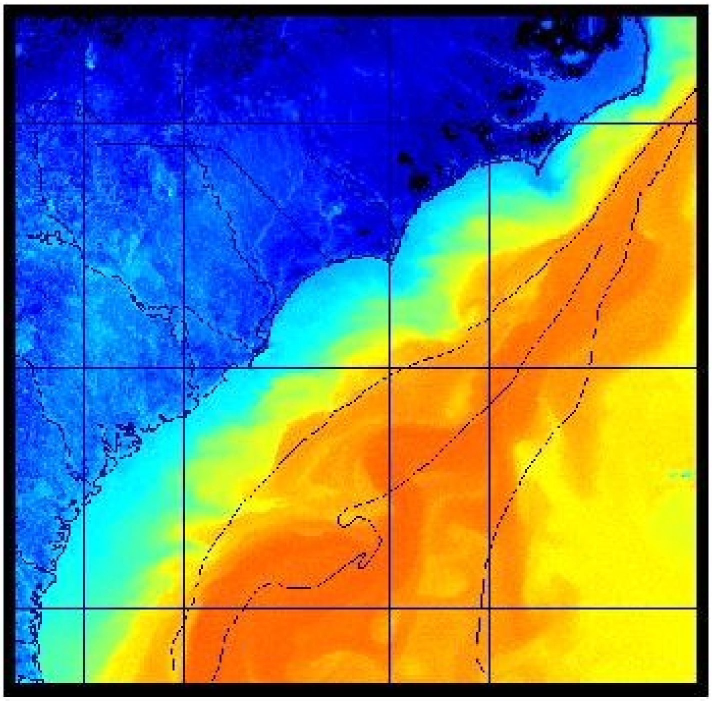
The Role of the Charleston Bump In the Life History of Southeastern U.S. Marine Fishes



Final Report

by

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Project Final Report

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Year 1

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Abstract

The Charleston Bump is a complex bottom feature of great topographic relief located southeast of Charleston, South Carolina. A Colloquium convened in Charleston reviewed historical and recent data on the geology, oceanography and fisheries associated with the Charleston Bump. The bottom feature deflects the Gulf Stream offshore in the South Atlantic Bight, and establishes permanent and temporary meanders, 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. 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.

Bottom mapping conducted during this study concentrated on high-relief areas associated with wreckfish catches, and indicated a shoaling "ramp" that ascends northward from depths greater than 600 m to the top of a scarp at about 375 m depth. The ramp is smooth in places but also has rugged bottom topography associated with a series of ridges and valleys. Wreckfish are caught in these ridge areas. Northward of the top of the scarp the bottom drops precipitously into deep (>600 m) scour depressions, then rises again to 350 m.

Oceanographic data collected in this study indicated an area of upwelling in the trough of the Charleston Gyre, a large eddy formed in the meander of the Gulf Stream north of the deflection by the Charleston Bump. This upwelling area has a high concentration of chlorophyll-a, indicating higher productivity. This productive water is adverted onto the continental shelf near Long Bay NC.

A geographic analysis of commercial pelagic longline logbook data show 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. These fisheries target swordfish (*Xiphias gladius*), but also result in captures of non-targeted species such as sailfish (*Istiophorus platypterus*) and marlins that are abundant around the Bump. Satellite pop-off tagging of swordfish and sailfish show that these species move considerable distances away from the Bump, or are found in the vicinity of the Bump up to 90 days after tagging. A seasonal closure of the longline fishery on the Bump may not be effective in reducing fishing mortality on these species. 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.

Introduction

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^{o}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 on 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., 2000). The Bump includes over 100 m of rocky relief (Figure 2), with carbonate outcrops and overhangs, 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 between 31°30'N and 32°00'N and between 78°00'W and 79°30'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; Popenoe and Manheim, 2000; Sedberry pers. obs. 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; Cramer, 2000).

