented during the late period (1999-2005) have aided in that improvement.

The northern red drum stock was assessed using commercial, recreational, and independent data from 1986 to 2005. Results were broken into three regulatory periods with relatively uniform regulations (early: 1986-1991, mid: 1992-1998, and late: 1999-2005). A major assumption in this assessment was assigning an accurate length distribution to released fish from the recreational fishery. While several assumptions on the length distribution of recreational releases were calculated, the preferred matrix (Tagging) used length frequencies estimated from modeling of North Carolina Division of Marine Fisheries (NCDMF) tag returns. Late period age-3 selectivity was estimated to be 0.48 of fully selected fish (age-2), and was estimated from modeling of NCDMF tag returns. Two models were used: a backward calculating virtual population analysis (VPA) and a forward calculating spreadsheet catch-at-age model. Both models were updated from the Vaughan and Carmichael (2000) assessment. Fishing mortality (F) estimated from FADAPT ranged from 0.50 to 0.49, with escapement ranging from 40.6% to 41.0% and static spawning potential ratio (SPR) ranging from 40.4% to 40.8%. The spreadsheet catch-at-age model F estimates ranged from 0.66 to 0.63, with escapement estimated at 32.8% and static SPR estimated at 32.3%. All estimated runs using the TAGGING matrix from both models were above the threshold of 30% static SPR and the FADAPT estimates were above the target of 40% static SPR. All runs showed improvements in escapement and SPR from the previous regulation period (1992-1998).

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Introduction

Atlantic red drum (*Sciaenops ocellatus*) are an important marine species with the most recent stock assessment conducted in 2000. The first assessments were conducted using catch curves and separable virtual population analysis (SVPA) and treated the Atlantic red drum as a single stock (Vaughan and Hesler 1990; Vaughan 1992; Vaughan 1993). More recent assessments (Vaughan 1996; Vaughan and Carmichael 2000) divided the Atlantic coast into two stock regions: the northern region from North Carolina and north and the southern region from South Carolina through the east coast of Florida.

This assessment is an update of the northern region stock assessment that was conducted in 2000. The 2000 assessment is the approved assessment for Amendment 2 to the Atlantic States Marine Fisheries Commission (ASMFC) Red Drum Fishery Management Plan (FMP). The North Carolina Division of Marine Fisheries (NCDMF) Red Drum Plan Development Team (PDT) consensus in the development of this stock assessment was to maintain a methodology consistent with that used in the previous assessment. Exceptions to the previous methodology occurred as a result of regulation changes since the last assessment. These included assumptions about estimates of the length composition from recreational releases and the relative selectivity at age. Assumptions for these estimates were no longer valid primarily due to reductions in the bag limit and the prohibition of red drum greater than 27 in from harvest and new methods were developed to estimate these parameters. The North Carolina Marine Fisheries Commission (NCMFC) and Red Drum Advisory Committee will use this assessment to update the North Carolina Red Drum FMP.

Commercial Fishery Description

A directed commercial red drum fishery does not currently exist in North Carolina and historically red drum have made up only a small portion of North Carolina's total commercial landings. However, North Carolina's red drum landings are highest for all states along the Atlantic coast (Table 1). From 1999 to 2005, 96% of all red drum harvested commercially were landed in North Carolina. From 1972 to 2005, commercial landings of red drum in North Carolina fluctuated annually, averaging 161,433 pounds (lb) and ranging from 19,637 lb in 1977 to 372,942 lb in 1999 (Figure 1).

Red drum have been commercially harvested over the years using a variety of commercial gears, with Outer Banks fishermen occasionally targeting large red drum in Pamlico Sound (SAFMC 1990). Throughout the 1970's long haul seines and common haul seines were generally the most productive gears, while gill nets, pound nets and trawls were also commonly used (Mercer 1984). Since the 1980's, gill nets have become the dominant gear. In the years leading up to the implementation of daily trip limits in 1999, nearly one-half of the total annual commercial harvest of red drum was harvested by a small number of trips with high landings. From 1994 to 1998, nearly half of all red drum landed (48.5%) was taken by only 1.1% of the total number of trips that harvested red drum. During this time, runaround gill nets became a significant contributor to the red drum commercial harvest (Figure 2). The runaround gill net and long haul seine fisheries typically had the largest individual red drum landings per individual trip during this time because of their effectiveness in encircling large schools of red drum. Pamlico Sound had the highest annual red drum landings in the state (Table 2). Much of the harvest and the largest individual catches occurred from Oregon Inlet to Ocracoke Inlet. Although there were a few exceptional long haul seine catches of up to 10,000 lb, a typical catch for a runaround gill net ranged from 100 to 1,000 lb per trip. Now that regulations prohibit a directed fishery, red drum are most commonly encountered as bycatch in the southern flounder estuarine gill net fishery but are also still common bycatch in many of the gears in which they were traditionally captured.

With the changes in regulations over the years, the size structure of the commercial harvest has also shifted towards larger fish (Figure 3). During the initial management period of 1987 to 1991 most red drum harvested were ~14 in total length (TL) and age-1. In 1992, when the size restrictions changed (18 – 27 in TL), the modal length for red drum harvested shifted to 19 in TL and age-2. As a result of decreasing the available sizes that can be retained within the slot limit, landings are now primarily from a single year class of fish and dependent on year class strength. While the regulatory changes in 1999 removed the ability to retain one fish over 27 in, the reductions in harvest resulting from the daily trip limit did correspond with a shift in the modal length of harvested fish from 19 in TL to 23 in TL. In addition, fish at the upper end of the slot limit that were once rare in the landings are now commonly encountered.

Recreational Fishery Description

North Carolina accounts for most of the recreational landings in the northern region (Table 3 and Table 4). Landings in Virginia can be substantial for some years. Landings are minor North of Virginia. Angling methods used to catch red drum include conventional, spinning, and fly tackle; using live, dead, and artificial bait. Red drum are targeted by recreational anglers year-round throughout the sounds, rivers and beaches of North Carolina. Red drum are consistently reported as one of the top target species by shore-based recreational anglers, and were the number one or two target species in 1993, 1995, 1996 and every year from 1999 to 2003.

