Age composition and distribution of red drum (*Sciaenops ocellatus*) in offshore waters of the north central Gulf of Mexico: an evaluation of a stock under a federal harvest moratorium

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Abstract—Because of a lack of fishery-dependent data, assessment of the recovery of fish stocks that undergo the most aggressive form of management, namely harvest moratoriums, remains a challenge. Large schools of red drum (*Sciaenops ocellatus*) were common along the northern Gulf of Mexico until the late 1980s when increased fishing effort quickly depleted the stock. After 24 years of harvest moratorium on red drum in federal waters, the stock is in need of reassessment; however, fishery-dependent data are not available in federal waters and fishery-independent data are limited. We document the distribution, age composition, growth, and condition of red drum in coastal waters of the north central Gulf of Mexico, using data collected from a nearshore, randomized, bottom longline survey. Age composition of the fishery-independent catch indicates low mortality of fish age 6 and above and confirms the effectiveness of the federal fishing moratorium. Bottom longline surveys may be a cost-effective method for developing fishery-independent indices for red drum provided additional effort can be added to nearshore waters (<20 m depth). As with most stocks under harvest bans, effective monitoring of the recovery of red drum will require the development of fishery-independent indices. With limited economic incentive to evaluate non-exploited stocks, the most cost-effective approach to developing such monitoring is expansion of existing fishery-independent surveys. We examine this possibility for red drum in the Gulf of Mexico and recommend the bottom longline survey conducted by the National Marine Fisheries Service expand effort in nearshore areas to allow for the development of long-term abundance indices for red drum.

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Data generated from the fishing industry are important for making population estimates and for evaluating management strategies in fisheries stock assessments. When stocks are severely depleted, harvest closures must be considered. Although such strong measures are likely to accomplish the goal of halting overfishing, the harvest ban simultaneously makes the determination of stock biomass status (e.g., overfished, recovered) increasingly difficult to assess. Although complete harvest bans are seldom used in the United States, recent mandates to end overfishing (2006 reauthorization of Magnuson-Stevens Fishery Conservation and Management Act [MSFCMA, 2006]) have required regional fisheries management councils and the National Marine Fisheries Service (NMFS) to consider this option more often. In 1987, red drum (*Sciaenops ocellatus*) in the Gulf of Mexico (GOM) was one of the first species to be designated as overfished; consequently, a fishery management plan (FMP) was developed and aggressive management actions were taken. As part of the GOM red drum FMP, the harvest of red drum in federal waters of the GOM was prohibited. After eighteen years of restrictions, red drum were no longer undergoing overfishing; however, the stock condition remains unknown (listed as undefined in 2004; Hogarth[1]). To properly evaluate this stock, updated biological information about adult red drum in the GOM is required. Typically, this information is collected directly from commercial and recreational fishermen, but owing to the harvest ban little is known about the current age structure, condition, and distribution of adult red drum in the GOM. We address these deficiencies in data and evaluate the current status of the red drum population in the north central Gulf of Mexico (ncGOM) and, most importantly, recommend monitoring measures for the stock.

Red drum occur throughout the GOM and along the Atlantic states to Massachusetts (Murphy and Taylor, 1990) and are the target of an important recreational fishery in all South Atlantic and GOM state waters. Red drum in the GOM use estuarine habitats as juveniles, including marshes, oyster reefs, seagrasses, and small creeks (Wenner, 1992; Rooker et al.,

[1] Hogarth, W. T. 2004. A message from the NOAA assistant administrator for fisheries: Welcome to NOAA's National Marine Fisheries Service report on the status of the U.S. fisheries for 2004. NOAA,Washington D.C.

1998; Stunz et al., 1999; Stunz and Minello, 2001) and offshore habitats as adults (Beckman et al., 1988). Red drum reach adulthood and emigrate from the estuaries into offshore waters, typically between 3 and 6 years of age (Murphy and Taylor, 1990). Once offshore, these fish are believed to inhabit the waters along the continental shelf during most of the year. During the fall, adult red drum are known to aggregate near inlets to spawn (Overstreet, 1983). Spawning occurs along the continental shelf and within some estuary complexes, indicating that there is plasticity in spawning locations (Holt et al., 1985). Although not characterized as a coastal pelagic, adult red drum can be highly mobile; red drum have been recaptured farther than 700 km from where they were originally tagged (Overstreet, 1983). Because of this capacity for large-scale movement, management of red drum is dependent on cooperation among all GOM states and the federal government.

Harvest of red drum by both the commercial and recreational sectors has seen a marked change since the implementation of the FMP in 1987. Before the 1980s, the harvest was primarily commercial, with catches typically around 1–2 million kg yr^{-1}. By the mid-1980s, and the marketing of "blackened redfish," the harvest increased to a maximum of 6 million kg yr^{-1}. The increased harvest occurred mostly in the offshore waters of the GOM and coincided with the development of a purse-seine fishery for adult red drum. Owing to the schooling behavior of red drum and the tendency of large schools to remain near the surface, red drum were easily targeted with the use of aerial spotters that direct purse-seine vessels. This expedited reduction in the number of adult fish led to decreased spawning stock biomass and resulted in the implementation of a FMP that required a total cessation of red drum harvest in federal waters in 1987. Since that time, commercial red drum harvest has remained near or below 40,000 kg yr^{-1} (a small commercial fishery, however, exists in Mississippi state waters).

