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Characterizing Bull Shark (*Carcharhinus leucas*) Assemblages Near the Sabine Pass Inlet

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The developmental stages of bull shark (*Carcharhinus leucas*) life history and the impact of selected environmental variables on the utilization of a Gulf of Mexico habitat by this species were characterized during late spring through summer 1992–1999. Entanglement nets 91.4 m in length of varying depth (2.40–4.88 m) and mesh sizes (12.7–25.4 cm) were deployed adjacent to jetty and beachfront sites near Sabine Pass. Bull sharks (N = 720) were incidentally captured as part of a study to monitor the population of Ridley sea turtles. The bull shark bycatch portion of the parent study data was expanded in 1997–1999 to record sex and in 1999 to include total length (TL) of individual bull sharks. Bull shark life history stages were estimated for the 1999 study from length and sex. Bull shark TL data when evaluated using size ranges of the *Final Fisheries Management Plan for Atlantic Tunas, Swordfish, and Sharks* indicate that no adult sharks were captured. Total length frequency compared to generally accepted length at age data supports that 94% of the Sabine Pass captures would be at most 6 yr old. A strongly correlated power model (r^2 = 0.91) extended the length-weight relationship data for immature life history stages of bull sharks. Bull shark catch (1992–1999) was positively correlated with water temperature (20.0–40.0°C), salinity (12.3–34.8 parts per thousand), and water clarity (0.0–1.6 m) and inversely correlated with dissolved oxygen (4.4–9.1 mg/liter). The findings suggest that the area surrounding Sabine Pass functions as a nursery/development area for early life-history stages of bull sharks during late spring and summer months when specific environmental factors are present.

In 1980, the Gulf of Mexico Fisheries Management Council (GMFMC) instituted a shark management plan that addressed the issues of season and quotas (GMFMC, 1980). By September 1998, however, bull shark populations were considered overfished (National Oceanic and Atmospheric Administration [NOAA], 2003). After this time period, the *Final Fisheries Management Plan (FMP) for Atlantic Tunas, Swordfish, and Sharks* was developed and allowed a year-round harvest of bull sharks with no annual quota for recreational fishers (NOAA, 1999). Presently, the FMP maintains the open season on recreational catches but limits per vessel catch to one shark with a minimum fork length of 137.2 cm, and restricts commercial fishers in the Gulf of Mexico to an annual quota for bull sharks of 1,017 metric tons dry weight (mt dw) (NOAA, 2004). Within the guidelines of the federal plan, Texas and Louisiana have instituted very different policies. Texas regulations allow recreational fishers a quota of one shark with a minimum length of 61.0 cm per day within nine nautical miles of the coast (Texas Parks and Wildlife Department, 2004). Louisiana limits the recreational landing of bull sharks to one per vessel per trip with a minimum fork length of 137.2 cm but closes the fishing season from 1 April through 30 June (Louisiana Department of Wildlife and Fisheries, 2004).

Shark life history has been divided into four stages: neonates, juveniles, adults, and mating adults (NOAA, 1999). The FMP categorizes the bull shark life history stages into neonate and early juveniles (≤110 cm total length [TL]), late juveniles and subadults (between 111 and 225 cm TL), and adults (≥226 cm TL) (NOAA, 1999). Bull sharks in the early life history stages may be most vulnerable in nearshore waters (Pearce, 1987), making definition of nursery ground characteristics and age composition of the shark assemblages in nearshore waters an important aspect of the biology of the constituent species (Musick et al., 1993). The Magnuson-Stevenson Act has recommended scientific investigations to determine both age and gender composition of nearshore shark assemblages and spatial and temporal conditions of shallow water environs in assessing the importance of these areas to the continued welfare of shark stocks (NOAA, 1999).

Previous investigations have determined that bull sharks are cosmopolitan (Castro, 1996) existing in both freshwater and marine habitats (Thorson, 1972; Bass et al., 1973; Thomerson and Thorson, 1977; Montoya and Thorson, 1982). They have low fecundity, reach sexually maturity late in life, and exhibit a long gestation period (Compagno and Cook, 1995) with females believed to breed only once every 3 yr (Clark and von Schmidt, 1965). Because gravid females enter nearshore Gulf of Mexico waters to give birth, neonates have been found in waters ranging from 28.2 to 32.2°C and at salinities between 18.5 and 28.5 parts per thousand [ppt] (NOAA, 1999). Similarly, juvenile bull sharks have been documented in the Gulf of Mexico across a broad range of water temperature (21.0–34.0°C), dissolved oxygen content (3.7–8.4 mg/liter), and salinity (3.0–28.3 ppt) conditions (NOAA, 1999).