Recreational fishermen must adhere to the same slot limit (18 – 27 in TL) as commercial fishermen and are allowed to harvest one fish per person per day. Similar to the commercial fishery, recreational landings vary annually in response to changes in year-class abundance. For example, landings increased from

38,286 lb in 1997 to 591,435 lb in 1998 (Table 3). When there was a five fish creel limit, recreational landings averaged 286,548 lb and accounted for approximately 60% of the total red drum harvested in North Carolina from 1992 to 1998. After the creel limit was reduced to one fish per day, annual landings dropped to an average of 204,628 lb from 1999 to 2005 and accounted for approximately 56% of all red drum harvested.

Undersized red drum accounted for 19% of the recreational harvest from 1994 to 1998, with a range of 1% in 1998 to 35% in 1997. Undersized red drum only accounted for 3.4% of the harvest from 1999 to 2005, with a range of 0% in 2003 and 2005 to 5.5% in 1999. Prior to the prohibition of red drum greater than 27 in TL in 1999, North Carolina offered award citations for red drum captured weighing 45 lb or greater. A citation could also be received for the release of a captured red drum greater than 40 in TL. All award citations issued since 1999 are for releases only. Trends in the NCDMF citation data show an increasing trend in the percentage of citations that were awarded for releases prior to 1999, indicating an increasing tendency by anglers to practice catch and release ethics (Table 5). In addition, release citations increased substantially in 1999 and appear to be trending upward. While this appears encouraging, it is difficult to ascertain if this is due to increases in availability of large fish, increases in fishing effort or due to increased popularity of the citation program.

General Life History

Red drum is an estuarine-dependent species, common along the Atlantic coast over a wide range of habitats from Chesapeake Bay to Key West, Florida. Historically, red drum have ranged as far north as Massachusetts and there was a moderate commercial fishery off the New Jersey coast in the 1930's (Lux and Mahoney 1969, Mercer 1984). There are few landings reported from areas north of Chesapeake Bay since the 1950's, suggesting a decline in red drum distribution along the Atlantic coast.

Red drum spawning has been observed occurring at night in high salinity areas in or around the major estuarine passes and inlets (Pearson 1929, Johnson 1978). Evidence now suggests that substantial spawning activity may take place inside the estuaries. Red drum have been collected in spawning condition inside Hatteras and Ocracoke Inlets and near the mouths of bays and rivers on the western side of the Pamlico Sound (Ross et al. 1995). More recent work used passive acoustic techniques to document suspected spawning activity. Using the drumming sounds produced by males during courtship, Luzkovich et al. (1999) documented spawning activity along Ocracoke Inlet and in the mouth of the Bay River in western Pamlico Sound. Barrios (2004) further documented spawning red drum with this technique in western Pamlico Sound near the mouth of the Neuse River.

Subsequent to spawning, larvae are distributed throughout the estuary by wind and tidal currents. The majority of larvae will settle out in shallow, low salinity areas with abundant food supplies. These habitats include coastal creeks, protected bays with sandy or mud bottoms, and grass beds (Mercer 1984, Daniel 1988, Wenner et al. 1990, Ross et al. 1992). Juvenile distribution in the estuary varies seasonally as the fish grow and disperse. In North Carolina, juvenile red drum are found year-round over a wide range of salinity and habitats, although they generally prefer the shallow shorelines of various bays and rivers and the shallow grass flats behind barrier islands (Ross and Stevens 1992). Red drum grow rapidly during the first few years and most will reach the legal size limit of 18 in TL by 20 months of age. Most red drum have grown beyond the current maximum size limit of 27 in TL before they reach age-3. The earliest mature females occur at age-3 and all are mature at age-4 (30-35 in TL). Males mature sooner with 100% maturity occurring by age-3 around 27-32 in TL (Ross et al. 1995).

Movement and migration of red drum in North Carolina and along the Atlantic coast have been documented using tagging studies. Studies in North Carolina and South Carolina indicate high site fidelity. For subadult and adult red drum tagged in North Carolina estuaries, 99% of the red drum tag recaptures occur in North Carolina coastal waters (Ross and Stevens 1992, Marks and DiDomenico 1996). South Carolina tagged fish were mainly caught within nine nautical miles of their release site (ASMFC 2002). Less than 5% of subadult recaptures occurred outside of South Carolina coastal waters and no adults were recovered outside coastal waters (ASMFC 2002). Further north, large red drum schools have been reported to move from Virginia south along the beaches of the Outer Banks during the fall as water temperatures decline. These schools then return north in the spring (Mercer 1984). Tagging data provides evidence for separate stocks that should be considered as separate management units. Therefore, beginning with the 1995 assessment, red drum have been assessed as northern and southern stocks, with the stock split occurring at the North Carolina/South Carolina border (Vaughan 1996, Vaughan and Carmichael 2000).

Regulations and Management History

When assessing the northern stock of red drum the assessment results can easily be segregated into three distinct management periods which will be referred to throughout this document: early (1986-1991), mid (1992-1998), and late (1999-2005). A regulatory summary for each period is summarized in Table 6.

Red drum regulations in North Carolina began in 1976, with a 14 in TL minimum size limit and a limit of two fish per day exceeding 32 in TL. In December of 1987, proclamation authority for the NCDMF director was established for areas, seasons, quantity, means/methods and size. Management of red drum at the federal level began in the 1980's with red drum being managed by multiple management entities. The first plan was developed by the ASMFC in 1984, although this plan had no regulatory requirements. The South

Atlantic Fishery Management Council (SAFMC) FMP was subsequently adopted in 1990 and closed federal waters to the harvest of red drum. This plan was then adopted as Amendment 1 to the ASMFC FMP in 1991. The goal of Amendment 1 was to obtain optimum yield from the fishery over time. Optimum yield (OY) was defined as the amount of harvest that could be taken while maintaining a 30% spawning stock biomass per recruit (SSBPR). This goal however, was not attainable due to a lack of information on the adult population. This led to a 30% spawning potential ratio (SPR) being used as a proxy to SSBPR. Because the SPR at this time was estimated to be 2 to 3%, Amendment 1 recommended that all states implement harvest controls to attain at least a 10% SPR as a phase-in approach to rebuilding the stocks. The result was a significant increase in management of red drum in North Carolina during the 1990's. In 1990, the recreational creel limit was set at five fish per day, harvest of red drum over 32 in TL was limited to one fish per day, and a 300,000 lb commercial cap was established. A commercial cap was enacted to prevent North Carolina's commercial red drum fishery from expanding beyond historical harvest levels at a time when other markets (i.e. Florida) were prohibiting the sale of red drum. The commercial cap was further reduced to 250,000 lb in 1991 and the size limit was changed to a slot limit of 18 to 32 in TL with one fish greater than 32 in. All of these regulations constitute the 'early' period as defined above. By 1992, North Carolina had in place the current 18 to 27 in TL slot limit, a five fish creel limit, and allowed the harvest of one fish over 27 in TL. The regulations from 1992-1998 remained unchanged and referred to as the 'mid' period in this report.