The recreational harvest of red drum is limited to state waters and remains heavily regulated. In contrast to the offshore commercial fishery of the 1980s, the historic and current recreational fishery targets primarily juveniles (1–4 yr old) in inshore habitats (Murphy and Crabtree, 2001). Annual landings have increased to over 6 million kg yr^{-1}. Even at this level, escapement of juveniles into the adult stocks was reported to be in excess of the 30% as required by the FMP (Powers and Burns[2]) for all GOM states. This increase suggests that the stock may be on a trajectory for full recovery; however, there is little current information about the age, growth, condition, and population status of red drum that inhabit offshore waters, to evaluate this conclusion. To address this deficiency, we examined age composition, distribution, and condition of red drum from offshore waters in the ncGOM, using red drum collected during fishery-independent surveys from 2006 through 2010.

Materials and methods

Sample collection

Red drum (>660 mm total length, TL) were collected from Alabama, Mississippi, and federal offshore waters in the ncGOM during a monthly bottom longline survey (n=428 red drum, May 2006–May 2010). All longline set locations were randomly generated in predefined strata within the study area. From May 2006 through November 2008, sampling was stratified in blocks established along the shelf (east to west) as well as across the shelf (north to south). In both instances, sampling occurred from the shoreline (~2 m depth) to approximately the 20-meter isobath. Twelve stations were selected each month, allocated evenly across blocks and across the 2–20 m depth. Effort varied during the sampling period, with 93, 148, and 141 stations sampled in 2006, 2007, and 2008, respectively. Beginning in 2009, nearshore sampling was complemented with transect sampling wherein a line of longitude between 88°30′ and 87°30′W (the approximate longitudinal boundaries of Alabama) was randomly selected. Once chosen, stations were fished from the shoreline to approximately 200-m depth. Eighty nine stations were fished in 2009 and 30 in 2010 (Fig. 1A). For each longline set, commercial-style bottom longline gear was used. A monofilament mainline (454-kg test, 2-km length) was deployed off the stern through a block. High flier buoys were used at the start and end of each set. Five-kg weights (start, mid set, end set), and 3.66-m gangions (318-kg test) with 15/0 circle hooks were clipped to the mainline during deployment. Soak time was determined from the time the last high flier buoy was deployed until the first high flier buoy was retrieved to begin the haulback. Hooks were baited with Atlantic mackerel (*Scomber scombrus*) cut to fit the circle hooks (Driggers et al., 2008; Drymon et al., 2010). Measurements of abiotic variables were collected at each station with a Seabird SBE911-plus or an SBE25 conductivity-temperature-depth (CTD) probe (Sea-Bird Electronics, Inc., Bellevue, WA[3]). Nominal catch per unit of effort (CPUE) of red drum caught on the monthly longline survey was calculated as red drum ·100 $hooks^{-1}hour^{-1}$. To standardize CPUE, the delta-lognormal index of relative abundance (I_y) as described by Lo et al. (1992) and Ingram et al. (2010) was estimated as

[2] Powers, S. P., and K. Burns. 2010. Summary report of the red drum special working group for the Gulf of Mexico Fishery Management Council. Special red drum assessment report. Prepared for the Gulf of Mexico Fishery Management Council, Scientific and Statistical Committee. [Available from http://gulfcouncil.org/Beta/GMFMCWeb/downloads/BB%20AUGUST%202010/G%20-%204%20Report%20of%20the%20Red%20Drum%20Working%20Group.pdf, accessed March, 2012.]

[3] Mention of trade names or commercial companies is for identification purposes only and does not imply endorsement by the National Marine Fisheries Service, NOAA.

