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The Charleston Bump: An Island of Essential Fish Habitat in the Gulf Stream

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Abstract.—The Charleston Bump is a complex bottom feature of great topographic relief located southeast of Charleston, South Carolina. This bottom feature deflects the Gulf Stream offshore in the South Atlantic Bight, and establishes permanent and temporary eddies, gyres, and associated upwellings in the warm Gulf Stream flow. Thermal fronts associated with Gulf Stream deflection, and the bottom feature itself, are believed to be attractive to large pelagic fishes, or result in concentrations of larvae, juveniles, and prey for larger fish. Upwelling in the region supports early life history stages of important fishery species. Deflection of the Gulf Stream may also play a direct or indirect role in transport of early life stages toward, or away from, nursery areas. Sea surface temperatures (SSTs) influenced by the Gulf Stream response to the Charleston Bump appear to have a role in determining recruitment success in gag *Mycteroperca microlepis*, a continental shelf reef fish. Relative cohort strength in gag was correlated ($r = 0.89$) to SST at 33°30′N, 78°30′W. Variability in conditions that affect recruitment of larvae and juveniles, combined with heavy fishing pressure on prespawning adults, may result in recruitment failure in gag. In addition to strongly influencing circulation patterns in the South Atlantic Bight, the rugged bottom topography of the Bump is an important habitat and spawning ground for wreckfish *Polyprion americanus* and supports the U.S. fishery for this species. As a result, the Bump is an essential habitat for this species in U.S. waters. A geographic analysis of commercial pelagic longline logbook data shows that the Charleston Bump is an area of concentrated commercial fishing effort, and that pelagic longline fisheries also concentrate along fronts at the edges of Gulf Stream gyres and eddies downstream. The "Charleston Bump Complex" of rough bottom topography and dynamic oceanography is an essential habitat for wreckfish and highly migratory pelagic fishes, and may influence recruitment success in some continental shelf fishes.

The Charleston Bump is a deep, rocky, bottom feature located on the Blake Plateau southeast of Charleston, South Carolina. Although Brooks and Bane (1978) first formally named and described the feature and its effect on Gulf Stream flow, there are several earlier references to disturbances in the Gulf Stream near the topographic feature now known as the Charleston Bump (see Singer et al. 1983 for review). The sea floor in the Bump region is characterized by a spreading and shoaling of isobaths northward of the Straits of Florida. Shoaling results in isobaths at about 31°N latitude tending in a perpendicular to the coast and to the northward-flowing Gulf Stream, which is the dominant current flow in the region. These bottom features lie on the relatively flat Blake Plateau, a feature that interrupts the steeper continental slope and separates the inshore Florida–Hatteras slope from the offshore Blake Escarpment (Figure 1). This "island" of topographic relief in an otherwise relatively flat bottom in the path the Gulf Stream causes a disturbance in the flow of one of the earth's dominant oceanographic features. This island in the Gulf Stream has profound effects its flow, causing a change in flow direction and propagation of downstream eddies that, together with complex bottom topography, provide a unique habitat that supports populations of pelagic and demersal fishes. The Bump may provide nursery habitats for early life history stages, and a "stepping stone" in the migratory route of several highly migratory pelagic fishes.

In the re-authorization of the Magnuson-Stevens Fishery Conservation and Management Act, through the Sustainable Fisheries Act, the U.S. Congress included Essential Fish Habitat (EFH) provisions that required fishery management councils to identify EFH, to include "those waters and substrate necessary to fish for spawning, feeding, or growth to maturity" (Schmitten 1999). While broad in scope, and perhaps including most aquatic habitats, this definition would certainly include the "Charleston Bump Complex" of bottom features and associated oceanographic phenomena, which constitute a known feeding, spawning, and aggregation area for wreckfish *Polyprion americanus*, and perhaps other species (Sedberry et al. 1999; Govoni et al. 2000).

Oceanographic, Historical, and Geographic Setting

The Charleston Bump includes an underwater ridge and trough feature on which the seafloor rises from 700 to 400 m within a relatively short distance and at a transverse angle to both the general isobath pattern of the upper slope, and to northerly-flowing Gulf Stream currents (Brooks and Bane 1978; Bane et al. 2001, this volume). The Bump includes over 100 m of rocky relief (Figure 2), with carbonate outcrops and overhangs,

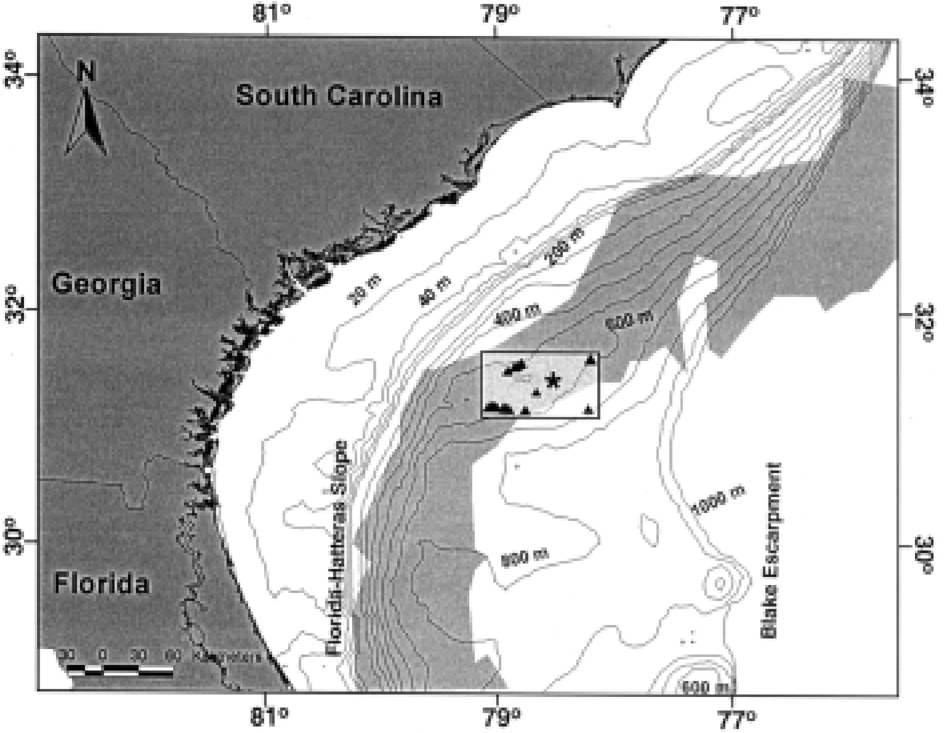

FIGURE 1. Bottom topography of the Blake Plateau, showing wreckfish grounds (lightly shaded box) on the Charleston Bump. Black triangles indicate captures of wreckfish from research vessels. Asterisk indicates the approximate center of the Charleston Bump, and corresponds to the approximate center indicated by Bane et al. (2000, this volume, Figure 2). The approximate location of the Gulf Stream (darker shading) is indicated by plotting its position on 2 August 2000, from data posted by the Naval Atlantic Meteorology and Oceanography Center (http://www.nlmoc.navy.mil/newpage/oceans/). Depth contours are in 20-m intervals to 100 m, then in 100-m intervals.

as well as flat hard bottom consisting of phosphorite-manganese pavement (Sedberry et al. 1994) (Figure 3). The ridge/trough and scarp feature is located at approximately 31°30′N and 79°00′W, in the main axis of the Gulf Stream, 130–160 km southeast of Charleston, South Carolina. The feature includes precipitous rocky slopes, scarps, and scour depressions (Figure 2), with numerous caves, overhangs, and coral pinnacles (Sedberry et al. 1994; Sedberry, personal observation from submersible). The bottom relief is important to deep reef species and provides habitat that supports the deepwater demersal wreckfish fishery (Sedberry et al. 1994). The waters overlaying the Bump are an important pelagic longlining area and there has been a concentration of longline sets that caught swordfish *Xiphias gladius* at the location of the Charleston Bump (Cramer 1996).

The feature was formally described by Brooks and Bane (1978), who noted that the Charleston Bump deflected the Gulf Stream offshore (Bane et al. 2001). This deflection and the subsequent downstream meanders, eddies, and upwellings may increase productivity and concentrate fishes, sea birds, and other organisms along thermal fronts (Dewar and Bane 1985; Haney 1986; Collins and Stender 1987; McGowan and Richards 1989; Lee et al. 1991; Govoni et al. 2000; Govoni and Hare 2001, this volume). Similar increases in productivity have been noted around other deepwater bottom features (e.g., Haney et al. 1995; Cresswell et al. 1996; Koslow 1997).

The northern part of the South Atlantic Bight (SAB, Cape Hatteras to Cape Canaveral) is known as the Carolina Capes Region, while the middle and southern areas are called the Georgia Embayment, or Georgia Bight. The Carolina Capes Region is characterized by complex seafloor topography, with prominent shoals extending from the Capes to the break at the edge of the continental shelf. These shoals are effective in trapping Gulf Stream eddies spun off by the Charleston Bump, whereas the shelf to the south is smoother, and does not disturb Gulf Stream flow (See Figure 1 in Bane et al. 2001; also Bush et al. 1985; Pietrafesa et al. 1985).