In 1998 the SAFMC adopted new definitions of overfishing and OY for red drum, setting the levels at 30% SPR and 40% SPR, respectively. Later in 1998, North Carolina, through the development of a state FMP, implemented management measures designed to eliminate overfishing and achieve OY. As a result, the recreational bag limit was reduced to one fish per day and a 100 lb daily commercial trip limit (set at the Director's discretion) was imposed, while the previous 250,000 lb commercial cap remained in place. Harvest of any fish outside of the slot was prohibited. After exceeding the commercial cap in 1999 and 2000, a commercial trip limit of seven fish per day was established in 2001. In addition to the daily commercial trip limit, targeting of red drum was prohibited by requiring that the total weight of red drum make up no more than 50% of the total marketable catch (excluding menhaden) for each trip. The North Carolina FMP with these regulatory changes was approved by the NCMFC in 2001. Amendment 2 of the ASMFC FMP was adopted in 2002 and required that all states implement management measures necessary to obtain a 40% SPR. As a result of the North Carolina Red Drum FMP of 2001, no additional management measures were required by North Carolina. With the exception of changing the trip limit in the commercial fishery, regulations in North Carolina have remained unchanged since 1999 and comprise the 'late' period. This assessment will determine if the management action taken in the 'late' period was adequate to obtain OY as defined in the NCFMP and Amendment 2 to the ASMFC FMP.

Virginia's regulatory history is similar to North Carolina's regulations. In 1986, a 14 in TL minimum size limit was established with a possession limit of no more than two fish greater than 32 in TL. In late 1992, the slot limit was established at 18 - 27 in TL with a five fish bag limit, allowing only one fish greater than 27 in TL to be harvested. In 2003, the slot limit was changed to 18 - 26 in TL with a three fish bag limit and no allowance for red drum harvest outside of the slot limit. Virginia's regulations apply to both commercial and recreational fisheries.

Previous Assessment Results

Atlantic red drum have been previously assessed on five occasions, with the most recent coastwide assessment occurring in 2000. The first assessment was conducted using catch curve analysis and VPA. The best estimates indicated that SPR and escapement (relative survival from age at entry into fishery to age four) were low (Vaughan and Helser 1990). All of the estimates were well below the SAFMC threshold of 30% SPR. Assessment updates occurred in 1992 and 1993. For assessment purposes, the stock was split into northern (North Carolina and north) and southern (South Carolina, Georgia, and the east coast of Florida) regions beginning in 1995. Estimates of escapement from 1992 to 1994 for the northern region were 10.4%, which was an increase from the estimate of 0.6% for the early period (Vaughan 1996). The SPR estimate increased from 0.2% for the early period to 9.0% in the 1992-1994 period, putting it just below the 10% SPR level for first phase recovery. Results of the 2000 stock assessment used data through 1998 and indicated that escapement had improved for the entire period of 1992 to 1998 to around 18% (Vaughan and Carmichael 2000). This estimate however, falls short of the 30% overfishing definition. This assessment is intended to evaluate the effectiveness of the most recent regulatory changes in improving the red drum stocks. This iteration of the red drum stock assessment was conducted as part of the North Carolina Red Drum FMP update. The next coastwide assessment is scheduled for 2009 by the ASMFC.

Assessment Data

Commercial

North Carolina commercial landings data have been collected through the North Carolina Trip Ticket Program (NCTTP) since 1994. Between 1978 and 1993, landings information was gathered through the National Marine Fisheries Service (NMFS)/North Carolina Cooperative Statistics program. Reporting was voluntary during this period, with North Carolina and NMFS port agents sampling the state's major dealers (Lupton and Phalen 1996). Since 1994, commercial landings reporting has been mandatory. For further information on the sampling methodology for the NCTTP, see Lupton and Phalen (1996). Virginia has also had mandatory commercial reporting since 1993. Like North Carolina, Virginia's landings information prior to 1993 was collected on a voluntary basis through a cooperative program with the NMFS.

Commercial length frequency data were obtained by the NCDMF commercial dependent sampling program. Red drum lengths were collected at local fish houses by gear, market grade (not typical for red drum) and area fished. Individual fish were measured (mm, FL) and total weight (0.1 kg) of all fish measured in aggregate was obtained. Subsequent to sampling a portion of the catch, the total weight of the catch by species and market grade was obtained for each trip, either by using the trip ticket weights or some other reliable estimate. Length frequencies obtained from a sample were then expanded to the total catch using the total weights from the trip ticket. All expanded catches were then combined to describe a given commercial gear for a specified time period. Sample sizes obtained for Virginia commercial length frequencies were inadequate to describe the length distribution of red drum taken by gear type and year. As a result, North Carolina length frequency distributions from the same or similar gears were used to describe Virginia's commercial harvest (Table 7). Commercial length sampling intensity was determined by number of fish sampled per thousand pounds of catch for four major gears: gill nets, long haul seines, pound nets and winter trawls (Table 8). A rough reference for sampling adequacy used in the 2000 assessment was a minimum of 100 fish sampled per 200 metric tons. This converts to the current standard of greater than 0.23 fish sampled per 1,000 lb. By this standard, the major gears of gill net, long haul seine, and pounds nets were sampled adequately during the late time period. It is important to note that the nature of this fishery (small landings, large variability) likely requires larger sampling proportions. Gill nets and long haul seines had previously been determined to be adequately sampled for all years but 1986 and gill nets in 1987 and 1988 (Vaughan and Carmichael 2000). Commercial samples were taken throughout the year and from all areas where red drum are landed. Combined, gill nets, long haul seines and pound nets made up over 98% of all commercial landings for the northern region for the period of 1999-2005. Of these, gill net landings dominated, accounting for between 88% and 94% of all commercial harvest annually.