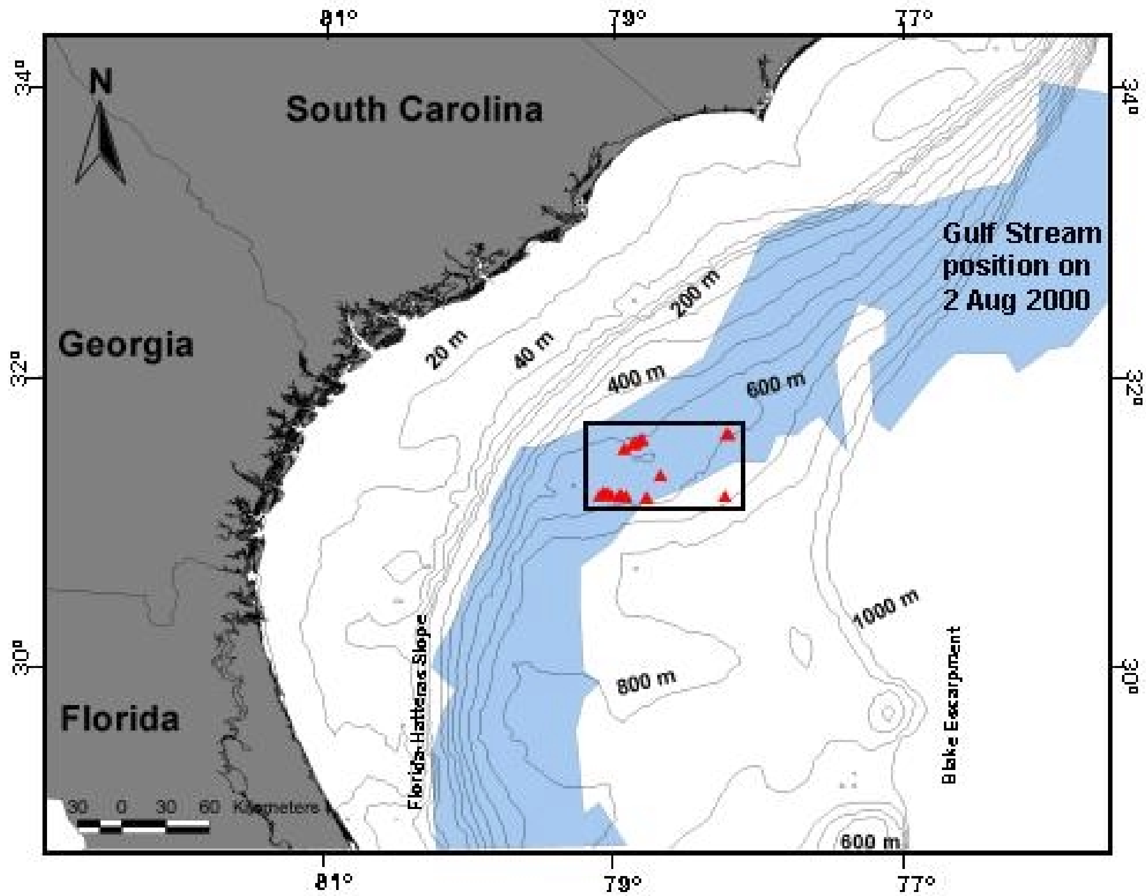


Figure 1. Bottom topography of the Blake Plateau, showing wreckfish (*Polyprion americanus*) grounds (box) on the Charleston Bump. Triangles indicate captures of wreckfish from research vessels. The approximate location of the Gulf Stream (shading) is indicated by plotting its position on 2 August 2000, 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. The Bump occurs on the Blake Plateau, a relatively flat area that interrupts the continental slope and divides it into the Florida Hatteras Slope inshore and the Blake Escarpment offshore. The topographic high and the spreading of isobaths as they emerge from the Florida Straits cause the Gulf Stream to be deflected offshore at the Bump.