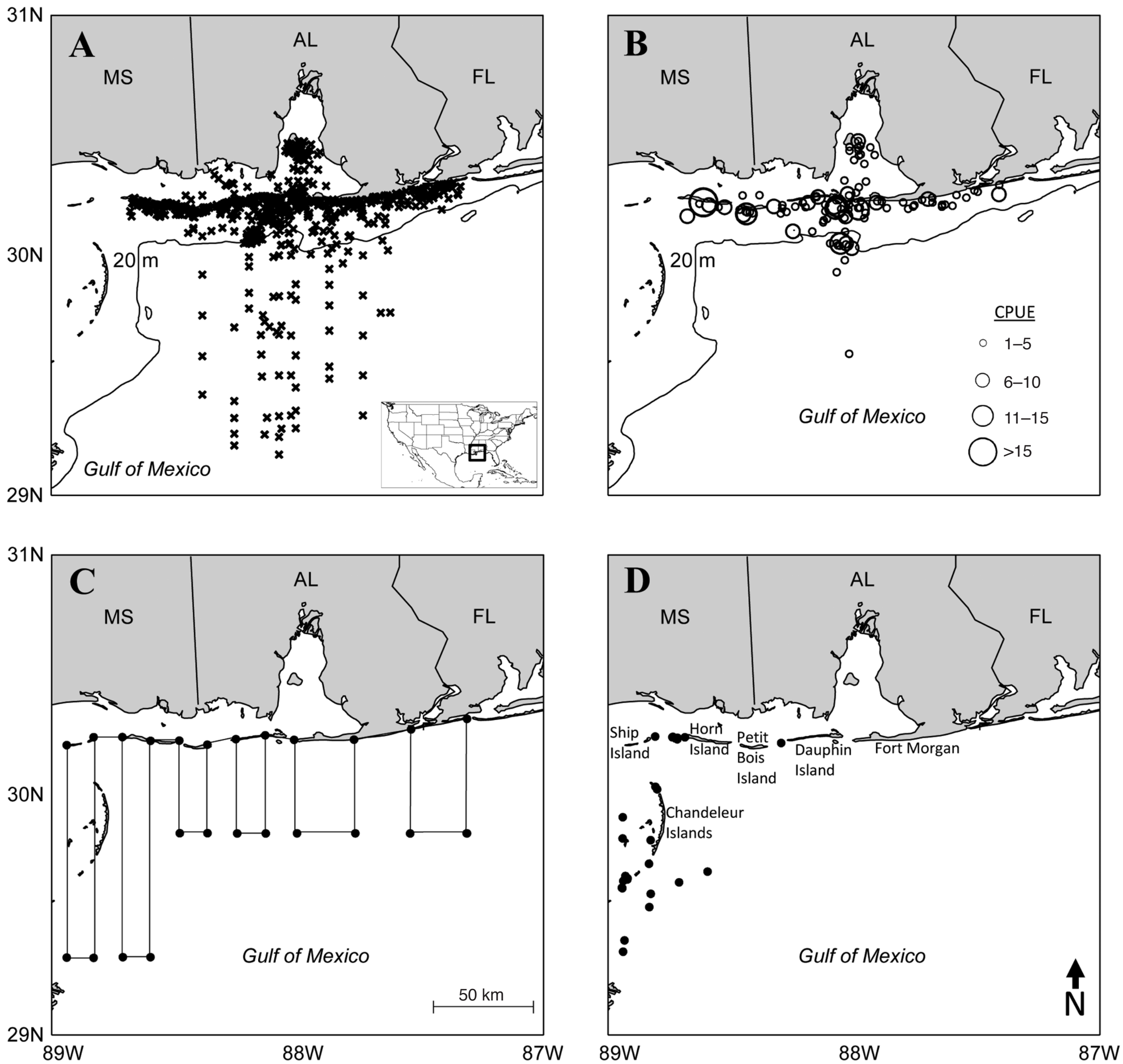

Figure 1

(**A**) Sampling locations and (**B**) catch per unit of effort (fish·100 hooks^{-1} hour^{-1}) for red drum (*Sciaenops ocellatus*) collected between 2006 and 2010 during the bottom longline surveys. (**C**) Transect lines and (**D**) locations of sightings of red drum from the aerial surveys.

$$I_y = c_y p_y, \quad (1)$$

where c_y = the estimate of mean CPUE for positive catches only for year y; and
p_y = the estimate of mean probability of occurrence during year y.

Both c_y and p_y were estimated with generalized linear models (GLMs). Data used to estimate abundance for positive catches (c) and probability of occurrence (p) were assumed to have lognormal and binomial distributions, respectively. The final standardized index is the product of the back-transformed year effects from the two above mentioned GLMs. All GLMs were computed with year and month as factors. The standard error and coefficient of variation were estimated with a jackknife routine on factors with greater than two positive observations. Models were run by using the R programming environment, vers. 2.10.1(R Development Core Team, 2009).

We complemented the red drum distribution data collected by bottom longline with data from aerial survey sightings for red drum conducted from August 2008 through March 2010. Aerial transect surveys were conducted with a Piper Apache PA-23 aircraft. The design covered the ncGOM from the shoreline to 20 nmi south (29°51′N) on eastern transects and out to 60 nmi south (29°19′N) on western transects to cover the Chandeleur Islands. The longitudinal coverage extended from the Chandeleur Islands in the west (88°59′W) to Pensacola, FL, in the east (87°19′W) (13 surveys). Two observers wearing polarized sunglasses conducted the survey by scanning the water to identify organisms from an average altitude of ~213 m. When fish were spotted, the observer signaled to the pilot to circle the object to confirm species identification, record GPS location, and take photographs of the fish school. These aerial surveys lasted approximately 8 hours and were conducted in two 4-hr flights with a fuel stop in between flights (Fig. 1C).

To increase the sample size for growth determination, we augmented our fishery-independent samples with a fishery-dependent collection of red drum greater than 660 mm TL at the 2009 Alabama Deep Sea Fishing Rodeo (ADSFR) on Dauphin Island, AL. Alabama state law allows 1 red drum >26 inches (660 mm) TL to be kept per day in state waters (within 3 miles from the coastline). Tournament anglers were entered into a random drawing if they turned in a red drum >26 inches. Prizes were not based on weight or length and hence anglers had no incentive to "high grade" the fish and turned in the first large red drum they caught. This tournament provided an additional 176 samples. Fish landed at the ADSFR were caught from the nc-GOM, including adjacent bays and coastal waterways, bounded on the east at longitude 85°, south at latitude 28°, and west at longitude 91°.

Standard measurements were collected for all red drum sampled by fishery-independent (bottom longline) or fishery-dependent (ADSFR) gears. Standard length (SL), fork length (FL), and TL for each fish were measured to the nearest millimeter. Total length was defined as natural total length without pinching the tail. Each fish was also weighed (g) and sex was determined. Gonads and any intraperitoneal fat were removed and weighed (g). Two-sample Kolmogorov-Smirnov (KS) tests were used to examine for differences in size distribution between fishery-independent and fishery-dependent sampled red drum.