Recreational

The Marine Recreational Fishery Statistics Survey (MRFSS) collected the recreational landings data. The survey has two parts: a coastal county household telephone survey and an angler intercept survey at access sites. The survey data were combined to estimate numbers of fish caught, released, and harvested, harvest biomass, total trips and numbers of people fishing recreationally. Beginning in 1987, North Carolina has supplemented the MRFSS sampling targets for the state, increasing the sample size by nearly six times. The supplemental sampling has greatly improved catch estimate precision. Proportional standard error (PSE) is used to examine the precision of MRFSS estimates. For further information on MRFSS and the recreational sampling methodology see http://www.st.nmfs.gov/st1/recreational/pubs/data_users/index.html.

Trip effort estimates for 1986-2005 were generated using programs developed by Holiman (1996). Trips where red drum were identified as a species of interest were defined as target trips. Both successful and unsuccessful trips were included. From this data set, two indices were generated including a catch-per-unit effort index that used targeted trips and corresponding catch data and a probability of success index that used the proportion of successful targeted trips to the total number of targeted trips (Figure 4).

Ageing

Red drum sagittal otoliths were collected from the commercial and recreational fishery, with supplemental samples collected from fishery independent surveys. Age samples were collected monthly with sampling targets set for specified length bins. When possible, fork and total length to the nearest millimeter, weight to the nearest 0.1 kg, date, gear and water location were recorded for each sample. Otoliths (sagittae) were excised from all fish and stored dry. Dorso-ventral sections of the left sagitta were made through the core to the nucleus perpendicular to the anterior-posterior plane with a Hillquist thin-sectioning machine as described by Cowan et al. (1995). Sections were mounted on slides with ultra-violet curing glue. All sections were read from a high resolution monitor coupled to a video camera mounted on a microscope. Otolith sections were read independently by two readers. Age determination for red drum was based on the presence of annuli but had to be adjusted because the first annulus is not formed until 19-21 months after the hatching date. Validation of this technique is presented in Ross and Stevens (1992). Age-length data for this updated assessment were provided by the NCDMF (2,917 fish from 1999-2005) and Old Dominion University (via Virginia Marine Resources Commission (VMRC); 289 fish from 1999-2005). Old Dominion University has been ageing red drum since 1998 from Virginia catches. Samples from North Carolina and Virginia were combined to generate age-length keys for the red drum catch-at-age.

Fishery Independent Data

<u>North Carolina Seine Survey</u>

A juvenile abundance index (JAI) was developed using data from the NCDMF red drum beach seine survey. The program was established to determine a red drum JAI and to evaluate habitat requirements for juvenile red drum. The survey was first conducted in 1987 as a pilot study. Through 1990, between 20 and 24 stations were randomly selected for sampling. Since 1991, set stations in internal waters have been sampled twice monthly from September to November. Seining is conducted using a bag seine measuring 18 m (60 ft) by

1.8 m (6 ft) with 6.4 mm (1/4 in) bar mesh in the body and 3.2 mm (1/8 in) bar mesh in the bag. A standard tow has one net end at the water's edge while the other end is pulled perpendicular to the shore. The end in the water is pulled a quarter sweep in the direction of tide or flow, and then fished to shore. The CPUE was defined as the average number of juvenile red drum captured per tow.

The assessment included the time period from 1991 to 2005, excluding only 1996 because of known environmental causes that decreased availability of fish (Figure 5). The trends prior to 1999 were highly variable. It appears that juvenile abundance was generally low from 1999 to 2001. Since 2001, the JAI has steadily increased to present.

Pamlico Sound Independent Gill Net Survey (IGNS)

Age-1 and age-2 indices were calculated using data from the Pamlico Sound independent gill net survey. The program began in 2001 with four objectives: to calculate annual abundance indices for key species in Pamlico Sound (including red drum), to provide supplemental samples for age, growth, and reproduction studies, to evaluate catch rates and species distribution in relation to bycatch, and to characterize habitat utilization. The survey used a stratified-random survey design with depth (greater or less than 6 ft) and region as strata. Regions were overlaid with a one-minute by one-minute grid system, with sampling sites selected randomly using PROC PLAN in SAS (SAS 2006). Each grid selected was sampled with a net array of 30-yard segments of 3, 3 ½, 4, 4 ½, 5, 5 ½, 6, and 6 ½ in stretch mesh webbing for 240 total yd of gill net fished in each regional deep and shallow strata. For each month, random samples were obtained from 16 shallow and 16 deep water sites. Gear was deployed within an hour of sunset and soaked for approximately 12 hours before retrieval. The sampling season occurred from February 15 to December 15 annually. The CPUE was defined as the number of red drum captured at age per sample.

The short time period limits the ability to determine trends for the age-1 and age-2 indices independently, although they appear highly variable from year to year (Figure 6). There are indications that the IGNS can follow cohorts as they progress through time. An example is the large age-1 value in 2002, which does appear as a high value in the age-2 index in 2003. The 2003 age-1 value is low, which corresponds with a low age-2 index value in 2004.

Life History Parameters

Natural Mortality

The natural mortality (M) rates previously used by Vaughan and Carmichael (2000) for the northern region were 0.20 for subadults (ages 1-5) and

0.12 for adults (ages 6 and older) and were based on a size at age relationship (Boudreau and Dickie 1989). These values are used in this assessment.

Age and Growth

Age and growth data were used both to estimate the von Bertalanffy-type growth equations and to develop annual age-length keys for converting catch at length data to catch at age. In order for the for the results to be based on a calendar year it was necessary to adjust the ages so that the age assigned to an individual red drum would coincide with a calendar year. Because September 1 is the theoretical birthdate for red drum in the northern region, all ages were adjusted so an age-1 fish (based on a January-December calendar year) would range in actual age from 5 to 16 months (Vaughan and Carmichael 2000). All age-length keys were annual and used two-inch length bins with bin designation using the midpoint (Table 9).

Previous red drum assessments have fitted growth data to both standard and linear versions of the von Bertalanffy (1938) growth equations (Vaughan 1996; Vaughan and Carmichael 2000). The linear von Bertalanffy equation assumes that L_∞ is a linear function of age rather than a constant, which is the assumption in the standard von Bertalanffy equation. The equations were fitted using the PROC NLIN function in SAS (SAS 2006). The preferred parameters for the previous assessment were estimated from the linear growth equation as opposed to the standard equation. The linear growth equation includes an extra parameter that is significantly different from zero. The linear model is capable of better fitting the higher growth rates at earlier ages and the slower growth rates at later ages. For this assessment linear and standard von Bertalanffy parameter estimates are shown in Table 10 and equations can be found in Appendix 2.