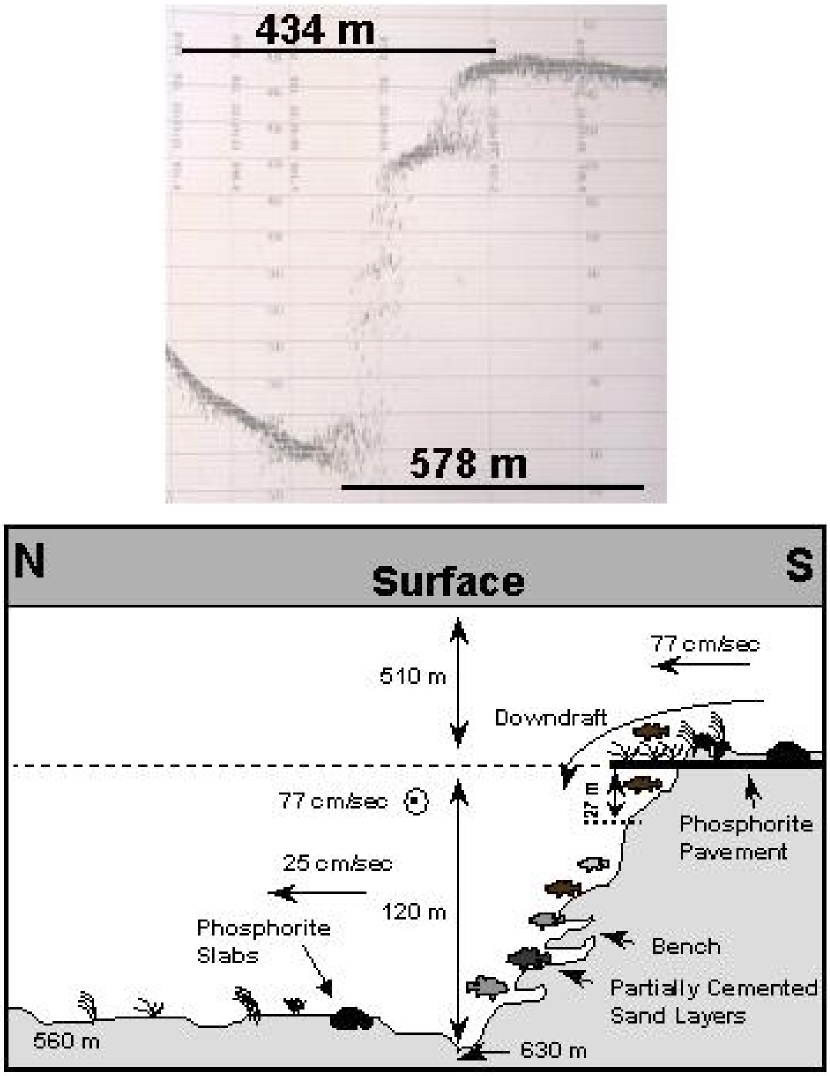


Figure 2. Echogram (top) showing steep scarp on the Charleston Bump at 31°39.7'N, 78°46.6W, and drawing of wreckfish habitat on a scarp near 31°15'N, 79°03'W, based on submersible observations (Sedberry et al., 2000).