The warming influence of Gulf Stream waters is especially notable in the winter near the shelf break

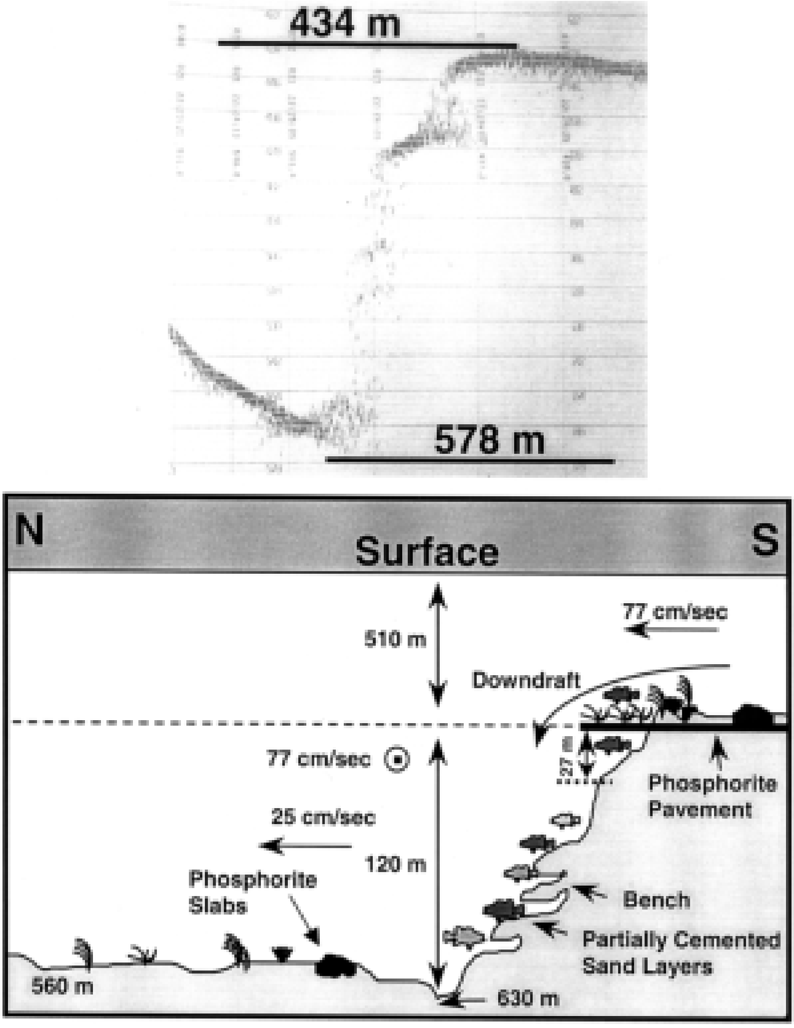

FIGURE 2. Echogram (top) showing steep scarp on the Charleston Bump at 31°39.7′N, 78°46.6W, and drawing of wreckfish habitat on a scarp near 31°15′N, 79°03′W, based on submersible observations.

where tropical species of fish, corals, and other animals are found (Wenner et al. 1983; Sedberry and Van Dolah 1984). A warm band of relatively constant temperature (18–22°C) and salinity (36.0–36.2 ppt) water is observed near bottom year-round just inshore of the shelf break. This band is bounded by seasonally variable inshore waters and by fluctuating offshore waters that are subject to cold upwelling events and warm Gulf Stream intrusions (Miller and Richards 1980; Mathews and Pashuk 1986).

Small frontal eddies and meanders propagate northward along the western edge of the Gulf Stream every 1–2 weeks. They provide small-scale upwellings of nutrients along the shelf break in the SAB (Lee and Mayer 1977; Brooks and Bane 1978; Chew 1981; Lee et al. 1981; Yoder et al. 1981; Lee et al. 1985; Lee et al. 1989; Lee et al. 1991; Glen and Ebbesmeyer 1994; Miller 1994; Bane et al. 2001). In contrast to transient upwellings, there are two areas in the SAB where upwelling of nutrient-rich deep water is more permanent. One such upwelling, that is caused by diverging isobaths, is located just to the north of Cape Canaveral (Atkinson et al. 1979; Blanton et al. 1981; Paffenhöfer et al. 1984; Atkinson 1985). The other much larger and stronger upwelling occurs mainly between 32°N and 33°N, and it results from a deflection of the Gulf Stream offshore by the topographic irregularity of the Charleston Bump (Singer at al. 1983; Atkinson 1985; Mathews and Pashuk 1986).

In general, the Gulf Stream flows along the shelf

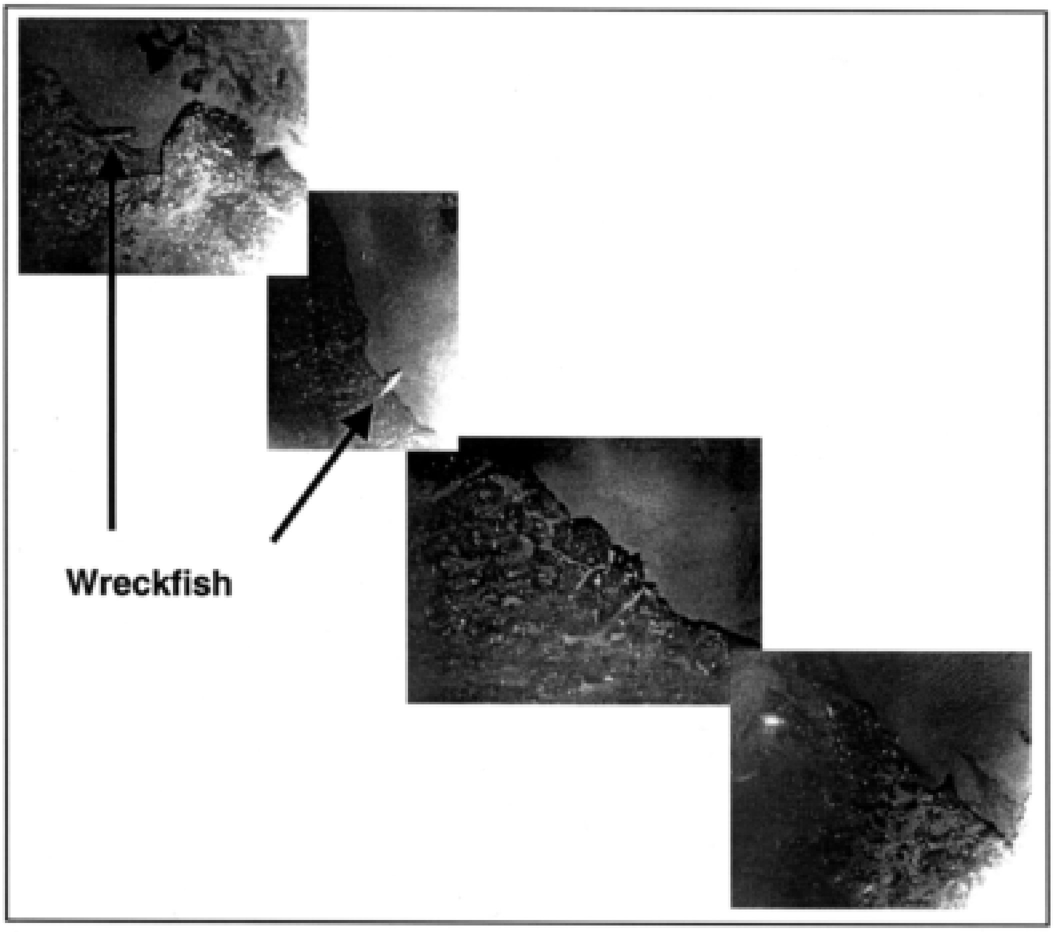

FIGURE 3. Mosaic of photographs taken vertically from the submersible *NR-1*, showing phosphorite-manganese pavement and hard bottom on the Charleston Bump. Wreckfish are associated with this hard bottom.

break, with very little meandering, from Florida to about 32°N where it encounters shoaling bottom topography and is deflected seaward forming a large offshore meander (Brooks and Bane 1978; Singer et al. 1983; Lee et al. 1989; Lee et al. 1991; Glenn and Ebbesmeyer 1994; Miller 1994; Barnard et al. 1997). The cyclonic Charleston Gyre is formed in the trough of the meander, with a large upwelling of nutrient-rich deep water in its cold core. Downstream of the geological feature of the Charleston Bump, enlarged wavelike meanders can displace the Gulf Stream front up to 150 km from the shelf break (Pietrafesa et al. 1985). These meanders can be easily seen in satellite images (e.g., Figure 1 in Bane et al. 2001).