Efforts to define the stages of development in the bull shark's life history have been conducted in the Gulf of Mexico off Alabama (Branstetter and Stiles, 1987), central west and east coasts of Florida (Clark and von Schmidt, 1965; Snelson et al., 1984), south-central Louisiana (Caillouet et al., 1969), and off Nicaragua and Costa Rica (Thorson and Lacy, 1982). Branstetter and Stiles (1987) used time of year of catch and observed growth patterns to determine that while certain pups at birth may be greater than 75 cm TL, as Clark and von Schmidt (1965) and Springer (1967) determined, the majority are between 60 and 75 cm TL at birth, which concurs with reports by Bigelow and Schroeder (1948) and Dodrill (1977).

Based on lengths of mature shark catches, the von Bertalanffy curve estimated the growth rate to be approximately 10 to 15 cm per year for immature sharks within the first 5 yr (Branstetter and Stiles 1987). Thorson and Lacy (1982) reported the growth rate of immature sharks to be closer to 15 to 20 cm per year over approximately this same development period. These studies and others using weight-length relationships (Clark and von Schmidt, 1965; Caillouet et al., 1969; Branstetter, 1981) have contributed to suggestions of bull shark age as correlated to size throughout its maturation process. Total length at maturity, however, differs by gender with mature females being 220 cm TL and mature males between 210 and 220 cm TL (Springer, 1950; Clark and von Schimdt, 1965; Sadowsky, 1971; Branstetter, 1981; Garrick, 1982; Snelson et al., 1984; Castro, 1996).

This study investigated the role of nearshore Gulf of Mexico waters at the Texas/Louisiana border near Sabine Pass in the life history of bull sharks. The objectives of the study were as follows: 1) to determine temporal utilization of the study area by immature bull sharks; 2) to quantify their relative abundance, size composition, and sex ratio; and 3) to assess the potential impact of selected environmental variables on their utilization of the greater Sabine Pass study area.

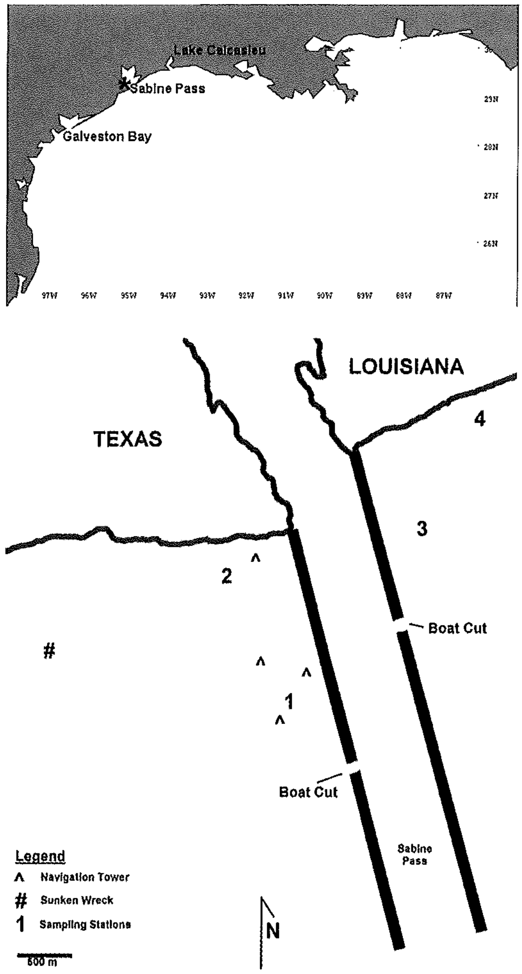

Fig. 1. Sabine Pass geographical location and sampling area with relative location of four primary sites in Texas and Louisiana waters.