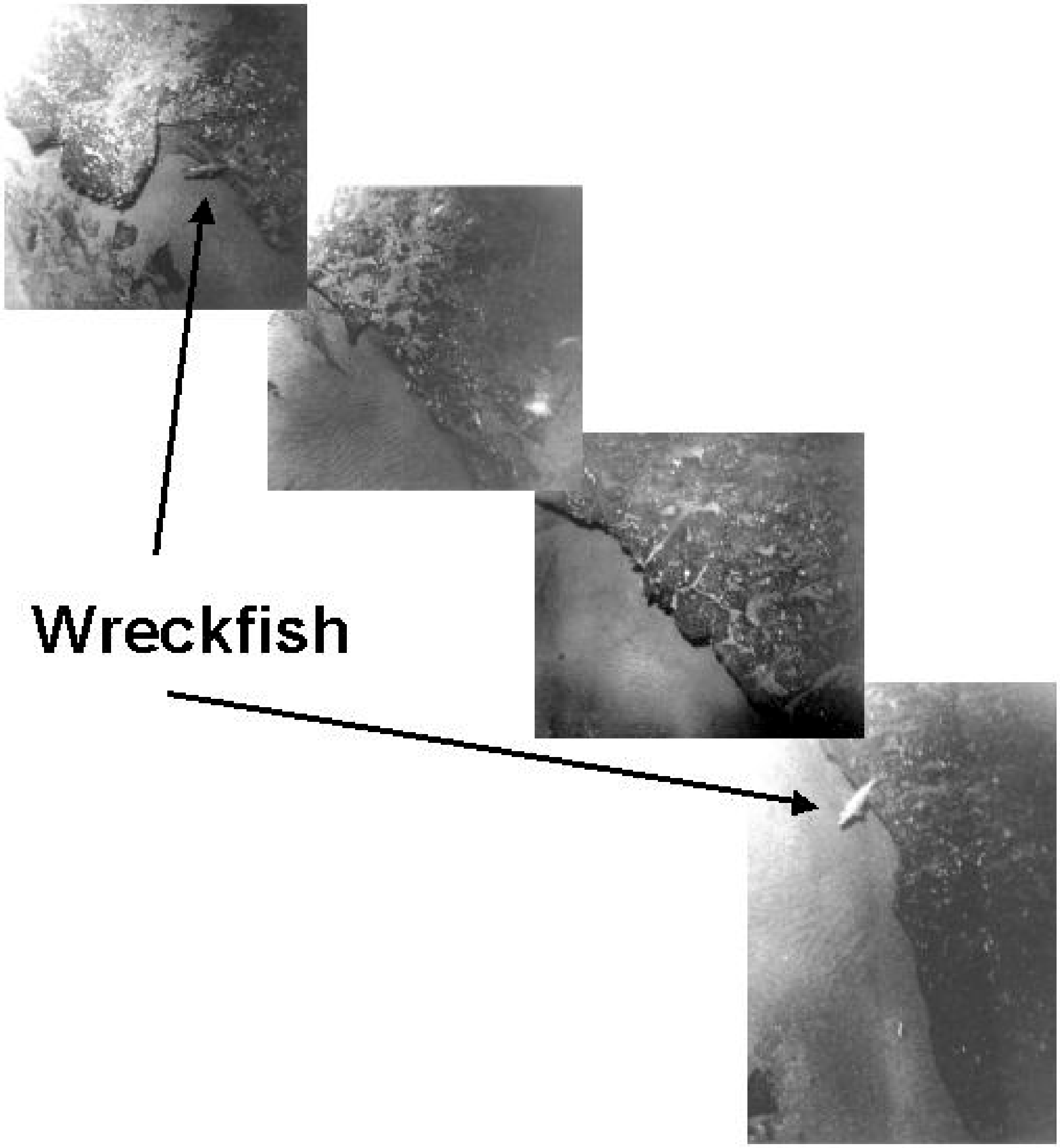


Figure 3. Mosaic of photographs taken vertically from the submersible *NR-1*, showing phosphorite-manganese pavement and hard bottom on the Charleston Bump. Wreckfish are associated with this hard bottom.

The feature was formally described by Brooks and Bane (1978), who noted that the Charleston Bump deflected the Gulf Stream offshore (Bane et al., 2000). This deflection and the subsequent downstream meanders, eddies, and upwellings may increase productivity and concentrate fishes, sea birds and other organisms along thermal fronts (McGowan and Richards, 1989; Dewar and Bane, 1985; Haney, 1986; Collins and Stender, 1987; Lee et al., 1991; Govoni et al., 2000; Govoni and Hare, 2000). 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 (Figures 1 and 4; 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 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^{o}C) and salinity (36.0-36.2 psu) 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 (Figure 4). 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; Glenn and Ebbesmyer, 1994; Miller, 1994; Bane et al., 2000). 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^{o}N and 33^{o}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 break, with very little meandering, from Florida to about 32^{o}N where it encounters shoaling bottom topography and is deflected seaward forming a large offshore meander (Figure 4; 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. 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 4).