Maturity at Age

The maturity schedule used in this assessment is based on Ross et al. (1995) and is consistent with that used in the previous update. The maturity schedule was used to determine the percent SPR and used only the female maturity schedule. The maturity schedule at age was as follows: age-2 was 0.01, age-3 was 0.58, age-4 was 0.99, and age-5 was 1.00. All fish collected during the maturity study were collected between September 1 and the end of the calendar year and for this reason no adjustments were necessary to align the adjusted calendar based ages with the age at maturity data.

Catch at Age Matrices

Annual catch-at-age (CAA) matrices were calculated for the period from 1999 to 2005 and followed the assumptions used by Vaughan and Carmichael (2000). The period from 1986 to 1998 used the existing CAA calculated for the 2000 assessment. For the current period, a CAA matrix was generated for four major commercial gears including gill nets, long haul seines, pound nets and winter trawl. The remaining commercial gears were not sampled and accounted for less than 1% of the annual commercial harvest in any year. These gears were combined with gill nets in the CAA workup. The recreational CAA matrices were generated based on information derived from MRFSS. The age-length keys used to in calculating the CAA are based on 12-month periods rather than 6-month periods.

Five different CAA matrices were calculated for different assumptions about the length frequency distribution of the recreational releases (Tables 11-13). The first, BASE0, assumed that there was no recreational discard mortality. The BASE1 matrix assumed 10% discard mortality and that the length frequency distribution was the same as the observed recreational harvest length frequency. The DELTA matrix assumed a 10% discard mortality rate and assumed that the length frequency distribution equaled the positive difference between the observed recreational harvest length frequencies of the early period (1986-1991) and the late period (1999-2005). The PROP catch matrix assumed a 10% discard mortality rate and used a weighted average of the MRFSS length frequencies from the BASE1 and DELTA catch matrices. The weights were 40% BASE1 and 60% DELTA, based on the 40% reduction that was required by Amendment 2. The last, TAGGING matrix, assumed a 10% discard mortality rate and based the length frequency distribution on the estimated selectivity at length for the B2 catch from an analysis of the North Carolina tagging data described below (Figure 7).

Length-based selectivity patterns were estimated for recreationally released red drum using NCDMF mark-recapture data (Burdick et al. 2006). The differences in selectivity were examined by time periods established for fisheries regulation changes. The selectivity of discards (fish released alive) and harvested fish could be estimated separately for recreational tag returns. Selectivity patterns were estimated using a generalized linear model that fitted an expected tag return rate using the rate of tag recovery by gear (Myers and Hoenig 1997). In this method, length-based selectivity of red drum for recreationally released fish is estimated by fitting a model for the expected tag return rate of tagged fish through multiplying four factors: the number of fish tagged by tag type and length bin, the tag recovery rate for recreationally released fish and tag type, the exploitation rate by gear type and tag type, and the selectivity of gear type in each length bin, with the equation in Appendix 2. The tag recovery rate is the product of the proportion of fish that survive tagging, the proportion of tags that are not lost (shed), and the proportion of recovered tags that are reported. This method assumes that tag loss, tagging mortality, M, and tag reporting are independent of length and age for recapture. It also assumes exploitation and recovery did not change and that fish did not grow out of their assigned length bin before recapture. For length-based analysis, the maximum allowed time at-large and length bin designations were adjusted to achieve the optimum combination given available data. If fish grew out of assigned length bins before recapture, the resultant selectivity curves could be biased and the optimal combination was 100-mm length bins and 90-day time periods (Burdick et al. 2006). The GENMOD procedure in SAS was use to perform the analysis (SAS 2006) and data were log transformed with an assumed binomial error distribution. The GENMOD procedure was modified to scale to the length bin with the maximum selectivity.

Commercial discard estimates were not available for this assessment and have not been available for previous assessments. Research is currently being conducted to determine commercial discard estimates for the 2009 coastwide assessment.

Methods

Separable Virtual Population Analysis (SVPA)

Previous red drum assessments used SVPA to estimate fishing mortality (F) and population numbers. For this assessment, an SVPA was employed solely to estimate the terminal year selectivity vectors for the FADAPT analyses. For the SVPA, catch-at-age data (ages 1-5 and years 1986-2005) were divided into the three previously defined management time periods. The catch-at-ages were analyzed separately for each management period and B2 calculation.

The SVPA computer program requires specification of a fully recruited reference age and relative selectivity for a second age (Clay 1990). Typically, the selectivities of the first fully recruited age and the oldest age are equal; within the model both would be equal to 1.0. This is not appropriate for this assessment because of the decreased availability of older fish from harvest. In the previous assessment, as well as this assessment, the age at full recruitment was age-2 and the second age to be determined was age-3. How this selectivity was determined varies by time period. For the early period, selectivity for age-2 and age-3 was considered equal. The selectivity of age-3 fish during the mid period was initially estimated to be 0.43. This estimation was based on an investigation of the size distribution of age-3 fish relative to age-2 fish that fell within the 18 to 27 in TL slot limit for the northern region. This value was considered inappropriate because the selectivity of 0.43 assumes no harvest of red drum outside the slot limit and during the mid period harvest of one red drum greater than 27 in TL was allowed. As a result an age-3 selectivity assumption of 0.7 was used in the 2000 stock assessment. This assumption is no longer appropriate for the late period, as fish can no longer be harvested above the slot limit.