Fish condition

Beginning in 2008, 3 indices were calculated to assess fish condition: gonadosomatic (GSI), intraperitoneal fat (IPF), and Fulton condition indices. Gonadosomatic and IPF indices are measures of condition where gonad weight (GSI) or fat content (IPF) is divided by total body weight then multiplied by 100 (Wilson and Nieland, 1994; Craig et al., 1995). The Fulton condition index was calculated by dividing weight of the fish by TL^3 and multiplying by 100,000 (Ricker 1975). Differences in IPF between males and females were tested for using a nonparametric Mann-Whitney U test on pooled $\log(x+1)$ transformed data. Differences in sex ratio were tested for using a G-test (Zar, 1999) against an expected 1:1 male-to-female ratio.

Age determination

Beginning in 2008, ages were determined for all red drum captured on the bottom longline survey (n=227) and for fish collected at the ADSFR in July 2009 (n=176). Sagittal otoliths were removed and processed according to the methods described in the otolith manual of the Gulf States Marine Fisheries Commission (VanderKooy and Guidon-Tisdel, 2003). Each otolith was weighed to the nearest gram. Material from the left otolith was removed starting from the anterior side with a thin-section saw (Hillquist, Inc., Denver, CO) until the core was reached. The sectioned otolith was polished and mounted on a glass slide with Loctite 349™ (Henkel Corp., Düsseldorf, Germany) light-sensitive glue and left to set overnight under an ultraviolet light. The otolith was then sectioned to approximately 0.50 mm. Each otolith section was polished and covered with a thin coat of liquid cover slip to smooth out any remaining scratches. Opaque zones (annuli) were counted from the core to the margin in the medial direction. The right otolith was used when the left was not available or when there was a disagreement between otolith readers (Beckman et al., 1988). Each otolith was aged independently by two readers, and the estimated ages were compared. If the reader's initial estimates did not agree, they jointly examined the otolith in question. If the resulting ages still disagreed, the otolith was read by a third reader. If the third reader did not agree with one of the two initial readers, the otolith was excluded from the sample set (Johnson et al., 2010). Average percent error (APE) was calculated by the methods outlined in Beamish and Fournier (1981).

Von Bertalanffy growth curves were fitted to both males and females for the complete data set, the fishery-independent (longline) data set, and the fishery-dependent (ADSFR) data set by using the following equation:

$$L_t = L_\infty \left[1 - e^{k(t-t_0)}\right], \tag{2}$$

where L_t = TL at time t;
L_∞ = the asymptotic length;
e = the base of natural logarithms;
k = the von Bertalanffy growth coefficient,
t = age; and
t_0 = the theoretical age at which TL equals zero (von Bertalanffy, 1938).

Differences in growth curves between males and females were tested for using a likelihood ratio test (Kimura, 1980; Haddon, 2000).

Results

Distribution of red drum

A total of 428 adult red drum were captured on bottom longline cruises at multiple locations from Mississippi and Alabama from 2006 through 2010 (Fig. 1B). The highest concentrations of fish were collected near the pass between Dauphin Island and Ft. Morgan (mouth of Mobile Bay) and offshore Petit Bois Island. Twenty-four percent of sets produced red drum, and a maximum of 23 individuals were captured during a single set (October 2007). Standardized mean monthly CPUE for red drum was bimodal with the greatest concentrations of fish captured in March (2.7 fish·100 hooks^{-1} hour^{-1}) and April (2.3 fish·100 hooks^{-1}hour^{-1}) followed by November (1.5 fish·100 hooks^{-1}hour^{-1}). Mean monthly temperatures followed a predictable seasonal pattern, ranging from a low of 12.3°C in February to 31.7°C in August (Fig. 2). The majority of red drum were collected in water <20 m deep, although effort was high throughout waters <60 m deep. The maximum depth red drum were collected from was 63 m.

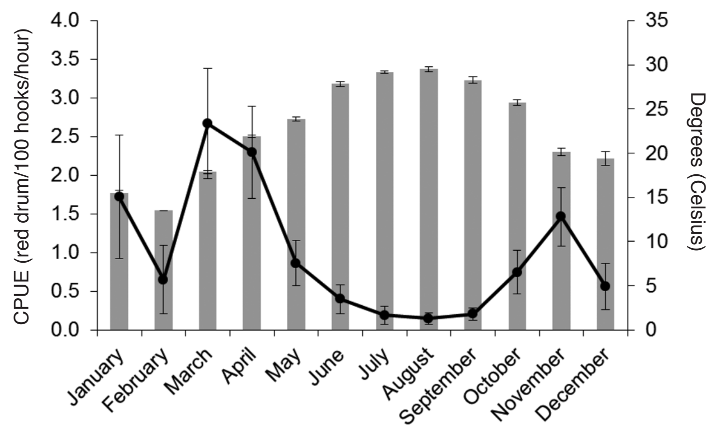

Figure 2

Mean monthly catch per unit of effort (CPUE [±standard error, SE], line) and temperature (±SE, bar) for longline-caught red drum (*Sciaenops ocellatus*), May 2006–May 2010.

In general, red drum distributions revealed in the aerial surveys complemented the spatial distribution patterns determined from the bottom longline gear. Red drum schools were spotted during 8 out of 13 aerial surveys. All red drum schools were spotted west of Mobile Bay (88°W longitude), many near the barrier islands of the ncGOM. Sightings occurred most frequently in the shallow waters around Dauphin Island and Petit Bois Island, and around the Chandeleur Islands (Fig. 1D).