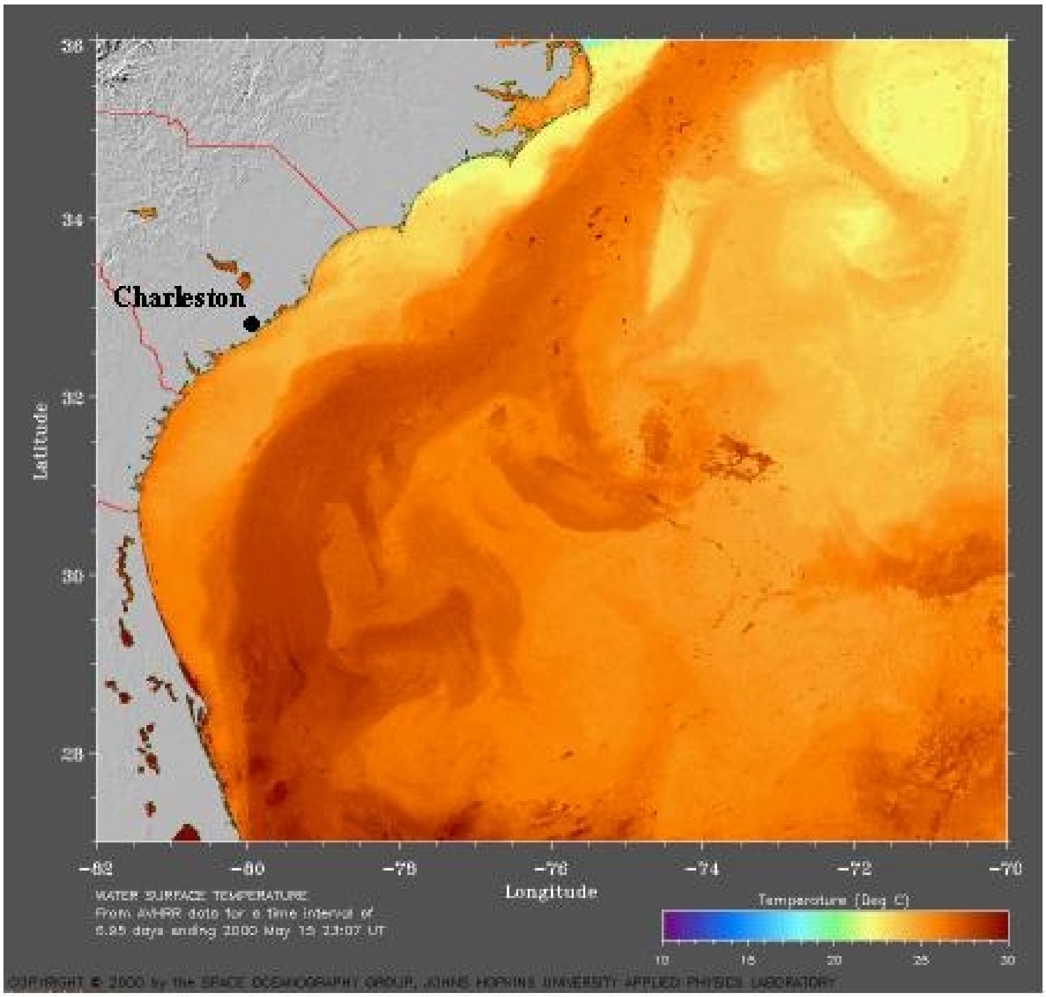


Figure 4. Composite sea surface temperature image (7-d image, ending 15 May 2000). Deflection of the Gulf Stream offshore is clearly visible at about 32°N. Note Charleston Gyre at about 32°30'N, and warm filaments southeast of Charleston and east of the Carolina bays. This is a composite image from about the time of sampling aboard the R/V *Palmetto*.

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 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, 2000). Many reef fishes with pelagic eggs and larvae spawn in the vicinity of gyres near the shelf edge (Johannes, 1978). Such topographically-induced 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., 2000), the Charleston Gyre may be responsible for transport the larvae of estuarine-dependent species such as gag *Mycteroperca microlepis* (Serranidae) far onto the shelf when the leading edge of the large gyre intrudes into Long Bay NC (Sedberry et al., 2000). During the small-meander mode (Bane et al., 2000), the Gyre may facilitate the retention of eggs and larvae of other reef fishes (e.g. snappers, Lutjanidae) near the shelf break (Powles, 1977; Sedberry et al., 2000). 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, 2000). 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., 2000; Wenner and Barans, 2000).

Fish and Fisheries

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 (Weaver and Sedberry, 2000; 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).

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 (2000), 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 non-fishery 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 non-targeted 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 to the north of the Bump, 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). In order to further examine catches in relation to bottom and thermal features of the Charleston Bump Complex, we conducted a spatial analysis of longline catches in the western Atlantic, using the National Marine Fisheries Service (NMFS) longline data set (Cramer, 1996).

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., 2000) 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.