Materials and Methods

Study area.—Sabine Pass is a nearshore gulf habitat that serves as a conduit for freshwater inflow from the Sabine Lake estuary to the study area. Four sites in shallow Gulf of Mexico waters near Sabine Pass (Fig. 1) were sampled for bull sharks from 1992 to 1999 (see Sampling Protocol). Two sites were sampled near the West Jetty (Sites 1 and 2) in Texas waters and two were sampled on the East Jetty (Sites

3 and 4) in Louisiana waters. Sites 1 and 3 were sampled immediately adjacent to the outside of each jetty and approximately 1,200–1,500 m from shore. Water depth ranged from 1.5 to 3.0 m, and tidal currents were undetectable to strong. Sites 2 and 4 were located within 1 km of each jetty and between 300–800 m from shore. Water depth ranged from 0.6 to 2.0 m, whereas currents rarely exceeded slight tidal variations.

Sampling protocol.—Duration of research project: Bull sharks were taken as bycatch associated with sea turtle netting activities during the late spring and summer months (May–August) from June 1992 through August 1999 (see Landry et al., 1994, 1995). Sampling took place, weather permitting, for approximately 7 consecutive days each month.

Bull shark capture.—Bull sharks were captured in #9 twisted nylon stationary entanglement nets that measured 91.4 m long, and varied in depth (2.40–4.88 m) and bar mesh (12.7–25.4 cm). At least two stationary entanglement nets were deployed adjacent to one another and perpendicular to jetty or beachfront stations (or both) for 6–12 hr each sampling day. Entanglement nets were checked every 45 min or more frequently as auditory (splashes) and visual (float line not visible or actual sighting of animal, or both) signals were dictated, and all captured organisms were removed.

From 1992 through 1998, bull sharks were counted and released. In 1997–1999, bull sharks were sexed, and in 1999 were measured for TL to the nearest centimeter by taking the straight-line distance from the tip of the snout to the terminus of the epicaudal (Branstetter and Stiles, 1987). All sharks captured from 1997 to 1999 were sexed by presence or absence of claspers. Those sharks that could not be sexed due to difficulties during capture were classified as unknown sex.

Bull sharks captured in 1999 were also weighed on a spring scale to the nearest kilogram. To account for weighing error resulting from boat motion, minimum and maximum readings were averaged to give the approximate weight of each shark (Branstetter and Stiles, 1987).

Although neonate bull sharks can be distinguished from juveniles by the presence of an unhealed umbilical scar on the belly between the pectoral fins, the bycatch study did not allow for this examination. Rather, the size ranges defined in the FMP were used to assist in estimating developmental stages of neonates and early juveniles, late juveniles and subadults, and adults. Weight-length relationship was determined by plotting shark length against its corresponding weight. Previous literature was used to evaluate TL to age at capture (Clark and von Schmidt, 1965; Caillouet et al., 1969; Branstetter, 1981; Thorson and Lacy, 1982; Branstetter and Stiles, 1987).

Environmental variables.—Environmental variables, including water temperature (to the nearest 0.1°C) and salinity (to the nearest 0.1 ppt), were recorded with an 85-m Yellow Springs Instrument Company (YSI) during the 1992–1999 sampling period. In addition, dissolved oxygen content (to the nearest 0.01 mg/liter) was monitored from 1996 through 1999. Measurements were taken as time permitted at each netting site during early morning (between 0630 and 1030 hr), mid-day (between 1100 and 1400 hr), and late afternoon (between 1415 and 1900 hr). A field thermometer, American optical refractometer, and Hach Company dissolved oxygen kit were used to calibrate the digital YSI equipment. Water clarity/turbidity (to the nearest 0.1 m) was estimated with a 20-cm diameter Secchi disc attached to a metrically calibrated line.

Ranges and means of each environmental variable were calculated from the raw data across months and years for the 1992 through 1999 sampling periods in order to identify any trends. Simple Pearson's linear correlations were run to determine whether statistical correlations existed between bull shark catch numbers and each environmental variable. Significance of each correlation was determined by a Student's t-test, where t was determined to be r divided by its standard error (Zar, 1999).