Length, age, and growth of red drum

Length-frequency distributions differed between the longline- and ADSFR-collected fish. The mean (±standard error [SE] TL) of the 428 red drum collected on the bottom longline was 912 (± 3.0) mm with a range of 720 mm to 1101 mm TL (Fig. 3A). For the 176 red drum collected at the ADSFR, the mean total length was 849 mm with a range between 660 and 1156 mm TL (Fig. 3B). Fish collected on longlines were significantly longer than the fish captured at the ADSFR (two-sample KS test, D=0.416, P<0.0001). Males and females were analyzed separately for length differences. Females were longer than males for both bottom longlines and ADSFR. Mean total length for bottom longline females (n=114) was 923 (±6.09) and 885 (±6.23) for males (n=99). For the ADSFR, mean total length for females (n=106) was 870 (±12.25) and 811 (±15.03) for males (n=67).

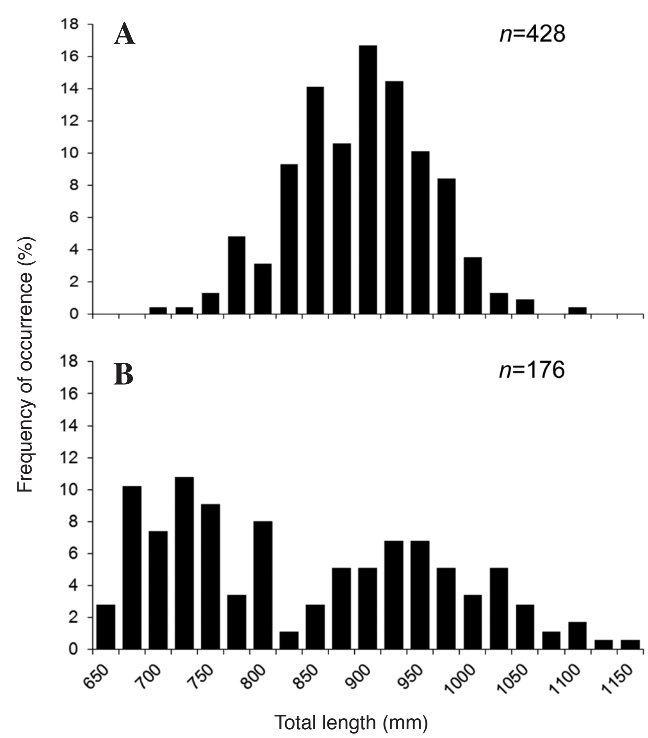

Figure 3

(**A**) Length frequency of red drum (*Sciaenops ocellatus*) sampled on the fisheries-independent longlines (2006–10) and (**B**) at the fisheries-dependent Alabama Deep Sea Fishing Rodeo (2009).

Ages were determined for both fishery-independent and fishery-dependent collections. Average percent error for the two readers was 0.004%, indicating precise aging. No otoliths were excluded owing to a discrepancy in counts of annuli. The mean (±SE) age for fish caught on the longline was 16.5 (±0.4) years with a range of 2–34 years (Fig. 4A). For fish sampled at the ADSFR, age composition ranged from 2 to 38 years. The mean age of an ADSFR fish was 9 years; however, 50% of fish collected were in the 2–4 year category (Fig. 4B). For longline fish, the age frequency distribution indicated a relatively constant proportion of red drum ages 5–24 and a lower frequency of fish 25 years and older. Assignment of aged red drum to a respective year class revealed a decreased contribution of red drum born in 1986 or earlier. The increased contribution of postmoratorium red drum was highest in 1992 and 1993. Fish collected by longline were significantly older than fish collected from the ADSFR ($F_{2,643}$=51.82, P<0.001). For the ADSFR-collected fish, higher proportions of 2-, 3-, and 4-year-old fish were evident in the distribution, alongside a relatively constant frequency of 7–24 year-old fish. The recreational fishery for red drum >660 mm was dominated by recent year classes (Fig. 4).