Although 2–3 large meanders and eddies can form downstream of the Bump, the Charleston Gyre is the largest and the most prominent feature. The consistent upwelling of nutrient-rich deep waters from depths of over 450 m to the near-surface layer (less than 50 m) is a source of nutrients near the shelf break within the entire South Atlantic Bight, and it contributes significantly to primary and secondary production in the region (Mathews and Pashuk 1986; Barnard et al. 1997). The Charleston Bump Complex, consisting of the Charleston Bump, Charleston Gyre, and associated fronts and eddies, may be an essential nursery habitat for some offshore fish species with pelagic stages. It has been implicated in retention of fish eggs and larvae and their transport onshore (Collins and Stender 1987; Govoni et al. 2000; Govoni and Hare 2001). Many reef fishes with pelagic eggs and larvae spawn in the vicinity of gyres near the shelf edge (Johannes 1978). Such topographically produced gyres (i.e., the Tortugas Gyre) are implicated in removal of pelagic eggs from the spawning site thus reducing predation, yet retaining fish eggs and larvae for the ultimate return of larvae to the shelf at later developmental stages (Lee et al. 1992; Limouzy-Paris et al. 1997; Lee and Williams 1999). It appears that the Charleston Gyre may function in this manner. During the large-meander mode (Bane et al. 2001), the Charleston Gyre may be responsible for transport the larvae of estuarine-dependent species such as gag *Mycteroperca microlepis* (Serranidae) far onto the shelf, whereas during the small-meander mode (Bane et al. 2001), the Gyre may facilitate the retention of eggs and larvae of other reef fishes (e.g., snappers, Lutjanidae) near the shelf break (Powles 1977). The Gyre may also serve as a nursery ground for juvenile swordfish, which are concentrated along thermal fronts (Govoni et al. 2000; Govoni and Hare 2001). In addition, the Charleston Gyre deposits large amounts of fine sediments such as clay and mica on the upper continental slope off Long Bay, North Carolina (Doyle et al. 1968). This deposition creates suitable habitat for burrowing slope-dwelling fishes such as tilefish *Lopholatilus chamaeleonticeps* (Harris et al. 2001; Wenner and Barans 2001, both this volume).

Deepwater rocky bottom habitats such as the Charleston Bump may support greater biomass and diversity of fishes than that found on adjacent soft bottom areas; however, little research effort has been directed at deep-water rocky habitats (Knott and Wendt 1985). Hard bottom habitat on the continental shelf and upper slope of the SAB supports drastically different and more diverse fish faunas than do soft bottom habitats in similar depths and thermal regimes (Wenner 1983; Sedberry and Van Dolah 1984). It is likely that these differences extend to the deeper waters of the Blake Plateau, Florida–Hatteras Slope, and the Charleston Bump.

Many reef fishes of the southeastern continental shelf are species that have extended ranges northward from the Caribbean, taking advantage of rocky reef habitat, and relatively stable thermal regimes on the middle continental shelf. It is unknown if the ichthyofauna associated with deep hard bottom of the Caribbean extends its range northward along the hard bottom habitat of the Blake Plateau to the Charleston Bump, although it is known that some species such as wreckfish, blackbelly rosefish *Helicolenus dactylopterus*, and bigscale pomfret *Taractichthys longipinnis* that occur in deep water in the Bahamas (Olander 1997) also occur on the Charleston Bump (Sedberry, personal observation). Similarly, the faunal affinities between the rocky bottom of the Blake Plateau and rocky North Atlantic islands such as Bermuda and the Azores are not known, although fishery landings (e.g., wreckfish, blackbelly rosefish) indicate many similarities. Islands of suitable habitat, such as the Charleston Bump on the Blake Plateau, may provide “stepping stones” that extend the distribution of rocky bottom deepwater fishes from the Caribbean to the eastern Atlantic, assuming that water temperatures and other conditions are favorable. Faunal studies of deep hard bottom habitats in the Caribbean, SAB, and farther northward are needed to address these questions.

The concentration of fishing effort by pelagic longliners (Cramer 1996) and wreckfish fishermen (Sedberry et al. 1994) on or near high-relief topography of the Charleston Bump suggests that the observed oceanographic phenomena do result in increased fish production or aggregation. This hypothesized increased abundance is supported by oceanographic studies that indicate upwelling of productive waters, and a dynamic oceanographic system similar to that found around islands, seamounts, submarine canyons, shelf banks, and other productive fishing grounds (see below). This coupling of oceanography and fisheries production at the Charleston Bump is described elsewhere in this volume (Bane et al. 2001; Govoni and Hare 2001).

An enigma of the Charleston Bump is that the very currents that swirl around the Bump and cause the upwelling should carry away the pelagic eggs, larvae, and juveniles of the fishery species such as wreckfish that spawn on the Bump, leaving questions regarding the recruitment of fishes to the feature. There may be downstream eddies that retain early life stages in a “nursery area” associated with the Bump, or recruitment to the Bump may come from upstream in the Caribbean. It may be that the Charleston Bump creates variable flow regimes in the Gulf Stream, and that these features serve to retain eggs and larvae during certain conditions, and transport larvae away from the Bump during other conditions. There are probably different species of fishes and invertebrates whose life histories are dependent upon both scenarios. The dynamic aspects of Gulf Stream deflection (Bane et al. 2001) may be responsible for recruitment variability in many species. Additional studies of spawning areas and associated hydrography are needed to further elucidate patterns of abundance, recruitment, and fishing effort. We have reviewed some new and previously published data to address this question, by examining available data from three fisheries: the continental shelf fishery for gag, the demersal wreckfish fishery on the Charleston Bump, and the pelagic longline fishery in the western Atlantic.

The Role of the Charleston Bump in the Life of Fishes: Case Histories

Continental Shelf reef fishes: The gag

The gag is a large (up to 130 cm total length, TL), slow-growing, protogynous grouper found associated with continental-shelf and shelf-edge (primarily 20–60 m) reefs in the western Atlantic including the Gulf of Mexico. In waters off North Carolina to southeastern Florida, gag spawn from December through May at depths of 49–91 m, with peak spawning occurring during late March and early April (Collins et al. 1987; McGovern et al. 1998). Gag larvae from spawning in this region are in the offshore plankton for about 40 d before entering estuarine waters along the east coast of the United States (Keener et al. 1988). Postlarval gag enter South Carolina inlets on flood tides during April and May of each year at an average size of 15 mm TL (Keener et al. 1988), and settle into oyster banks and shell rubble (Mullaney 1994). Young-of-the-year gag remain in the estuary throughout the summer months and move offshore as water temperatures decline in the fall (Keener et al. 1988; Ross and Moser 1995).

Gag, like many epinepheline serranids, form aggregations at specific spawning sites (Collins et al. 1987; Shapiro 1987; Waschkewitz and Wirtz 1990; Carter et al. 1994; Coleman et al. 1996; Domeier and Colin 1997). Gag may be particularly susceptible to overfishing since the locations of spawning aggregations are well known to fishermen. Intense fishing pressure on spawning aggregations of other grouper species (e.g., Nassau grouper *Epinephelus striatus*) has led to deleterious effects on population size, sex ratios, genetic diversity, and mating behavior (Craig 1969; Nelson and Soule 1987; Carter et al. 1994; Coleman et al. 1996). Presumably, these heavily-fished grouper aggregations form where currents are favorable for removal of vulnerable early life history stages from reef predators, or to ensure retention of larvae in areas of high food production or suitable settlement habitat. Because of the dominance of the Gulf Stream and the Charleston Bump Complex in the oceanography of the southeastern U.S. Atlantic, it is likely that timing and positioning of gag spawning aggregations, and subsequent success of recruitment of postlarvae to estuarine habitats, might be related to circulation patterns influenced by the Charleston Bump.

Variability in annual recruitment of gag and other fishes is the end result of a number of biotic and abiotic factors that affect the survival of early life stages of fishes. The most important factors are considered to be food for first feeding larvae, predation, suitable environmental conditions for development (i.e., water temperature) and transport towards favorable nursery areas (Rothschild 1986; Houde 1987; McGovern and Olney 1996). We have examined data on recruitment of gag to look at the role of the Charleston Bump, and its strong and weak deflections of the Gulf Stream (Bane et al. 2001), on recruitment of gag to continental shelf reef fisheries in the South Atlantic Bight. Our objective was to determine if cohort strength was linked to sea surface temperatures as influenced by the Charleston Bump Complex.

To examine recruitment of gag in relation to offshore hydrographic features, the cohort strength of gag caught was compared to the March (time of gag peak spawning) sea surface temperature anomalies at seven locations (28°30′N, 80°30′W; 29°30′N, 80°30′W; 30°30′N, 80°30′W; 31°30′N, 79°30′W; 32°30′N, 78°30′W; 32°30′N, 79°30′W; 33°30′N, 78°30′W). The sea surface temperature anomaly is the difference between the current monthly sea surface temperature and the historical (approximately 100 years) mean monthly value (U.S. Department of Commerce 1977). Temperature anomaly data for 1977–1980 were obtained from the monthly publication *Gulfstream* produced by the U.S. Department of Commerce, National Oceanic and Atmospheric Administration (NOAA), National Weather Service. Sea surface temperature data from 1981 were obtained from the *Oceanographic Monthly Summary* (published monthly by NOAA). Temperature data from 1977 to 1981 were collected with bathythermograph from research cruises. Data for 1982–1999 were provided by the International Research Institute for Climate Prediction and the NOAA Office of Global Programs. To simplify presentation, temperature plots were presented for only a few years to represent conditions correlated with good and poor recruitment (Figure 4). These data represented a blend of in situ and satellite data. Correlation Analysis (Jandel Scientific 1996) was used to compare the sea surface