Results

Data analysis.—Data for 1999 were analyzed with respect to time of day, net mesh size, and site of capture to determine whether either variable had a significant effect ($\alpha = 0.05$) on bull shark capture rates. Paired t-test results indicated that catch numbers did not significantly differ between netting periods. Therefore, the null hypothesis that time of day, 0700–1200 hr versus 1201–1700 hr, had no effect on bull shark catch was accepted ($t = -0.7002$, $n = 68$). No significant differences in catch numbers were detected for different net mesh sizes (for 12.7-cm vs 25.4-cm nets, $n = 10$, $t = 1.4728$; for 17.8-cm vs 25.4-cm nets, $n = 5$, $t = -1.7870$). Finally, an analysis of vari-

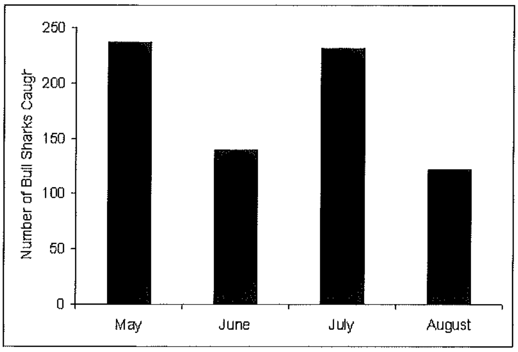

Fig. 2. Combined monthly numbers of bull sharks captured at the Sabine Pass study area during 1992 through 1999.

ance detected no significant variance in bull shark capture rates among the four netting sites. The null hypothesis that netting location had no impact on bull shark catch numbers was accepted ($F = 1.0227$).

With no significance of time of day, net size and site location on the capture data for 1999, an assumption was made that the same parameters would also have no significance to capture numbers recorded in 1992 through 1998 because sampling protocol with respect to these parameters was basically the same in all study years. Therefore, one database was created for 1992 through 1999 that included sampling date and number of sharks captured, and measurements of salinity, water temperature, and water clarity. In addition, dissolved oxygen content was included for 1996 to 1999, and bull shark sex was recorded from 1997 through 1999.

Bull sharks.—The monthly distribution of bull sharks captured across years is shown in Figure 2. The highest catch occurred in May, and the lowest in August. An alternating pattern of similar catch numbers existed during May through August in that capture rates in June and August averaged 45% less than that in the preceding month.

Extreme variability existed in both monthly catch numbers and across years. There was no apparent trend of increasing or decreasing numbers across months within respective years, and no single month dominated catch statistics. Yearly catch numbers show fluctuation among years without yielding any apparent trend (Fig. 3).

Length.—The 130 sharks measured in 1999 ranged from 76.0 to 198.1 cm TL, with nearly 94% of the catch <150 cm TL. Only 10% were

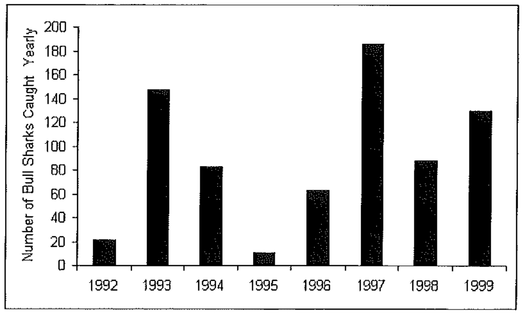

Fig. 3. Number of bull sharks caught yearly in the Sabine Pass sampling area from 1992 through 1999.

<90 cm TL, whereas 38% measured 90–119.9 cm TL and 46% were 120–149.9 cm TL.

Neonates and early juveniles represented 26% of the total catch, while no adult sharks were captured. Neonate/early juvenile catches peaked in July and late juvenile/subadults peaked in May. The lowest number of 1999 captures occurred in June, while the highest occurred in July (with 40% of the total catch). No neonate/early juvenile bull sharks were caught in June 1999, but overall catch numbers were few in this month (Fig. 4).

Weight-length comparison.—The power model of Weight $= 1.0 \times 10^{-4}$Length$^{2.406}$, with a coefficient of determination (r^2) of 0.91, yielded the best fit of the four models (linear, logarithmic, exponential, power; Zar, 1999) tested (Fig. 5).