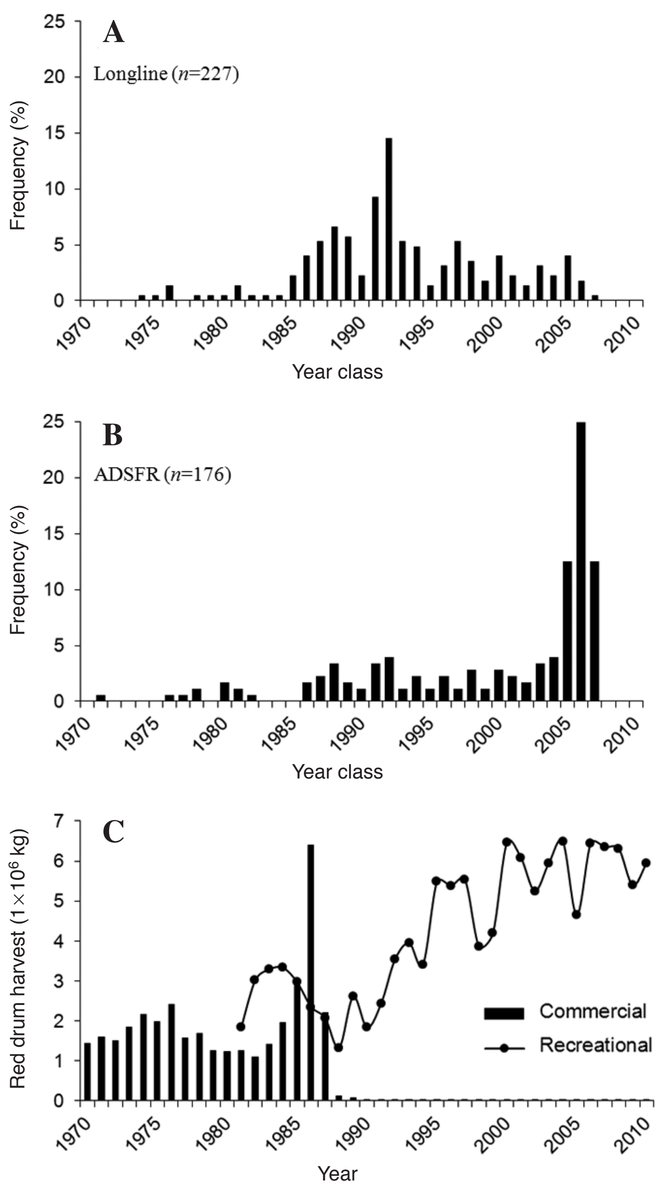

Figure 4

Age composition of red drum (*Sciaenops ocellatus*) sampled on the (**A**) fisheries-independent longlines (2006–10), and (**B**) at the fisheries-dependent Alabama Deep Sea Fishing Rodeo (ADSFR) (2009). (**C**) Commercial and recreational harvest of red drum from the Gulf of Mexico. Commercial data are available from http://www.st.nmfs.noaa.gov/st1/commercial, and recreational data are available from http://www.st.nmfs.noaa.gov/st1/recreational (accessed March 2012).

The von Bertalanffy growth model parameter estimates indicated disparities between males and females, similar to those seen in previous studies (Table 1). We determined the sex for a total of 387 fish from both longlines and the ADSFR and calculated a 1:1.3 male-to-female ratio. For the fish collected in this study, the population had a significant female bias (G_{obs}=3.932, df=1, P<0.05). Higher L_∞ were modeled for female red drum (1012 mm TL) than for males (969 mm TL), and females showed lower growth coefficients. This pattern was also seen with the data from each collection separately: bottom longline ($L_{\infty\ females}$=989 mm TL, $L_{\infty\ males}$=954 mm TL) and ADSFR ($L_{\infty\ females}$=1046 mm TL, $L_{\infty\ males}$=1009 mm TL) (Table 2).

Condition indices

The Fulton condition index remained relatively constant by month and sex, whereas the GSI and IPF indices varied throughout the year and between sexes. GSI values were highest in September and relatively low for nonsummer months. IPF peaked in May, remained relatively consistent through June and July and abruptly decreased in September. IPF remained low through the November sampling (Fig. 5). Males (mean IPF [±SE]=0.55 [±0.06]) had significantly less IPF compared to females (mean IPF [±SE]=0.65 [±0.07]) (Mann-Whitney U test, Z=–3.233, P=0.001).

Discussion

The mandate to end overfishing included in the Magnuson-Stevens Fisheries Conservation and Management Act (2006) requires aggressive management for species subjected to unsustainable exploitation levels. Harvest moratoriums may be viewed as the extreme end of a continuum of potential management interventions. Although full harvest closures are rare, harvest closures of any kind will decrease the quantity of fisheries-dependent data available for stock assessments. For species whose harvest moratoriums persist for extended periods or over large spatial scales, the lack of fisheries-dependent data may severely limit the ability to assess stock condition. Red drum are an example of such a scenario. The total ban on harvest in federal waters in the Gulf of Mexico has been in place since 1987 and little information is available on the spawning stock of

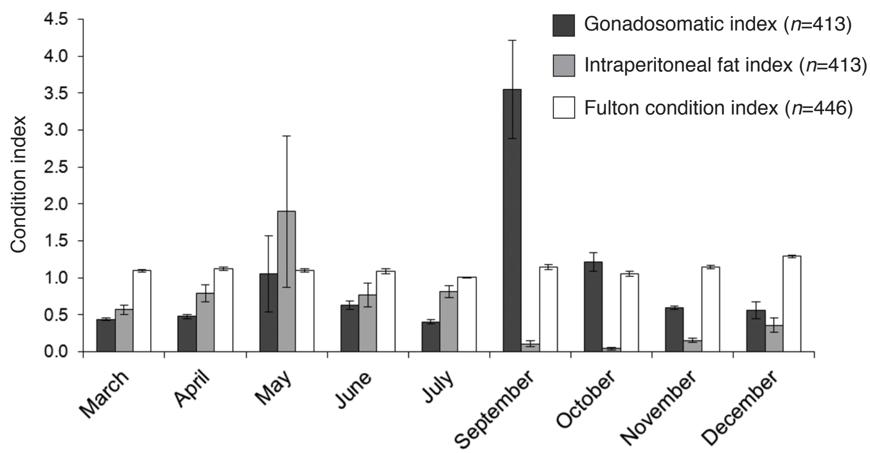

Figure 5

Mean monthly gonadosomatic index (GSI), intraperitoneal fat index (IPF), and Fulton condition indices for red drum (*Sciaenops ocellatus*) sampled from the north central Gulf of Mexico between March 2008 and May 2010. Gonadosomatic and IPF indices are measures of condition where gonad weight (GSI) or fat content (IPF) is divided by total body weight then multiplied by 100 (Wilson and Nieland, 1994; Craig et al., 1995). The Fulton condition index was calculated by dividing weight of the fish by TL^3 and multiplying by 100,000 (Ricker, 1975).