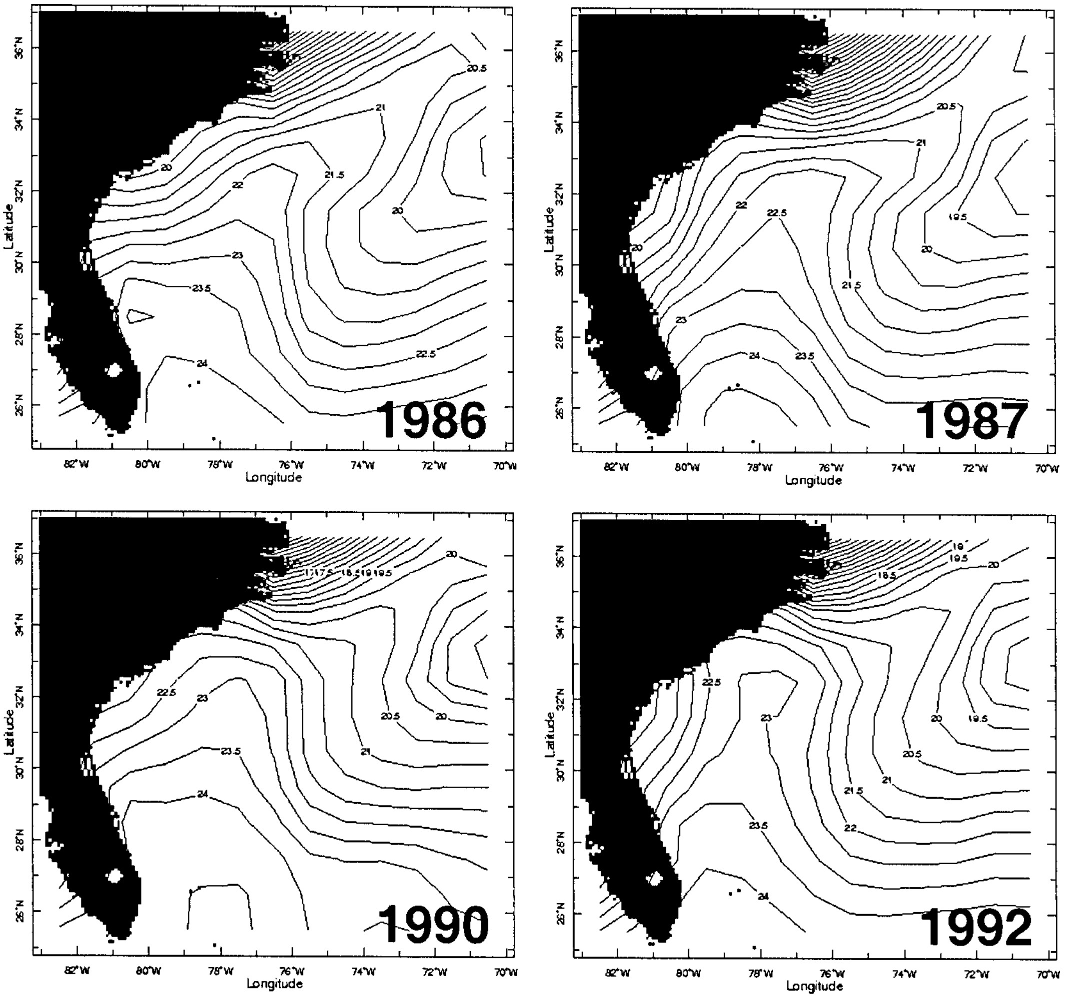

FIGURE 4. March sea surface temperature off the southeast coast of the United States during representative years of poor recruitment (1986, 1987) and good recruitment (1990, 1992). Note that during years of good recruitment (e.g., 1990), that warm water (>20°C) extends much farther inshore across the continental shelf than in poor years (e.g., 1987).

temperature anomaly at offshore locations to gag cohort strength. A gag age-length key (Harris and Collins 2000) was applied to data on gag landed in South Carolina, including length frequency of commercially landed gag, annual commercial catch estimates, and annual headboat landings, to produce an annual catch-in-numbers-at-age matrix. Long-term data from other southeastern states were not available. The landings of gag reported in a given year were divided by weights provided by Huntsman et al. (1996) and Potts and Manooch (1998) to estimate the number of individuals that were landed. Relative cohort strength (i.e., the strength of an individual cohort relative to other years) was determined by adding the number of fish in a cohort (ages 3–6) and dividing that number by the total number of fish (ages 3–6) taken with that cohort (Table 1).

Correlation analysis indicated that there was a positive relationship between cohort strength and sea surface temperature anomaly for March at 33°30′N, 78°30′W ($r = 0.89$; $p < 0.001$) and April at 32°30′N, 78°30′N (Tables 2, 3; Figures 4, 5, 6). Relative year-class strength appeared to be strong when March water temperatures exceeding 21°C were present in Long Bay, North Carolina (33°–34°N, 78°–79°30′W; Figure 4). A linear regression to predict cohort strength based on March sea surface temperature anomaly at 33°30′N, 78°30′N ($r^2 = 0.79$, $p < 0.001$; $n = 15$) was described by the equation:

TABLE 1. Catch-in-numbers at age (1–8) for gag landed in South Carolina based on length frequency of gag landed in South Carolina, and age length key from Harris and Collins (2000). Relative cohort strength was determined by adding the number of fish harvested from a cohort (ages 3–6 in shaded area) and dividing that number by the total number of fish (ages 3–6) landed with that cohort (represented by sum of numbers in box). Box and shaded area represent relative cohort strength for 1977.

	Age							
Year class	1	2	3	4	5	6	7	8
1980	0	6	155	1,274	1,527	888	846	903
1981	0	58	1,032	5,866	6,111	2,839	1,721	1,504
1982	120	235	1,373	5,987	5,841	3,173	2,996	3,051
1983	0	28	390	3,465	6,364	5,644	5,209	4,228
1984	228	338	1,361	4,134	4,206	2,491	2,197	2,174
1985	149	107	980	3,872	3,627	2,141	1,992	2,024
1986	118	159	880	3,893	4,198	2,134	1,561	1,486
1987	182	351	1,546	6,185	5,673	2,987	2,567	2,359
1988	229	293	1,136	4,700	4,586	2,506	2,166	1,929
1989	315	380	1,861	7,490	5,510	2,724	2,099	1,818
1990	807	608	2,552	7,792	5,380	1,932	1,316	1,285
1991	1,603	1,039	2,688	6,815	5,069	2,167	1,411	991
1992	1,189	1,821	4,613	8,455	4,724	1,695	997	683
1993	959	2,127	6,924	10,234	3,808	1,138	730	550
1994	489	1,234	4,895	9,630	4,824	1,315	654	490
1995	371	853	3,435	10,081	6,434	2,156	1,164	718
1996	240	756	2,424	7,345	5,917	2,202	1,266	872
1997	124	401	1,591	4,019	3,126	1,470	1,009	757

$$\text{relative cohort strength} = 0.306 + (0.0364 \times \text{sea surface temperature anomaly}).$$

A linear regression used to predict cohort strength based on April sea surface temperature anomaly at 32°30′N, 78°30′N ($r^2 = 0.68$, $p < 0.001$; $n = 15$) was described by the equation:

$$\text{relative cohort strength} = 0.328 + (0.0532 \times \text{sea surface temperature anomaly}).$$

The regressions based on sea surface temperatures (SSTs) and relative cohort strength were used to predict what the cohort strength would be in those years for which we had temperature data but insufficient landings data to estimate cohort strength.

TABLE 2. Results of correlation analysis comparing cohort strength (for the year hatched) and March sea surface temperature anomaly (by latitude) for 1977–1991. Cohort strength is the percentage of fish in a cohort (ages 3–6) relative to all the age 3–6 landed during the same years as that cohort.

Year	Cohort (%)	28°30′N 80°30′W	29°30′N 80°30′W	30°30′N 80°30′W	31°30′N 79°30′W	32°30′N 78°30′W	32°30′N 79°30′W	33°30′N 78°30′W
1977	48.02	−0.50	−0.60	2.10	−0.60	0.60	1.60	4.00
1978	32.10	1.40	−0.20	−0.90	−1.30	0.40	−1.50	−1.00
1979	24.63	0.20	0.20	0.60	0.10	1.90	−3.80	−1.50
1980	26.00	0.80	−0.50	−0.20	−3.70	−3.60	1.00	−1.10
1981	35.02	0.90	−1.10	0.00	−0.60	0.30	1.00	2.70
1982	33.25	0.69	0.37	0.25	0.72	0.75	0.60	0.73
1983	33.99	−0.33	−0.06	0.27	0.13	0.31	0.87	1.01
1984	27.68	−0.41	−0.39	−0.28	0.19	0.22	0.09	0.06
1985	31.80	0.93	0.76	0.44	0.12	−0.01	−0.30	−0.20
1986	29.01	0.89	1.13	0.95	−0.21	−0.62	−0.87	−0.83
1987	25.04	−0.33	−0.69	−0.92	−0.25	−0.06	−0.24	−0.26
1988	25.73	−0.85	−0.93	−1.01	−1.23	−1.54	−1.52	−1.85
1989	33.23	0.16	0.17	0.23	−0.12	0.08	−0.23	−0.05
1990	37.43	1.07	1.36	1.50	1.20	1.19	1.35	1.33
1991	35.93	0.54	0.64	0.66	0.25	0.31	0.39	0.68
	r	0.065	0.123	0.717	0.281	0.357	0.625	0.889
	p	0.817	0.661	0.003	0.310	0.191	0.013	<0.001