Sex comparison.—Of the 361 bull sharks captured in 1997 and 1999, 214 were male and 147 were female for a male to female ratio of 1.5:1. Sex ratios varied within sampling years. In 1998 the male to female ratio was 2:1 (n = 80), while in 1997 and 1999 it was 1.2:1 (n = 158 and n = 123, respectively). In 1999, for neonate/young juvenile sharks (n = 33), males outnumbered females by almost 2:1, whereas late juvenile/subadult males and females were

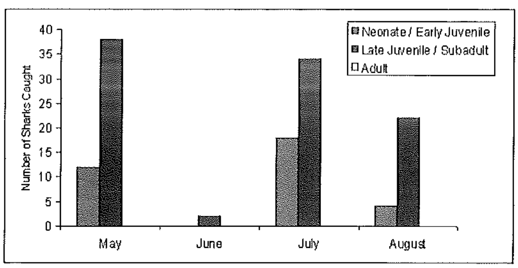

Fig. 4. Number of bull sharks caught monthly within the FMP classifications during 1999.

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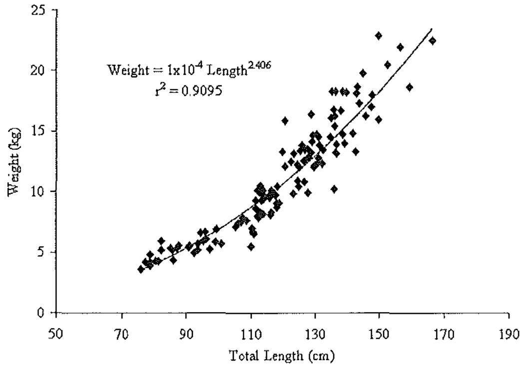

Fig. 5. Weight–total length relationship for bull sharks netted at the Sabine Pass study area during 1999 (N = 121).

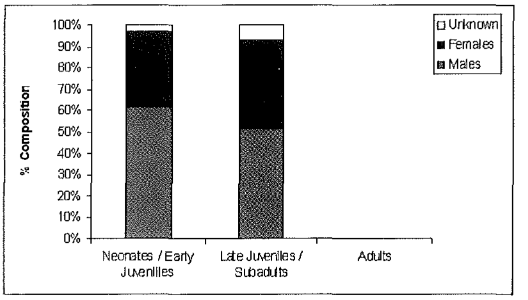

Fig. 6. Percent composition of bull sharks caught in the nets during the 1999 sampling season.

caught in approximately equal numbers (n = 90) (Fig. 6).

Environmental variables.—A total of 630 observations were made for water temperatures (°C), salinity (ppt), dissolved oxygen content (mg/liter), and water clarity (m) over the 210 netting days of the 8-yr study. Water temperature ranged from 20.0°C on 7 July 1993 to 40.0°C on 3 July 1992 (Table 1). Monthly mean water temperature increased from May to August, while 1992 and 1993 yielded the warmest and coolest annual means, respectively (Table 1).

Mean salinity values reflected a steady increase from May through August (Table 1). Mean dissolved oxygen content generally declined from May through August (Table 1). Mean water clarity monthly means were the same from May to July and then increased in August.

Linear regression with resulting correlation statistics were investigated for monthly mean environmental variables across the sampled years ($\alpha = 0.05$). Salinity and water temperature were strongly positively correlated ($r = 0.970$), as was visibility to both water temperature ($r = 0.835$) and salinity ($r = 0.944$). Dissolved oxygen was negatively correlated to water temperature ($r = -0.428$), salinity ($r = -0.719$), and water clarity ($r = -0.543$).

Effect of environmental variables on catch.—Bull shark catch numbers were significantly correlated ($\alpha = 0.05$) to all mean monthly environmental variables. Partitioning this correlation with respect to each variable revealed a moderately strong, negative catch relationship between numbers of sharks and water clarity ($r = -0.846$), salinity ($r = -0.758$), and water temperature ($r = -0.634$), and a positive and moderately strong ($r = 0.675$) catch numbers relationship with dissolved oxygen content.

TABLE 1. Environmental variable with ranges and monthly means at the Sabine Pass study area from 1992 through 1999.