Table 1

Comparison of von Bertalanffy growth parameter estimates from red drum (*Sciaenops ocellatus*) studies in the Gulf of Mexico. L_∞=the asymptotic length, k=the von Bertalanffy growth coefficient, and t_0=the theoretical age at which total length equals zero. TX=Texas; LA=Louisiana; MS=Mississippi; AL=Alabama; FL=Florida.

Study	Location	L_∞	k	t_0
Current study	AL			
Males		923	0.11	–10.00
Females		965	0.109	–10.00
Beckman et al. (1988)	TX, LA, MS, AL			
Males		909	0.137	–7.74
Females		1013	0.088	–11.29
Murphy and Taylor (1990)	FL	934	0.45	0.029

Table 2

Parameters for von Bertalanffy growth function by survey type (combined, longline and Alabama Deep Sea Fishing Rodeo [ADSFR]) and sex for red drum (*Sciaenops ocellatus*) in the north central Gulf of Mexico. N=total sample size, L_∞=the asymptotic length, k=the von Bertalanffy growth coefficient, and t_0=the theoretical age at which total length equals zero.

Data set	N	L_∞	k	t_0
Combined (both sexes)	403	993	0.109	–10.00
Males	166	969	0.110	–10.00
Females	221	1012	0.109	–10.00
Longline (both sexes)	227	979	0.108	–10.00
Males	99	954	0.114	–10.00
Females	114	989	0.113	–10.00
ADSFR (both sexes)	176	1037	0.127	–7.11
Males	67	1009	0.123	–7.58
Females	106	1046	0.126	–7.36

this species. Effective monitoring of the recovery of red drum stocks will require the development of fishery-independent indices that allow periodic examination of age composition—a strategy needed for many species under harvest moratorium. The most cost-effective approach to developing such monitoring is the expansion of existing fishery-independent surveys because of the limited economic incentive to evaluate nonexploited stocks. Using our bottom longline survey, which was designed to be an expansion of the NMFS Gulf of Mexico bottom longline survey into nearshore waters, we illustrate the benefits of such an approach.

Fishery-independent longline surveys proved to be an effective means of obtaining the data needed to calculate an abundance index for adult red drum in the nearshore waters of the ncGOM. Data from these surveys, coupled with fishery-dependent sampling in state waters, provide a means by which to calculate age composition, length frequency, and condition of ncGOM red drum. This combination of fishery-dependent and fishery-independent techniques allows an assessment of a population whose spawning stock is largely under a harvest moratorium.

Monthly red drum CPUE showed a bimodal distribution with peak catch rates occurring in spring (March to April) and fall (November). These peaks in catch may reflect the preferred temperature range of this species. Red drum CPUE dropped precipitously from May through September, during which time mean monthly water temperature averaged 28°C (±0.18SE). During the spring (March–April) and fall (November) peaks in CPUE, mean bottom temperature was 21 (±0.31SE) and 20 (±0.39 SE) °C, respectively. These data indicate that the distribution of red drum in coastal waters may be temperature dependent. Under laboratory conditions, greatest metabolic capacity was shown for red drum when exposed to near-optimum thermal regimes (Fontaine et al., 2007). Equally plausible, seasonal patterns in red drum CPUE may be linked to temporal changes in prey availability, as demonstrated for red drum in Texas (Scharf and Schlicht, 2000), although we lack the data to further examine this hypothesis. Regardless of the mechanism, the bimodal peak in distribution determined with the current sampling scheme has implications for designing monitoring programs. Our data indicate the benefit of monthly sampling when possible and provide evidence that surveys sampling exclusively during summer months will not provide high enough catches to generate specimens for age determination.

In contrast to the utility of bottom longlines, high variability in water clarity and sea conditions limited data from the aerial surveys. The aerial surveys were most useful in providing spatial distribution data. Ideally, abundances of red drum could be calculated from the aerial survey images; however, these abundances would only represent fish on the surface and not those found at depth within the school. Also, during the aerial survey, high variability in water clarity and sea state made it difficult to enumerate fish. Therefore, number of schools was the best descriptor of abundance. School size (area coverage) could be calculated from images where the lens size and altitude were known; however, lens angle is a significant covariate that is difficult to control. Logistic difficulties with aerial surveys and the fact that the survey produced no length or age estimates lead us to question the utility of these surveys in generating long term abundance indices.

Age composition of the red drum collected by fishery-independent sampling indicated that older age classes of red drum are present in the offshore population of Alabama and Mississippi. Red drum younger than 24 years old were present in much higher frequency than 25+ year-old fish. The age frequency distributions of 6–24 year-old fish was relatively constant with an average of 4.0 (±1.3%, 1 standard error) in each age class. In contrast, fish older than 26 years were present in low frequencies (0.7 [±0.4%]) per age class. Fish 25 years old at time of capture would be assigned to annual cohorts between 1983 and 1985 and therefore subject to fishing pressure prior to the federal moratorium (1987). Our findings agree with previous work conducted in Florida, where the distribution of adult red drum sampled with purse seines showed that fish before the 1984 year class were rare (Murphy and Crabtree, 2001).