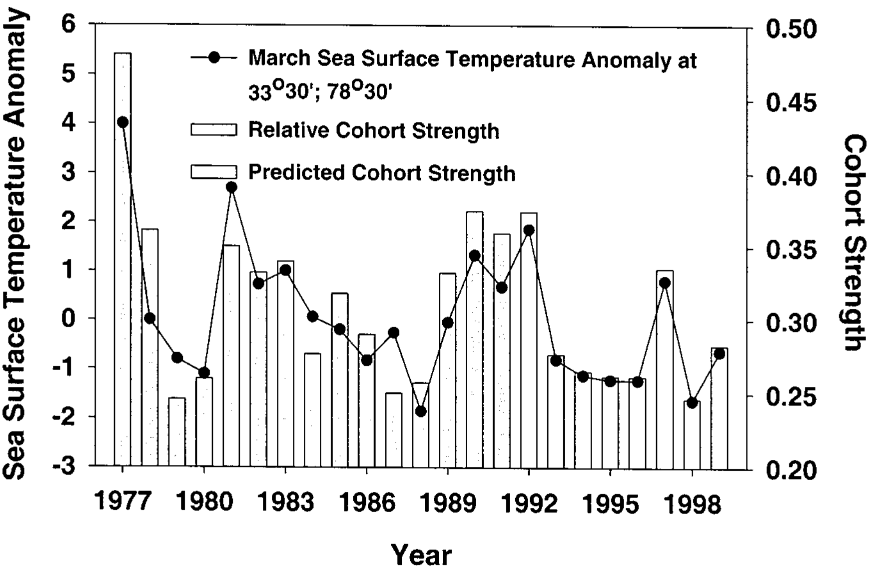

FIGURE 5. March sea surface temperature anomaly at 33°30′N; 78°30′W during 1977–1999, with relative cohort strength for 1977–1991 and predicted cohort strength for 1992–1999.

Recruitment appeared to be related to water temperature, as relative cohort strength was strongest when water temperatures at 33°30′N, 78°30′W (Long Bay, North Carolina) were above average. Water temperature has been implicated as a cause of recruitment variability in other fish species. For example, Francis (1993) reported that sea surface temperature explained 94% of the variability in year-class strength of *Pagrus auratus* in New Zealand. Other investigators (e.g., Roff 1981; Shepherd et al. 1984; Böhling et al. 1991; Rutherford and Houde 1994) also determined that water temperature explained much of the variability in year-class strength of fish species. McGovern and Olney (1996) found that year-class strength of striped bass in the Pamunkey River, Virginia, during1988 was much poorer than 1989 despite similar levels of egg production. Lower water temperatures and reduced food

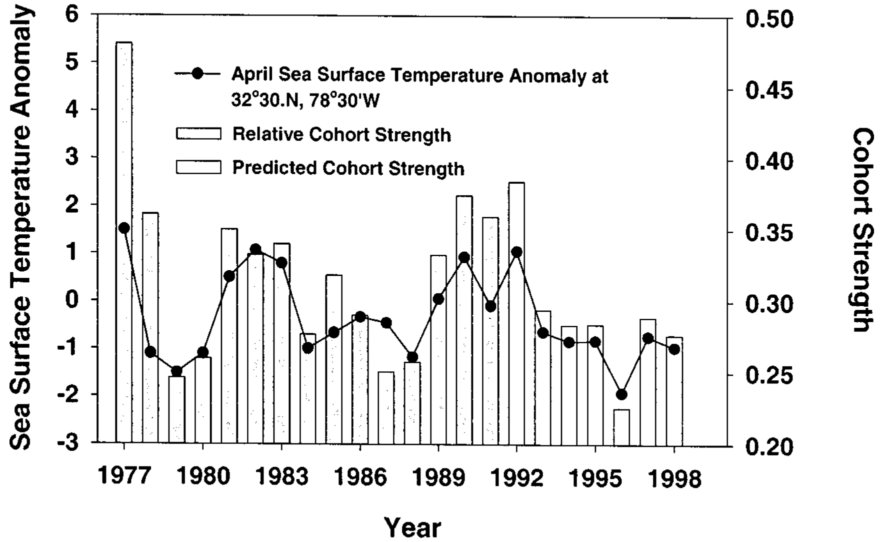

FIGURE 6. April sea surface temperature anomaly at 32°30′N; 78°30′W during 1977–1999, with relative cohort strength for 1977–1991 and predicted cohort strength for 1992–1999.

TABLE 3. Results of correlation analysis comparing cohort strength (for the year hatched) and April sea surface temperature anomaly (by latitude) for 1977–1991. Cohort strength is the percentage of fish in a cohort (ages 3–6) relative to all the age 3–6 landed during the same years as that cohort.

Year	Cohort (%)	28°30′N 80°30′W	29°30′N 80°30′W	30°30′N 80°30′W	31°30′N 79°30′W	32°30′N 78°30′W	32°30′N 79°30′W	33°30′N 78°30′W
1977	48.02	0	0	−1.00	1.50	0.50	0	4.00
1978	32.10	1.30	0.70	−0.10	−0.70	−1.10	−2.50	−2.40
1979	24.63	−0.30	1.10	−0.50	−2.50	−1.50	−0.30	−0.50
1980	26.00	0	0.30	−0.90	−5.60	−1.10	−1.20	−0.50
1981	35.02	0.90	−0.50	−0.80	−0.60	0.50	1.00	2.30
1982	33.25	0.74	0.52	0.75	1.11	1.07	1.39	1.11
1983	33.99	−0.01	0.53	1.02	0.92	0.79	1.47	1.35
1984	27.68	−0.08	−0.59	−1.10	−0.96	−0.99	−1.52	−1.44
1985	31.80	−0.04	−0.24	−0.48	−0.73	−0.66	−1.09	−1.02
1986	29.01	0.14	0.38	0.29	−0.28	−0.33	−0.68	−0.53
1987	25.04	−0.60	−1.09	−1.43	−0.85	−0.45	−0.79	−0.56
1988	25.73	−0.26	−0.41	−0.56	−0.94	−1.17	−1.27	−1.40
1989	33.23	0.59	0.73	0.78	0.14	0.05	−0.03	−0.11
1990	37.43	0.12	0.39	0.61	0.71	0.93	1.08	1.26
1991	35.93	0.67	0.69	0.57	0.18	−0.09	0.02	0.08
	r	0.361	0.151	0.253	0.531	0.822	0.523	0.424
	p	0.186	0.592	0.362	0.042	<0.001	0.046	0.115

densities during 1988 may have combined to prolong development of striped bass eggs and larvae making them more susceptible to elevated predator densities (McGovern and Olney 1996).

Warm water temperatures in the vicinity of Long Bay, North Carolina (33°30′N, 78°30′W) result from frontal eddies spun off of the Gulf Stream at the Charleston Bump (Bane et al. 2001). As a result of Gulf Stream deflection, the cyclonic Charleston Gyre causes shoreward intrusion of upper Gulf Stream water onto the continental shelf (Atkinson et al. 1985). The change from a weakly deflected to a strongly deflected state has been observed more often during winter than summer, with strong deflections occurring during February and March (Bane et al. 2001), the main gag spawning season (McGovern et al. 1998). Strong deflections are associated with the warm Charleston Gyre occurring closer to shore (Mathews and Pashuk 1986). We found that the March sea surface temperature anomaly (33°30′N, 78°30′W) was high and relative year-class strength of gag was very strong during 1990. During 1986, March sea surface temperature anomaly (33°30′N, 78°30′W) was below normal and relative cohort strength of gag was poor. Below normal temperatures in northern Long Bay may represent periods when there is not a great deal of shoreward intrusion of upper Gulf Stream water onto the continental shelf due to a period of weak deflection (Bane et al. 2001) of the Gulf Stream at the Charleston Bump. The correlation between cohort strength and sea surface temperature anomaly further supported the hypothesis that gag year-class strength was related to offshore water temperature (and possibly the intensity and location of the Charleston Gyre) during the spawning season. Regression analysis based on March sea surface temperature anomaly at 33°30′N, 78°30′W suggested the hypothesis that poor year-class strength would be expected during 1993–1995 and 1998–1999. Regression analysis based on April sea surface temperature anomaly at 32°30′N, 78°30′W suggested that poor year-class strength would be expected during 1993–1999. Additional future analyses of gag year-class strength and SST anomalies are needed to confirm these hypotheses.

Warm Gulf Stream water associated with the Charleston Gyre may enhance the survival of gag by allowing them to develop at a fast rate and making them available to predators for a shorter period of time. As gag spawn well offshore at depths of 49–91 m (McGovern et al. 1998), they are particularly dependent upon currents that will transport them to the estuarine nursery areas. In addition to the many different models that have suggested mechanisms of cross-shelf transport (e.g., Nelson et al. 1977; Miller et al. 1984; Norcross and Shaw 1984; Shanks 1988; Checkley et al. 1988; Govoni and Pietrafesa 1994), the Charleston Gyre may aid in the transport of larvae of continental shelf fishes that spawn offshore to estuarine nurseries. Furthermore, the core of the Charleston Gyre includes nutrient-rich upwelled water resulting in enhanced primary and secondary productivity (Paffenhöfer et al. 1995) thereby providing ample food for developing larvae along thermal fronts where warm Gulf Stream water and cooler upwelled waters meet.