Parameter		May	June	July	August	Overall
Water temperature (°C)	n	42	29	46	49	166
	range	20.3–38.1	20.9–38.3	20.0–40.0	27.4–39.5	20.0–40.0
	mean	26.6	28.1	30.0	31.4	29.2
Salinity (ppt)	n	48	47	56	49	200
	range	12.4–27.5	17.7–29.9	14.2–32.3	19.4–34.8	12.3–34.8
	mean	19.7	21.6	23.3	27.3	22.8
Dissolved oxygen (mg/liter)	n	18	18	22	18	76
	range	4.7–9.1	4.4–9.1	4.4–7.7	4.4–7.7	4.4–9.1
	mean	7.2	6.1	6.1	6.0	6.4
Water clarity (m)	n	50	48	59	51	208
	range	0.0–1.3	0.0–1.0	0.1–0.9	0.1–1.6	0.0–1.6
	mean	0.4	0.4	0.4	0.6	0.5

Discussion

Bull shark TL data when evaluated using the FMP size ranges for neonate/early juvenile, late juvenile/subadult, and adult indicate that no adult sharks were captured. Total length frequency data collected during the study also were compared with length-at-age estimates developed by Branstetter and Stiles (1987) to classify the age and maturity of the bull shark captures in the Sabine Pass study area. Assuming a 10- to 15-cm growth in length per year throughout the first 5 yr (Branstetter and Stiles, 1987) and a typical birth length of 60–75 cm (Bigelow and Schroeder, 1948; Springer, 1960; Clark and von Schimdt, 1965; Dodrill, 1977), 94% of the Sabine Pass captures would be considered to be 6 yr old at most. Comparison of the largest bull shark captured at Sabine Pass in 1999 (198 cm TL) with the smallest mature bull shark classified by Branstetter and Stiles (1967) (217 cm TL and characterized as 15 yr old) again supports that no mature sharks were captured in the study area.

The weight-length model generated from this study is one of the first such relationships for small bull sharks, and can be considered a major contribution. Weight-length relationships generated by this study provide a strongly correlated model for bull sharks <170 cm TL. Although Snelson et al. (1984) also reported a weight-length relationship based primarily on immature life history stages (70–250 cm TL), their study incorporated only 80 sharks and length-frequency data were somewhat skewed. Two other studies (Branstetter and Stiles, 1987; Cliff and Dudley, 1991) reported strong weight-length relationships for bull sharks that applied primarily to adults.

Three previous studies suggest that nursery/developmental areas would contain equal numbers of male and female bull sharks (Clark and von Schmidt, 1965; Snelson et al, 1984; Garayzar, 1996). In contrast, three other bull shark studies reported that females slightly outnumber males (Branstetter, 1981; Cliff and Dudley, 1991; Russell, 1993). Contrary to any of these studies, over a 3-yr period, males in the Sabine Pass study area were found to consistently outnumber females. The strongest inequality in male and female numbers was observed in the neonate/young juvenile life history stage.

The presence of bull sharks in the Sabine Pass study area was noted across wider temperature ranges (20–40°C; Table 1: Overall) than were conspecifics frequenting other areas of the Gulf of Mexico (23–32°C; Caillouet et al., 1969; Grace and Henwood, 1997) and the South Africa coast (20–25°C; Cliff and Dudley, 1991). A similar trend existed for dissolved oxygen content, wherein capture of bull sharks was made across a wider range of concentrations (4–9 mg/liter) than that reported from other studies (3–6 mg/liter; Grace and Henwood, 1997; Mark Grace, National Marine Fisheries Service, personal communication, 6 Dec. 1999). However, mean readings for water temperature and dissolved oxygen content would fall within comparable ranges of these previous studies.

Bull shark capture rate in the Sabine Pass study area exhibited a very strong inverse relationship with water clarity: as visibility decreased, catch numbers increased. All captures were in water clarity <2 m. This trend mirrored that reported by Cliff and Dudley (1991), who captured 67% of their bull sharks near Natal, South Africa, in water clarity <3 m. Although bull sharks discriminate between nets of differing colors in tanks (Wallace, 1972), they become more susceptible to netting capture at reduced visibilities (Snelson et al., 1984; Cliff and Dudley, 1991). Turbid waters of the study area probably enhanced bull shark capture by reducing their ability to see and avoid entanglement nets.

Based upon the size of sharks captured, Sabine Pass can be considered an essential early life history bull shark habitat as defined by the Magnuson-Stevenson Act (NOAA, 1999).

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