For the late period, two selectivities were initially investigated. Because the slot limit remained unchanged from the mid to late periods and harvest of red drum greater than 27 in TL was prohibited, the 0.43 selectivity estimated for age-3 red drum during the last assessment was considered for this assessment. A second selectivity was estimated for age-3 red drum based on tag return analyses conducted on the NCDMF tagging data for red drum (Nathan Bacheler, NCSU, unpublished data). A total of 22 years of tagging data from the NCDMF were used to assess the effect of two previous regulation changes, occurring in 1991 and 1998, on F and selectivity patterns of red drum in North Carolina. The model chosen was an age-dependent tag return model (Brownie et al. 1985; Hoenig et al. 1998a; Hoenig et al. 1998b) that accounted for both harvest and catch-and-release fishing by separating mortality of the tags (where the fish are released alive but the tags are removed and reported) from mortality experienced by the fish (Jiang et al. 2006). This model was very similar to the Jiang et al. (2006) model, but age-dependent M values were input, and the model estimated the tag reporting rate. Related equations can be found in Appendix 2. Tag retention of less than 100% was accounted for the two different tag types. Red drum were placed into four age groupings (age-1, age-2, age-3, and age-4+) at tagging based on a 6-month age-length key provided by NCDMF, which provided very good separation of length groupings. Hooking mortality was accounted for using Jiang et al.'s (2006) method of adjusting F upwards given a previously reported hooking mortality rate for red drum (10%; Jordan 1990) and an estimate of F', the tag mortality defined above. Burdick et al.'s (2006) estimate of annual tag retention of dart tags (0.74) was used based on double tagging analyses and annual tag retention of internal anchor tags (0.91). Age-dependent natural mortality rates (0.30 for age-1, 0.22 for age-2, 0.16 for age-3, and 0.10 for age-4+ fish) were fixed based on a life history estimator that related M to body size (Boudreau and Dickie 1989). The selectivity was allowed to vary by age and regulation period in our model, and model parameters were estimated using maximum likelihood estimators. Fish recovered within 7 days of tagging were excluded to allow time for mixing to occur. Assumptions were: (1) no deaths occurred from the tagging process, (2) tagged fish are independent, (3) equal reporting rates whether harvested or released, (4) no ageing errors, (5) selectivity of harvested and caught-and-released fish are equal, and (6) 7 days was enough time to allowed fish to mix adequately. Overall, the model produced robust estimates of age- and regulation period-specific selectivity that were usable in the North Carolina red drum stock assessment. The age-3 specific selectivity produced by this model for the late period was 0.48.

Spreadsheet Model

A forward projecting catch-age analysis was performed using Microsoft Excel and iteratively solved using the Solver function to produce estimates of F (Carmichael et al. 1999). This formulation allows for the inclusion of auxiliary information. The data included in this model were the catch-at-age matrix for 1986-2005, the JAI for the NCDMF from 1991 to 2005, which was used to tune recruitment estimates, and two MRFSS target indices, a CPUE and a probability of success, which was used to tune total annual abundance from 1987 to 2005. A second data configuration added the Pamlico Sound IGNS CPUE that was used to tune ages 1 and 2 from 2001 to 2005. Three selectivity periods were used to correspond to regulatory changes in the fishery. Each model run was restarted from several points to determine if the model had reached a global solution and uses a lognormal error structure. Basic equations can be found in Appendix 2.

FADAPT VPA

The FADAPT program is a modification of Gavaris (1988) by Restrepo (1996) and was the preferred assessment model from the 2000 assessment. This program does not assume separability and does allow for tuning by abundance indices at age. The model requires that a terminal year selectivity be input, which was determined by the SVPA runs (Table 14). Basic equations can be found in Appendix 2.

Data inputs include the catch-at-age matrix from 1986 to 2005, the NCDMF JAI from 1991 to 2005 and two MRFSS indices: a target CPUE from 1987 to 2005; and a probability of targeted trip successes from 1987 to 2005. This configuration was an update of the 2000 assessment. Additional runs were made including the Pamlico Sound IGNS CPUE for ages 1 and 2.

Escapement and SPR

The spawning stock biomass (SSB) for red drum cannot be directly estimated because data on adult fish are lacking. Overfishing thresholds and targets are determined through percent escapement and spawning potential ratio (SPR). The SPR benchmarks set by the ASMFC Amendment 2 were a 30% SPR threshold and a 40% SPR target. Escapement is determined as the percentage of fish recruiting to the adult population at age-4.

SPR is calculated using the %Maximum Spawning Potential (%MSP) method from Gabriel et al. (1989). Additional data required to calculate static SPR are a female maturity schedule and the growth estimates from the von Bertalanffy equation. Both escapement and SPR use the average F at age for each time period, recreational B2 discard assumption, and selectivity assumption. Basic equations can be found in Appendix 2.

Model Assumptions

The VPA models assume that the catch is aged without error. The forward projecting spreadsheet model does not have that assumption. Both the spreadsheet and FADAPT models tune to the catch-at-age matrix and the incorporated indices. Indices are assumed to reflect the actual population abundance and influences on abundance measurements (i.e. regulation changes in a dependent index) must be kept in mind when including the indices and analyzing the results. VPA models tend to exhibit some degree of retrospective bias, where the estimates are initially either over or underestimated. As the terminal year is replaced by subsequent terminal years, the estimates converge to a 'true' value. Concern about retrospective bias has resulted in the previous assessments omitting the terminal year estimates from the average F at age results, which was continued for this assessment. A limited retrospective analysis was also conducted to determine the extent and possible effects of the bias.

Data Limitations

Data limitations impact the assessment. There are no commercial discards included in the catch estimates. Available data are inadequate to estimate commercial discard levels. Therefore it is likely that model results are optimistic, though to what extent is unknown. The length characteristics of the B2 catch were estimated, as the MRFSS does not sample the fish that are caught and released. The MRFSS sampling can be limited in particular areas. A particular deficiency is the absence of intercepts for fisheries prosecuted at night. There is a notable catch-and-release fishery for over the slot limit red drum that occurs at night, though no extra red drum lengths would be observed, as fish greater than 27 in should be released. The adult spawning population cannot be estimated, therefore SSB is unknown and condition of the adult stock is inferred through the escapement estimates. There is also limited independent data on relative abundance of exploited ages (1-5).