Blake Plateau demersal fishes: The wreckfish

The fishery, life history, and population genetics of wreckfish have been recently reviewed by Sedberry et al. (1999), and Vaughan et al. (2001, this volume) reported on the status of the stock in U.S. waters. The wreckfish is a large (up to 2 m TL), slow-growing, demersal bass-like fish found associated with steep, rocky insular and continental slopes, in depths from 42 to 1000 m in the Atlantic. The species has a global anti-tropical distribution, but is absent from the eastern and North Pacific. The wreckfish is an important component of multispecies bottom longline fisheries in the eastern North Atlantic, and is the target of a directed fishery in the United States. The American fishery has occurred exclusively on the Charleston Bump (Figure 1). This is a closely-regulated fishery, with a total allowable catch, individual transferable quotas, and spawning season closure. Recent stock assessments indicate an increase in the spawning stock biomass and catch per unit of effort (CPUE), but a decrease in total landings (Figure 7; Vaughan et al. 2001).

The only known population of adult wreckfish in the western North Atlantic occurs on the Blake Plateau and in the Straits of Florida, at depths from 400 to 650 m. Wreckfish spawn in the area of the Charleston Bump from December to April, with a peak from January to March. Eggs, larvae, and juveniles of wreckfish are pelagic to a length of at least 60 cm, and pelagic juveniles are commonly caught at surface waters in the Gulf Stream, North Atlantic Drift, Portugal Current, and adjacent waters. Juvenile wreckfish may live at the sea surface for several months to a year or more. Wreckfish may be particularly susceptible to overfishing because of limited habitat availability (deep rocky slopes), bycatch of juveniles in pelagic fisheries, and the complex life history involving a long-lived pelagic stage that may be recruited to distant demersal fishing grounds (Sedberry et al. 1999). Because of the dominance of the Gulf Stream on the spawning grounds, deflection of the Gulf Stream may be important to dispersal of juveniles, and upwelling in the area may be important for supporting the demersal adult population.

We have observed wreckfish in spawning condition when caught on the Charleston Bump, and it is suspected that spawning also occurs on the Mid-Atlantic Ridge in the vicinity of the Azores (Fennessy 1998; Sedberry et al. 1999). Wreckfish may not be recruited to the Bump until they are a few years old, and most fish are recruited to the fishery between the ages of 10 and 20 (Sedberry et al. 1999; Vaughan et al. 2001). Submersible observa-

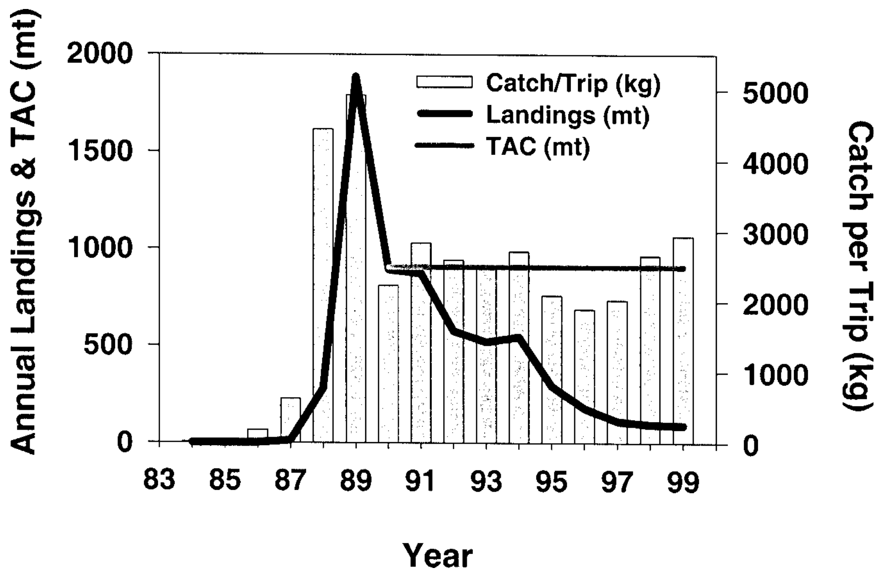

FIGURE 7. Wreckfish annual landings, catch per trip and total allowable catch, through 1999. There were no wreckfish landings in the United States prior to 1984.

tions and analysis of life history data and catch statistics indicate that the Charleston Bump is a habitat for large, mature wreckfish (Sedberry et al. 1999). Genetic studies indicate that there is a single genetic stock of wreckfish in the North Atlantic, with gene flow across the ocean basin, probably mediated by drifting of pelagic juvenile stages and perhaps by migration of adults (Sedberry et al. 1996; Ball et al. 2000). Recruitment to wreckfish habitats such as the Azores that lie downstream of the Charleston Bump may depend in part on spawning success of wreckfish at the Charleston Bump, and Gulf Stream flow and upwelling that are influenced by the Bump. For this reason, the Charleston Bump may be essential for providing wreckfish recruits to locations such as the Azores, Bermuda, and Madeira.

Length frequency data also indicate that the Charleston Bump may be a source of recruits to downstream fisheries. Pelagic juvenile wreckfish (modal TL around 60 cm) show up in the bycatch of pelagic driftnet fisheries in the eastern Atlantic during the summer months following winter and spring spawning on the Charleston Bump (Sedberry et al. 1999). Length frequency data collected from South Carolina landings indicate the absence of small fish in the landings, and no small wreckfish have been noted in surface waters over on the grounds or from submersible observations on the bottom. However, small fish are commonly landed in fisheries in the Azores and Madeira. The absence of small pelagic and demersal wreckfish on the U.S. grounds may result from their being carried off the grounds by the Gulf Stream, eventually settling out in the eastern Atlantic, or perhaps making the complete circuit of the North Atlantic and settling on the Blake Plateau at a larger size, after a lengthy pelagic phase (Sedberry et al. 1999). Tagging studies are needed to determine the role of the Charleston Bump Complex in the life history of wreckfish throughout the North Atlantic.

Squids are very abundant on the Charleston Bump, and are an important prey species for wreckfish (Weaver and Sedberry 2001, this volume; Sedberry, personal observation). Mesopelagic fishes are also important food items. These are species that migrate to productive surface waters to feed at night, then return to deep water during the day. On the Charleston Bump, this downward migration brings them in close contact with the bottom, providing food to bottom living wreckfish, supporting a population of large fish in depths that are generally not productive. Bottom features like continental slopes and the Charleston Bump on the Blake Plateau may be important in transferring energy from productive surface waters to the deep sea (Sedberry and Musick 1978). Vertically migrating food organisms on the Charleston Bump may be an important mechanism for transferring surface productivity associated with upwelling to deep waters of the Blake Plateau, and may support the large population of wreckfish. Migrating prey organisms may support large populations of alfonsinos *Beryx* spp., barrelfish *Hyperoglyphe perciformis*, and other species known from the Bump area, and that may exist in exploitable populations on the Charleston Bump.

Highly migratory pelagic fishes: Billfishes

The Charleston Bump region is an area where pelagic longline fisheries target highly migratory species such as swordfish, tunas, sharks, and dolphin *Coryphaena hippurus* (Cramer 1996; NOAA 1997). As noted by Govoni et al. (2000) and Govoni and Hare (2001), the Charleston Gyre may also be an important larval retention and nursery area for highly migratory species such as swordfish. Juvenile swordfish are often caught and discarded from longlines set in the Charleston Bump region (Cramer 1996).

In recent years, there has been much public concern regarding overfishing of swordfish, bycatch of juvenile swordfish, bycatch of other pelagic billfishes such as marlins and sailfish that are important to recreational fisheries, and interactions of longline gear with seabirds, turtles, marine mammals, and other protected or nonfishery species. There has been public and political support for time and area closures of the longline fishery to reduce fishing mortality on swordfish, bycatch, and other interactions with nontargeted species. Several alternative closure plans have included the Charleston Bump region as a seasonal or permanent closed area, as this is believed to be an area of high incidence of bycatch (Cramer 1996; NOAA 1999).

Although swordfish longliners often fish the area of steep bottom topography on the Bump (Sedberry, personal observation), they may also be directing longline gear at thermal fronts associated with the Charleston Gyre and other thermal structure created by deflection of the Gulf Stream at the Bump. Concentration of longline effort along thermal fronts been noted in waters north of Cape

Hatteras (Podestá et al. 1993). To further examine catches in relation to bottom and thermal features of the Charleston Bump, we conducted a spatial analysis of longline catches in the western Atlantic, using the National Marine Fisheries Service (NMFS) longline data set (Cramer 1996).

The NMFS longline data for the western North Atlantic (catch and discard locations) from five years (1992–1996) were combined into a single data set, which was queried for latitude, longitude, and catch data for swordfish, sailfish *Istiophorus platypterus*, blue marlin *Makaira nigricans*, and white marlin *Tetrapturus albidus*. These were the species most frequently occurring in the database for the Charleston Bump area. Data for each species were imported into ArcView Version 3.1 GIS software (ESRI 1999), which was used to create a shapefile, consisting of points on a map, with attributes attached. After creating the shapefile for a species, the “calculate density” command in ArcView Spatial Analyst Version 1.1 (ESRI 1998) was used to derive a density grid for longline locations. Density was calculated as the number of longline sets per square mile that caught the species of interest. The greater the density, the more longline sets in that square mile grid that caught the species in question. No catch totals (e.g., number of fish per set) or measures of effort (e.g., number of hooks, miles of line) were factored into the analysis because those data were often lacking or not standardized in the data set. This analysis was intended to look only at spatial relationships of longline set density and species occurrence as presence/absence. The species shapefiles (points) and density grids were then overlaid on existing GIS data to create maps of catch density (number of longline sets that caught the species in question per square mile). A total of 75,959 longline sets from the western North Atlantic were included in the analysis, of which 10,397 sets occurred in the South Atlantic Bight (29°11′ to 35°26′N and 73°48′ to 80°30′W).