Further evidence for the effectiveness of the moratorium was provided by the elevated frequencies of the 1991 and 1992 year classes. Red drum recruit to the offshore population between the ages of 3 and 6; therefore, the year classes in 1991 and 1992 would have been the first to recruit to the offshore population after the 1987 federal fishing moratorium. Data for the fish in year classes from 1987 through 1992 therefore provide evidence that the moratorium was effective in increasing recruitment to the offshore fishery. Using similar techniques, Murphy and Crabtree (2001) reported strong red drum year classes in 1986 and 1989. The authors attribute the persistence of these year classes to periods of low exploitation after state management actions. These studies show how the effectiveness of management measures can be tested by fishery-independent monitoring of year-class strength.

Our fishery-independent collections also allowed evaluation of individual fish condition and provide insight into timing of red drum spawning. Condition indices for longline-collected fish were relatively high, with the exception of the period after spawning. Our data suggest that those energy reserves stored as intraperitoneal fat are consumed during the energetically demanding red drum spawning period. In a concurrent survey of ichthyoplankton (January–December, 2006–10), Hernandez et al. (2010) reported red drum larvae only in September and October. This period of larval occurrence coincides with the highest GSI and lowest IPF indices and is consistent with a late September to early October spawning period.

Although a contrast between the fishery-independent and fishery-dependent collections is limited because the ADSFR collection was not a random sampling of all anglers in the region, contrasting the fisheries independent and dependent collections does provide a snapshot of the data that would be generated from future recreational surveys of red drum above the slot limit (i.e., fish within an allowable minimum and maximum length for harvest, 16–26 inches in AL). The comparison highlights potential differences and biases that are germane to monitoring a stock under the current federal harvest moratorium. The offshore population of red drum that serves as the spawning stock straddles the boundary between state and federal waters south of Alabama, Mississippi, and Louisiana (three miles from shore). From interviews with the 176 anglers that provided fish to the ADSFR, most anglers caught red drum in the higher salinity areas of Mobile Bay and Mississippi Sound and areas within a mile from shore (e.g., Dixie Bar, AL). Less than 25% of anglers reported fishing in waters greater than 3 miles offshore near artificial reefs. The majority (60%) of our bottom longline sampling effort occurred in state waters with the remaining 40% in federal waters. The vast majority of our catch occurred within 3 miles from shore and was highest near the inlets. Given that the spatial distribution of effort between the fishery-dependent and independent collections overlaps, differences between size and age frequency between the fishery-dependent and independent collections are likely due to the broader selectivity of the recreational (hook and line) gear than to the standardized hook size and bait type in our bottom longline survey. The bottom longline selected for fish age 6 and above (>800 mm), whereas 50% of the hook and line catch was 2–5 year-old fish and did not provide large sample sizes of older age classes. The bottom longline tended to capture older age classes of red drum and their abundance is a key determinant for stock condition for long-lived fish.

Central to the current management scheme for red drum is protection of the spawning population. A post-moratorium increase in adult red drum is apparent from examination of the year-class frequency in our data; however, the large increase after the moratorium declined to more modest levels in the last ten years during which fish could be considered fully selected for the longline gear (1996–2006). This trend corresponds to the overall landings pattern for the GOM. Peak, and apparently unsustainable, commercial landings occurred in 1986 around 6.3 million kg. After the moratorium, total landings decreased to 1.5 million kg annually but have steadily increased and recreational landings were approximately 6.3 million kg in 2010. Currently, Louisiana, Mississippi, and Alabama allow retention of one red drum above the catch limit per day, whereas Texas allows two oversized red drum per year. Data collected from the ADSFR suggest 2–5 year-old fish are readily available to recreational anglers and the recreational fishery could be a significant source of mortality for the spawning stock. Although our data represent a limited geographic range of the stock, the data indicate the need to re-assess the current management scheme and evaluate the bag limits and escapement rates of red drum.

Conclusions

Assessment of stock conditions for fish populations under severe harvest restrictions is complicated by a lack of fishery-dependent data. Fishery-independent surveys could be used to fill this void; however, funds for fishery-independent surveys targeting nonexploited stocks are limited. Key to monitoring these stocks will be increasing the efficiency of data collection (*sensu* Link et al., 2008). Stock assessments of red drum are complicated by the mosaic of differing state regulations and the harvest ban in federal waters. Commercial catch from the GOM red drum fishery is minimal (Mississippi allows a limited harvest) and recreational size limits vary between states. Given these differing spatial management schemes, fishery-independent sampling is critical for establishing long-term abundance indices and determining age composition across the GOM for effective monitoring. Our results suggest that bottom longline surveys could fill this role. Specifically, designs should be optimized by focusing in coastal waters <20 m deep, where 99% of our red drum catch occurs. Targeting effort in the spring (March–April) and fall (October–November) would be expected to maximize the sample size for age determination. Although annual bottom longline surveys are currently conducted by the National Marine Fisheries Service (*see* Driggers et al., 2008) and provide fishery-independent data for sharks and red snapper, effort is limited in <20 m depth and the survey occurs only from July through September. Expanding already existing fishery-independent surveys is likely the most cost-effective method of examining stocks that have limited fishery-dependent data.

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