Preferred Runs

The model configurations differed due to various assumptions and the inclusion or exclusion of various indices. The major assumptions were for selectivity and the assumed length frequencies of recreational discards. The red drum PDT met and determined the preferred runs that would be considered for the stock status determination. The decision was made to include runs with selectivity vectors of 0.48 for the late period. Sensitivity runs using the 0.43 selectivity vectors were conducted and are detailed in Appendix 1. These runs do indicate that lower selectivity vectors result in lower F estimates and higher estimates of escapement and SPR and that the FADAPT model is more sensitive to different selectivity vectors. While there are differences, 0.48 was selected as the appropriate value because it was estimated quantitatively through the tagging data and is more conservative than 0.43. The mid period used runs with a selectivity vector of 0.7, which was used in the previous assessment to determine stock status. The second major decision was selecting a preferred method to estimate the size distribution of recreational discards. A decision was made to solely use the TAGGING catch matrix in the late period as the preferred run. The PDT selected the TAGGING catch matrix because the results are based on analysis of observed recreational releases from the red drum fishery. In addition, because the data are based on observed lengths, the TAGGING matrix includes fish lengths not typically obtained by the MRFSS (the large fish released above slot limit fish during a predominantly night time fishery). The remaining other model runs for the late period using the various B2 discard assumptions can be found in Appendix 1. The mid period used the DELTA assumption for the preferred run for both this and the previous assessments.

Results

Fishing Mortality (F)

<u>FADAPT VPA</u>

The inclusion or exclusion of the IGNS showed little difference in the estimated F. Estimates of F for the late period ranged from 0.50 to 0.49 at age-2 for the TAGGING run (Table 15). Estimates of F at age-3 ranged from 0.24 to 0.23 and decreased dramatically for ages 4 and 5. The late period F vectors were lower than the mid period F Delta vectors.

<u>Spreadsheet Model</u>

When compared to the FADAPT results, the spreadsheet model had slightly greater variability in estimated F. Estimates of F for the late period were higher in the spreadsheet VPA than were exhibited by the FADAPT estimates. The TAGGING F ranged between 0.66 and 0.63 at age-2 (Table 16). Age-3 estimated F ranged from 0.32 to 0.30 then decreased dramatically at ages 4 and 5.

Escapement and SPR

<u>FADAPT VPA</u>

The escapement estimates for the TAGGING configurations ranged from 40.6% to 41.0% and the static SPR estimates were 40.4% to 40.8% (Table 15). All of the TAGGING configurations were just above the 40% static SPR target. Runs that included the IGNS indices were slightly lower than those runs that were strict updates of the 2000 assessment.

<u>Spreadsheet Model</u>

The escapement estimates for the TAGGING configurations were 32.8% and the static SPR estimates were 32.3% (Table 16). All the TAGGING configurations were above the 30% static SPR threshold and below the 40% static SPR target. Runs that included the IGNS indices were identical to those runs that were strict updates of the 2000 assessment.

Model Fit and Configuration

The residual sum of squares (RSS) was examined to determine the goodness of fit. The FADAPT runs including the IGNS indices fit slightly better than those that were strict updates of the 2000 assessment. When compared to PROP runs (see Appendix 1), TAGGING runs had consistently smaller RSS, indicating that TAGGING runs were better fits.

Residual plots for the tuning indices were examined (Figures 8-11). Plotted values are the difference between the observed survey value and the survey value predicted from the estimated catchability (q) and abundance. A ‘good’ residual plot shows a random scattering of points with no trends over time. For TAGGING run, regardless of inclusion or exclusion of the IGNS index, the MRFSS (CPUE and proportional) indices showed increasing trends through time for the late period (Figures 8 and 9). This could indicate changes in catchability over time. The residuals are only slightly different in magnitude between the IGNS included and excluded runs. For the JAI indices, the scatter of points appeared to be random (Figure 10). The IGNS indices also appear to be randomly distributed (Figure 11). For all of these analyses, the time period is fairly short as they have been constrained to the late period only and long-term trends cannot be determined.

The spreadsheet analysis goodness of fit was determined using a minimized sum of squares error for the catch and indices. The strict updates of the 2000 assessment had lower values than did those runs with the IGNS index included. Generally, the MRFSS CPUE and probability index estimates fit fairly well with a few notable departures in 1990, 1998, and 2002 (Figure 12). While the JAI estimates prior to 1996 were consistently over estimates and the IGNS index fit fairly well, except for 2002, which was much higher than the population estimate (Figure 13). Between IGNS included and excluded runs, predicted values were quite similar (Figure 14).

FADAPT Retrospective Analysis

A retrospective analysis was conducted to examine the uncertainty in the data for the assessment and the performance of the model configuration. The preferred runs did exhibit some degree of retrospective pattern. However, while the direction was relatively consistent, the magnitude and the duration did not exhibit clear consistency. Generally, F is overestimated and, as time passes, the estimates decrease (Figures 15 and 16). This is particularly true in 2002. The F overestimation in the 2002 terminal year was the highest of any years examined in the retrospective analysis. Typically, the bias is resolved within two to four years. The convergence is not perfect and there are some years in some configurations (2005 in the TAGGING configuration) that remain lower throughout the converged time series (Figures 15 and 16). The variation between runs was largely without pattern, except that 2002 consistently had the highest F values at ages two and three.

Discussion

The current red drum assessment indicates that F has decreased and escapement and static SPR have increased for the red drum northern stocks during the current (late) management period. The results from the 2000 stock assessment indicated that overfishing was occurring; with static SPR values were well below the threshold SPR. The current model estimates are all above 30% static SPR and, therefore, indicate that overfishing is not occurring. In general, it appears that the condition of the northern red drum stock has improved and that the more restrictive management measures implemented during the late period have aided in that improvement.

Results for both models, including and excluding the IGNS indices, over the entire assessment time period are summarized below:

Period	Model/Run	F	Escapement	SPR
Early	FADAPT/BASE1	1.39	1.0	1.1
	Spreadsheet/TAGGING IGNS	1.31	2.3	2.4
	Spreadsheet/TAGGING	1.32	2.2	2.3
Mid	FADAPT/DELTA	0.75	18.3	18.7
	Spreadsheet/TAGGING IGNS	0.59	30.3	30.4
	Spreadsheet/TAGGING	0.60	30.1	30.3
Late	FADAPT/TAGGING IGNS	0.50	40.6	40.4
	FADAPT/TAGGING	0.49	41.0	40.8
	Spreadsheet/TAGGING IGNS	0.66	32.8	32.3
	Spreadsheet/TAGGING	0.63	32.8	32.3

Assumptions of table runs (above): The B2 assumptions in the early and mid periods were the same across both models (early used BASE1 and mid used DELTA). The notation of TAGGING in the early and mid periods denotes the B2 assumption made in the late period only. Highlighted rows in early and mid periods denote preferred model runs. The early period age-2 to age-3 selectivity was 1.0 and 1.0. The mid period age-2 to age-3 selectivity was 1.0 to 0.7 and the late period age-2 to age-3 selectivity was 1.0 to 0.48. The external review also recommended using the TAGGING as the preferred run.