Logbook data from NMFS indicated that swordfish catches on longlines ranged from the tropical Atlantic, through the Gulf of Mexico, and up the eastern seaboard to the waters east of the Canada Maritime Provinces and Newfoundland (Figure 8). Density analysis of longline locations where swordfish were caught (at least one swordfish kept or discarded) indicated high densities of swordfish catch points in the Windward Passage (east of Cuba), in the Yucatan Channel, in the northern Gulf of Mexico (probably associated with the Mississippi Trough and the Gulf Loop Current), in the Straits of Florida, off the coast of Georgia and South Carolina, and around the submarine Canyons (e.g., Norfolk, Washington, Baltimore, Wilmington, Hudson Canyons), and seamounts of the middle Atlantic states and southern New England. Off Georgia and South Carolina, high density of swordfish catches were associated with the Charleston Bump Complex.

The Charleston Bump is an important swordfishing ground, and other billfishes are frequently encountered as bycatch in the vicinity of the Charleston Bump. Density analyses of large pelagic gamefishes such as sailfish, blue marlin, and white marlin indicated a high incidence of sailfish and blue marlin in the Charleston Bump area (Figure 9). White marlin were more frequently caught north of Cape Hatteras than on the Charleston Bump. Sailfish and blue marlin are more tropical in distribution, while white marlin is more migratory and temperate (Mather et al. 1972; Mather et al. 1974; Witzell and Scott 1990).

It is uncertain if high frequency of catches of swordfish and other billfishes that are associated with the Charleston Bump and the Charleston Gyre are due to higher abundance of these species there, or are due to greater effort being expended in those areas. It is likely a combination of the two. Swordfish fishermen have traditionally focused their efforts on bottom irregularities where swordfish are believed to be abundant. More recently, as in situ temperatures and satellite thermal images have become readily available, fishermen have begun to target thermal fronts and convergence zones, which are also believed to be areas where swordfish are concentrated (Podestá et al. 1993). Podestá et al. (1993) documented higher longlining effort and CPUE in the vicinity of thermal fronts than in nonfrontal areas from Cape Hatteras northward. Presumably, higher CPUE is due to higher abundance of swordfish in the vicinity of thermal fronts. The Charleston Bump and its deflection of the Gulf Stream results in a high density of thermal fronts from 31°30′N to Cape Hatteras, and a concentration of swordfishing effort along some of these major fronts. Spatial analysis of NMFS logbook data in relation to Gulf Stream thermal images indicates a high frequency of catches associated with the Charleston Gyre as well as with the Charleston Bump (Figure 10).

Because of concern for overfishing of swordfish, the high occurrence of nontargeted sport billfishes (marlins and sailfish) that must be discarded, as well as concerns with bycatch of turtles, birds, and other

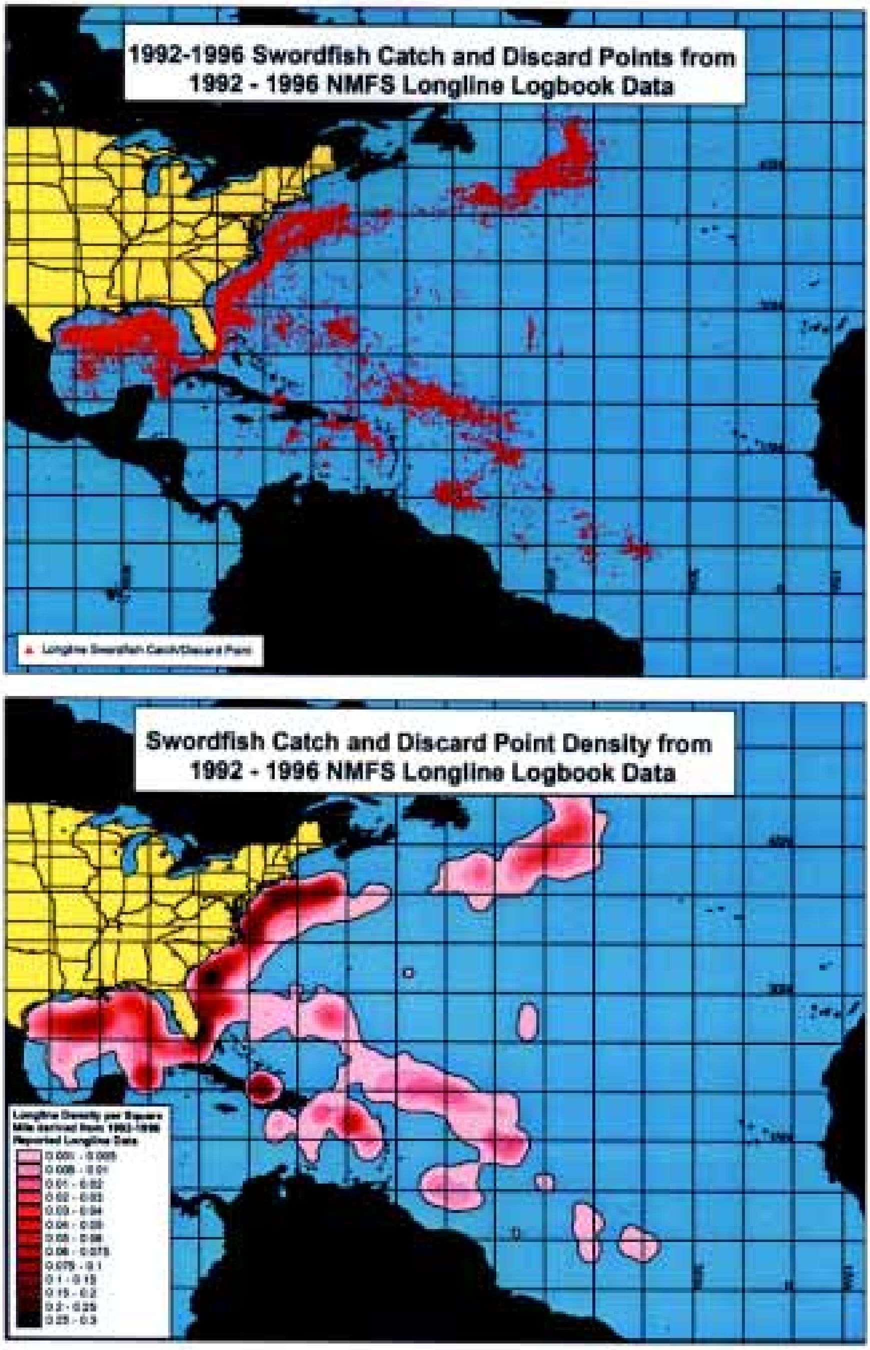

FIGURE 8. Location (top) of longline set points for sets that caught (kept or discarded) swordfish, and density analysis (bottom) of points (number of sets per square mile) from 1992–1996 U.S. National Marine Fisheries Service longline logbook data.

organisms, regulatory agencies have considered several alternative closures in the pelagic longline fishery in the SAB (NOAA 1999). On 1 August 2000, the NMFS enacted a time/area closure for the SAB that will prohibit longline fishing on the Charleston Bump from 1 February through 30 April (NOAA 2000). The NMFS concluded that while "pelagic longline activity in the Charleston Bump area results in bycatch of small