Although it is evident that swordfish and other highly migratory species are caught in the vicinity of the Charleston Bump (Cramer, 1996; Cramer, 2000), it is unknown if they are resident there. The seasonal migration of swordfish is one of the most complex of the pelagic fishes (Palko et al., 1981), and time or area closures may not have a significant impact in reducing fishing effort on this overfished species, if the fish migrate into areas that remain open to fisheries, or remain resident in a temporally closed area and are subject to fishing when the temporal closure ends. Traditional tagging of highly migratory species such as swordfish has given some information regarding movements and growth of such species (Beckett, 1974), but are not useful for determining residence times and short-term movements. In addition, reporting rates of highly migratory species tagged with traditional tags is low (2% of fish tagged on longline gear; Beckett, 1974). Acoustic telemetry has been used to track short-term movements of swordfish and has demonstrated diel vertical migration in the species (Carey, 1990). However, these transmitters are not appropriate for long-term tracking, as they can only transmit data for relatively short period of time (24 to 48 h). Satellite “pop-off” tags are a relatively new technology designed to provide a fishery-independent measure of distance traveled from tagging point to release point without the need to recapture the fish (Block et al., 1998). Because they do not require re-capture of the tagged fish, and return of the tag to the tagging agency, more information on movements can be obtained from fewer tagged fish. These tags can also archive temperature and other data while attached to the fish. Once the pre-programmed release deadline is reached, a corrosive linkage releases the tag from the fish. The tag then floats to the surface and transmits its archived data as well as real-time temperature and tag inclination measurements continuously to satellites in the Argos system. This type of tag has been proven effective in tagging studies on bluefin tuna, *Thunnus thynnus* (Block et al., 1998), and blue marlin, *Makaira nigricans* (Graves et al. in press).

Swordfish are believed to dive much deeper than blue marlin or bluefin tuna, and are known to feed on benthic species in waters up to 595 m deep (Palko et al., 1981; Carey, 1990). The satellite tags currently available are rated for a maximum depth of 650 m, so it is possible that swordfish may dive beyond this limit and render the tag inoperable. One of the objectives of this study was to evaluate the use of satellite pop-off tags for tracking deep-swimming fishes such as swordfish and to track the movements of swordfish captured near the Charleston Bump, which has been suspected to be a resident feeding ground for small swordfish (Cramer, 1996; Sedberry et al., 2000).

Study Goals and Objectives

In spite of our knowledge of the importance of the Charleston Bump as habitat for wreckfish, and its potential importance because of its effect on the flow of the Gulf Stream, no investigations have examined the role of the Charleston Bump in the life history of important fishery species of the southeastern U.S. This project was proposed to examine the role of the Bump and its associated oceanography in the life history of marine fishes. The overall goal of the project was to determine the role of the Charleston Bump as a habitat for fishery species off the southeastern coast of the U.S. We proposed the following hypotheses:

1. The geological feature of the Charleston Bump is an important habitat for highly migratory species, such as swordfish (*Xiphias gladius*), sailfish (*Istiophorus platypterus*), blue marlin (*Makaira nigricans*), white marlin *Tetrapterus albidus*), and tunas (*Thunnus albacares* and *Thunnus thynnus*). These migratory species utilize the Charleston Bump for up to 90 days as a feeding ground during annual spring/summer migrations.
2. The area of the Blake Plateau that produces oceanographic features such as upwelling and thermal fronts with convergence zones, that may attract or aggregate different life history stages of highly migratory species, consists of vertical relief of over 150 m, and it located primarily between 31°30'N and 32°N and 78°W and 79°W. Preliminary surveys of the western part of this area by the Principal Investigator indicates substantial surface anomalies (e.g. standing waves, changes in current velocity) associated with a high-relief north-facing scarp and scour depression at about 31°38'N, extending at least from 78°50'W to 78°45'W, and probably farther to the east. This feature apparently continues to the northeast, but has not been surveyed. It is unclear if this north-facing scarp causes the deflection of the Gulf Stream. We hypothesize that this feature at about 31°38'N causes the deflection of the Gulf Stream that results in oceanographic features that may be important in the early life history of some highly migratory fishes. Although we have observed surface flow disturbance associated with the scarp, many oceanographic features (eddies, upwellings) are generally downstream from the scarp, and concentrations of early life history stages may be associated with hydrographic features some distance from the Bump, but which are generated by the effect of that bottom feature on Gulf Stream flow.

The following specific objectives were established to address the hypotheses:

1. Conduct a workshop to summarize the state of knowledge of the Charleston Bump, and publish the proceedings.
2. Map bottom topography on the Charleston Bump, to pinpoint bottom features that may attract fishes and which influence oceanography of the region.
3. Describe seasonality of occurrence of adults and juveniles of economically valuable pelagic and bottom-living species, using existing NMFS longline logbook data, on-board observers on commercial longline vessels, and tagging of regulatory discards and other fishes.
4. Describe oceanographic features (currents, circulation, sources, productivity) that may explain the distribution and abundance of early life stages of fishes, relative to the Bump.