When compared with the 2000 stock assessment results, the average F values in the current assessment do not appear to be greatly different than those in the previous assessment, yet the estimates of SPR were improved (Tables 15-16). This may be the result of changes in selectivity between the two periods. During the mid period, the harvest of a single red drum over the slot limit was allowed. During the late period, possession of red drum over the slot was prohibited. This prohibition likely decreased F on the older fish and thus would have resulted in higher SPR estimates. Other possible reasons are the overall decrease in harvest, which occurred at basically all ages and may have had a more considerable cumulative effect.

The spreadsheet model indicated few differences in terms of F, escapement, and static SPR between the mid and late regulation periods. It should be noted that during the previous assessment, the red drum TC considered the results of the spreadsheet model to be optimistic and that may continue to be true for the period. This was not true of the late period, as both models gave more similar results with the spreadsheet estimating static SPR values that were less optimistic than the FADAPT. The mid period has remained highly divergent between the two models. It may be the result of the significant change in regulation that occurred between the early and mid periods, as the FADAPT estimates were determined in discrete periods while the spreadsheet estimated the entire time period with the selectivity fixed by period. It is not clear why the differences still exist but the spreadsheet mid period estimates may still be considered high.

The retrospective analysis indicated that the model configurations or data exhibit some uncertainty. The 2000 assessment did not include the terminal year in the average F at age calculation from the FADAPT because of retrospective bias concerns. The bias tendency is to overestimate F and to converge within two to four years. Therefore, estimates for the late management period may be conservative in nature. However, while there appears to be direction in the bias, it is important to note that the estimates are clearly uncertain in the most recent years.

The other source of uncertainty is discard characterization for, both the commercial and recreational fisheries. Commercial discards are not included in the assessment because reliable estimates are not available. The length frequencies could be inferred in a similar manner as the DELTA method, but the magnitude, unlike the B2 estimates, is unknown. While the quantity of loss due to discards in the gill net fisheries continues to be unknown, the NCDMF has taken steps to minimize the loss of undersized red drum. In October of 1998, as part of the North Carolina Red Drum FMP, measures were taken requiring the attendance of small mesh gill nets (<5" stretch mesh). Gill nets of this mesh size select for red drum less than 18" TL and are a significant source of the bycatch mortality, particularly in months when water temperatures are high. Current North Carolina regulations require the attendance of small mesh gill nets from May 1 through October 31 in areas known to be critical for juvenile red drum. These include all primary and secondary nursery areas, areas within 200 yd of any shoreline, and the extensive area of shallow grass flats located behind the Outer Banks. Because commercial discard mortalities were not included, the overall fishing mortality is likely underestimated and the escapement and SPR are likely overestimated to an unknown degree. Recreational discards are estimated, but the length and age characterization must be inferred, as it cannot be directly measured. The red drum PDT believed that the assumed TAGGING discard length frequency distributions most accurately reflected the current recreational fishery releases.

Current and ongoing research using tagging data from North Carolina fish was explored in this assessment. The age-3 selectivity for the current regulation period estimated from the tagging model was 0.48, which was similar to 0.43, the estimate from the length frequency analysis done for the 2000 assessment. The analysis of the NCDMF tagging data that was incorporated into the TAGGING run was capable of examining fish that were captured and released for regulatory reasons. It found that the late regulatory period had the highest estimate of older fish in the CAA of any of the discard assumptions (Table 13). This may be a reflection of a catch-and-release fishery that exists for red drum over the slot limit. The sizes and ages of fish captured in the over the slot limit fishery could not be captured in MRFSS and therefore could not be appropriately factored into the CAA. The tagging studies had returns from the over the limit fishery, which were the basis for the TAGGING CAA.

Research Recommendations

The previous assessment listed the following as the three primary needs for future assessments: 1) Catch statistics (sampling of at-sea discards in particular), 2) Length frequency distributions by gear, and 3) age-length keys. Of these, commercial at-sea discards and discard size frequencies remain data gaps for this update.

The lack of at-sea commercial discard sampling continues to be a data limitation in the northern region. The needed data include the amount of fish discarded, the discard mortality by gear type, and the size distribution of those discarded fish. The data on recreational discards continue to be limited in terms of characterizing the fish size distribution. The tagging model estimates may be a step in the direction of observed size distributions. All the methods for recreational B2 size distribution continue to be limited because a common size distribution is used throughout a regulation period. Methods for determining size distribution on an annual basis should be investigated. Also, as recreational landings represent the majority of landings coastwide, the MRFSS intercepts should be increased to accurately characterize this large segment of the total fishery.

The VPA models that were used for this update can be sensitive to M. Better estimates of both subadult M and adult M should be investigated. The model was also demonstrated to be sensitive to changes in the selectivity vector. Research should continue to determine vectors that most closely represent the fishery selectivity and the migration pattern of the fish. Maturity at age was last investigated in 1995 and that data should be updated to reflect the current population conditions as much as possible.

Appendix 3

The current TAGGING configuration is based analysis of tagging data that allowed for the combined selectivity of harvest and released fish to be estimated. Updated tagging models conducted during the completion of the assessment allow for separate selectivity estimates for harvested and released fish (Bacheler et al., In progress). Altering the models to accommodate two selectivities based on the fate of the fish was beyond the scope of this update, but should be investigated for future assessments.

The previous assessment called for continued standardized sampling of the subadults. The northern region had a single fishery-independent index at the time of the last assessment (the North Carolina JAI). Currently, there is also the North Carolina IGNS, which was included as a tuning index for this assessment. Though the time series is short (2001-2005), the IGNS index could track the large 2001 cohort and may be a good indicator of recruitment to the fishery. Future assessment should thoroughly examine the index for its use in those assessments.

There is still a need for the monitoring of adult red drum to provide a fishery-independent spawning stock index. As was discussed in the previous assessment, applying a VPA to the entire age structure, which would extend through ages 50 to 55, is functionally impractical. There are currently very few adult fish age samples and because of the extremely slow adult growth there are too many ages that could be applied to a given length. However, information on the adult population abundance, length, and age structure could provide some indication of the condition of the spawning red drum stock.

Appendix 3

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