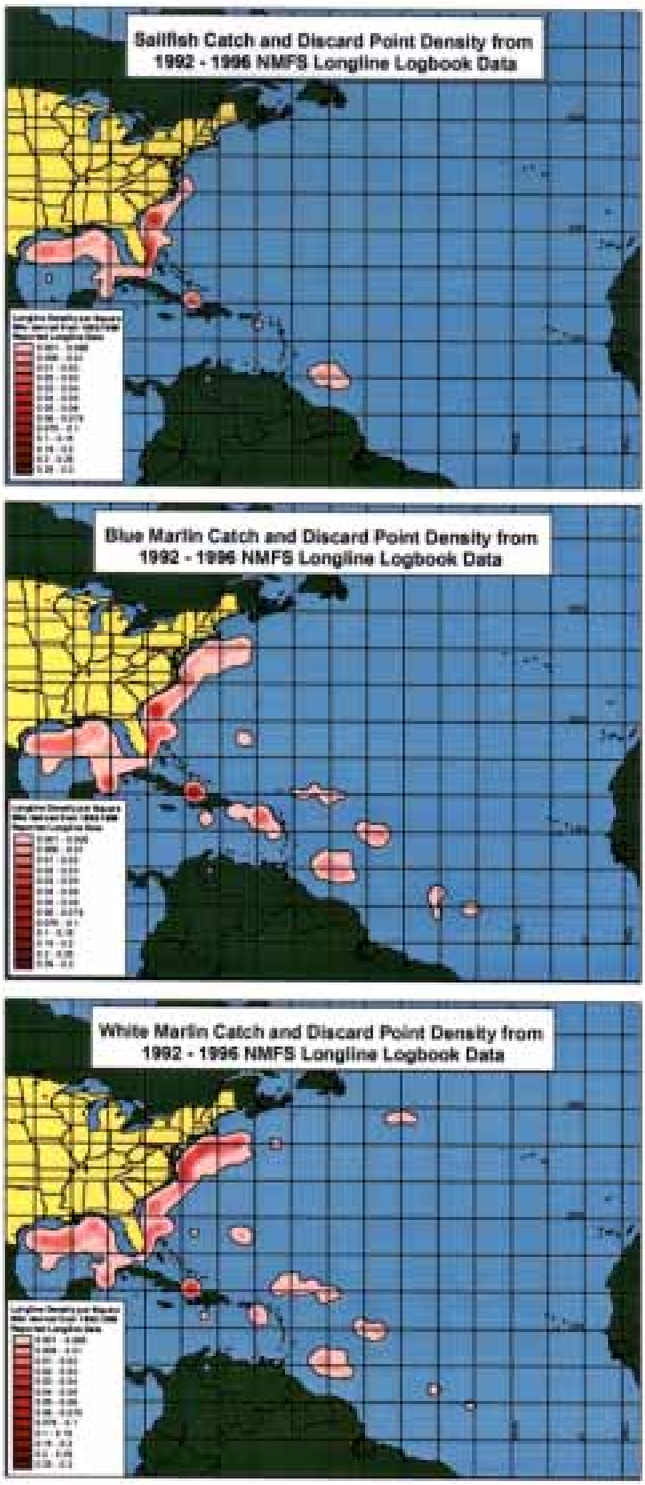

FIGURE 9. Density of longline set points for sets (number of sets per square mile) that caught sailfish (top), blue marlin (middle) or white marlin (bottom), from 1992–1996 U.S. National Marine Fisheries Service longline logbook data.

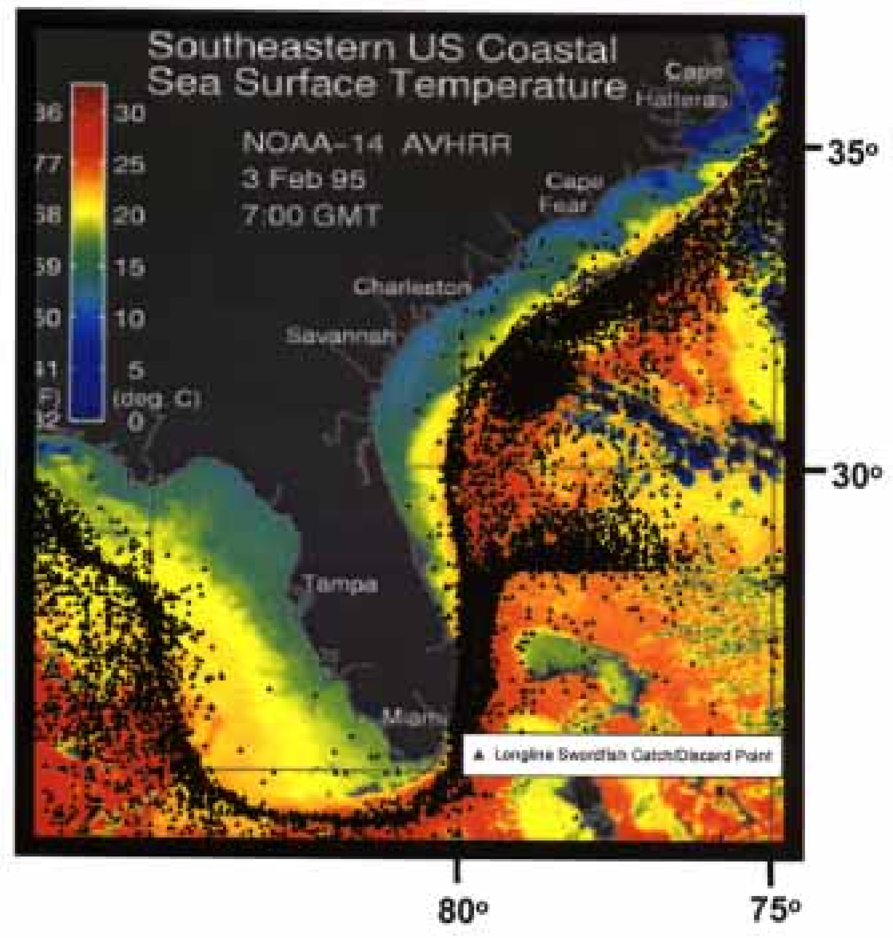

FIGURE 10. Sea surface temperature image and longline set points where swordfish were captured, indicating a concentration of effort on the Charleston Bump and the Charleston Gyre.

swordfish throughout the year, over 70% of the swordfish bycatch takes place during February through April. Therefore, NMFS is closing the Charleston Bump area for this 3-month time frame of the highest discard rates" (NOAA 2000). It was felt that the partial year closure will address the bulk of swordfish discards while minimizing social and economic impacts of the rule by allowing fishing for nine months. It was also felt that minimizing the temporal component of the Charleston Bump closure would reduce the magnitude of potential increases in sea turtle interactions and white marlin discards predicted by the displaced effort model (NOAA 1999, 2000). In this model, considerations of a year-round closure of the Charleston Bump indicated a possibility for displacement of effort to the north, with the potential for increased interactions with white marlin (see Figure 9) and sea turtles. The NMFS will monitor fishing activity to determine whether a larger or longer closure is necessary in the Charleston Bump area (NOAA 2000).

Analysis of the NMFS logbook data presented herein and elsewhere indicates a high incidence of sport billfishes and undersized swordfish associated with the Charleston Bump (Cramer 1996). Cramer (1996) found the highest proportion (relative to legal-sized fish) of undersized discards in the fourth quarter of the year, so the February to April closure may not reduce the catch of undersized swordfish. The high frequency of occurrence of nontargeted species and undersized swordfish in the Charleston Bump area may be associated with increased fishing effort. Although seasonal closure of the area may reduce effort and reduce discard of undersized and other illegal fishes, the closure may simply displace effort to historically important grounds to the north (e.g., those in Figure 9), or to times when more undersized fish may be in the Charleston Bump area (Cramer 1996). Displacement of effort to the north might reduce bycatch of more tropical species such as sailfish, but the results are difficult to predict (NOAA 1999). The effects of this closure should be closely monitored to determine their value in conservation and sustained fisheries.

It is apparent from the NMFS logbook data that there is a high frequency of encounter of swordfish and large pelagic game fish in the Charleston Bump area. Although many of these species may be transitory in the area, it is obvious that the Bump and its associated bottom and oceanographic features are important in the life history of these species.

Conclusions

The Charleston Bump Complex functions as EFH on several levels. For resident demersal fishes such as wreckfish, the physical bottom feature of the Bump is an important adult habitat, feeding, and spawning ground. Additional research is needed to determine with certainty if the Bump is important as a nursery habitat for juveniles of wreckfish and other demersal fishes. The Bump may also be an important nursery area for swordfish and other highly migratory fishes. Preliminary analysis of NMFS longline logbook data indicate a high incidence of juvenile swordfish (discards) in the vicinity of the Bump, at least seasonally (Cramer 1996). These observations need to be standardized with good CPUE data from on-board observers, as logbook data may not be reliable. Ideally, fishery-independent CPUE should be monitored as is done for several demersal fisheries (e.g., Clark and Brown 1977; Azarovitz 1981; McGovern et al. 1998). Limited data from ichthyoplankton surveys indicate that thermal fronts created by the Charleston Bump are areas where larval swordfish are often caught (Govoni et al. 2000; Govoni and Hare 2001). Additional ichthyoplankton surveys are needed to determine the importance of the Charleston Bump and its associated oceanographic features as spawning and larval recruitment areas for swordfish and other fishes.

The Charleston Gyre and other oceanographic features generated by the Charleston Bump may be important transitory habitats for shelf fishes that spawn at the shelf edge and are recruited to estuarine and coastal nursery habitats. The Gyre may be important in providing nutrients during critical early larval stages, and cross-shelf transport of larvae to settlement habitats on the inner shelf. Although shelf species such as gag are not resident on the Bump or within the Gyre, these features have an important influence on recruitment success in this species, and may be important in the life history of other shelf species that spawn offshore.

While EFH includes “those waters and substrate necessary to fish for spawning, feeding or growth to maturity,” much of the evaluation of EFH (and concentration of management efforts to date) has been with freshwater, estuarine, coral reef, seagrass, and coastal habitats (SAFMC 1998; see also Benaka 1999). Consideration of deepwater EFH has been limited to deepwater coral (e.g., *Lophelia prolifera*) banks occurring primarily in the Straits of Florida (SAFMC 1998). The deep *Oculina* coral banks in the Straits of Florida have been declared a Habitat Area of Particular Concern (HAPC) by the SAFMC (1998). The SEAMAP bottom mapping program, an aim of which was to assist the SAFMC in identifying EFS, does not extend deeper than 200 m. In spite of the concentration on shallow habitats, the SAFMC (1998) considered the Charleston Gyre as “an essential nursery habitat for some offshore fish species with pelagic stages, such as reef fishes,” because of increased productivity that is important to ichthyoplankton. The SAFMC also acknowledged that there is insufficient knowledge of the biology of golden crab *Chaceon fenneri* to determine if there are spawning and nursery areas for this species in the SAB that should be declared EFH. Wenner and Barans (2001) have demonstrated that benthic habitats in the vicinity of the Charleston Bump Complex are important habitat for this and other crabs. Because the Charleston Bump Complex is important in the life history of several current and potential fishery species, it should be considered Essential Fish Habitat.

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