These objectives were addressed in the first year of a planned three-year study of the Charleston Bump. The investigators intend to seek additional funding to extend this project for at least an additional two years, to conduct follow-up studies related to initial findings. Additional funding will be sought to describe seasonality of occurrence of larvae and juveniles of economically valuable pelagic and bottom-living species, by conducting plankton surveys and experimental longline and trapping surveys designed for sampling early life stages; to determine relative abundance of these early life stages in relation to the location of the Charleston Bump; and to examine recruitment to the bottom of pelagic early life stages of wreckfish (*Polyprion americanus*) and other bottom-living fishes [alfonsin (*Beryx splendens*), barrelfish (*Hyperoglyphe perciformis*), blackbelly rosefish (*Helicolenus dactylopterus*), sharks (*Squalus cubensis, Squalus blainvillei, Hexanchus griseus*)], using experimental fish traps and longlines.

The purpose of this report is to describe the results of the Year 1 efforts. First year tasks consisted of the Charleston Bump Colloquium, bottom mapping, oceanographic description, satellite tagging of swordfish and description of pelagic longline efforts on the Charleston Bump.

Methods

Charleston Bump Colloquium and Proceedings

The Charleston Bump Colloquium was convened in Charleston, South Carolina, on 28-29 October 1999 (program and abstracts included in Appendix 1). Approximately 80 participants from around the U.S. and two foreign countries heard 19 presentations on the geology, oceanography and fisheries of the Charleston Bump, and additional papers on similar habitats and fisheries from other regions (Madeira, Bermuda, Gulf of Mexico, Hawaii, Middle Atlantic Bight). Manuscripts from the presenters were submitted by the authors, peer reviewed, and most of these have been forwarded to the American Fisheries Society Books Department for incorporation into an edited volume to be published later this year (Sedberry, 2000).

Bottom Mapping

Mapping of bottom topography of the Charleston Bump was conducted from the NOAA Ship *Whiting*, during opportunities provided by NOAA while the ship was in transit from its home port in Norfolk to Florida. Three surveys were conducted (April and June, 1999; April 2000). Bottom mapping from the *Whiting* concentrated on the wreckfish grounds (see Figure 1; Figure 5). Soundings were recorded continuously using a single beam echosounder interfaced with GPS. GPS positions were recorded every 200 m along transects. Transects were spaced 500 m apart, and generally ran in a north-south direction. Occasional transects were conducted at an angle to the main transects, in order to cross-check previous soundings. Soundings were taken at a vessel speed of 10 knots, except in areas of steep relief, where the vessel speed was lowered to 5 knots.

Soundings data for the first *Whiting* cruise (April 1999) were collected using a Raytheon DSF-6000N echosounder using a 12kHz frequency transducer. On subsequent *Whiting* cruises (June 1999, April 2000) an ODOM Hydrographic Systems Echotrac DF3200 MKII echosounder was used with a 24kHz transducer. A Sea-Bird SEACAT SBE-19 CTD (conductivity, temperature, depth probe) was used to determine temperature and salinity profiles. Sound velocity profiles from CTD data were calculated with Seasoft 3.3M and Seacat 3.1 software. The program Velocity 4.0 for windows (5.0 for 2000 cruise) was used to process the collected data and calculate sound velocity corrections for depth measurements. A TSS DMS-05 dynamic motion sensor collected heave, pitch and roll (HPS) data. HPS data were applied to raw soundings data for correction during HPS processing. Tidal time and ratio correctors were received from NOAA/HSD and applied during post-processing to 6 min tidal values based on the Charleston tide gage. Positioning information was collected using a Trimble DSM212L GPS Receiver with integrated DGPS VHF receiver. Differential corrections were received from either the Ft. Macon NC, Charleston SC or Miami FL radiobeacons. Antenna positions were corrected for offset and layback and referenced to the position of either the ODOM or Raytheon echosounder transducer depending upon which was in use at the time. Accuracy requirements were met as specified in the NOAA Hydrographic Manual and Field Procedures Manual (FPM). The Horizontal Dilution of Precision (HDOP) and Estimated Position Error (EPE) as specified in

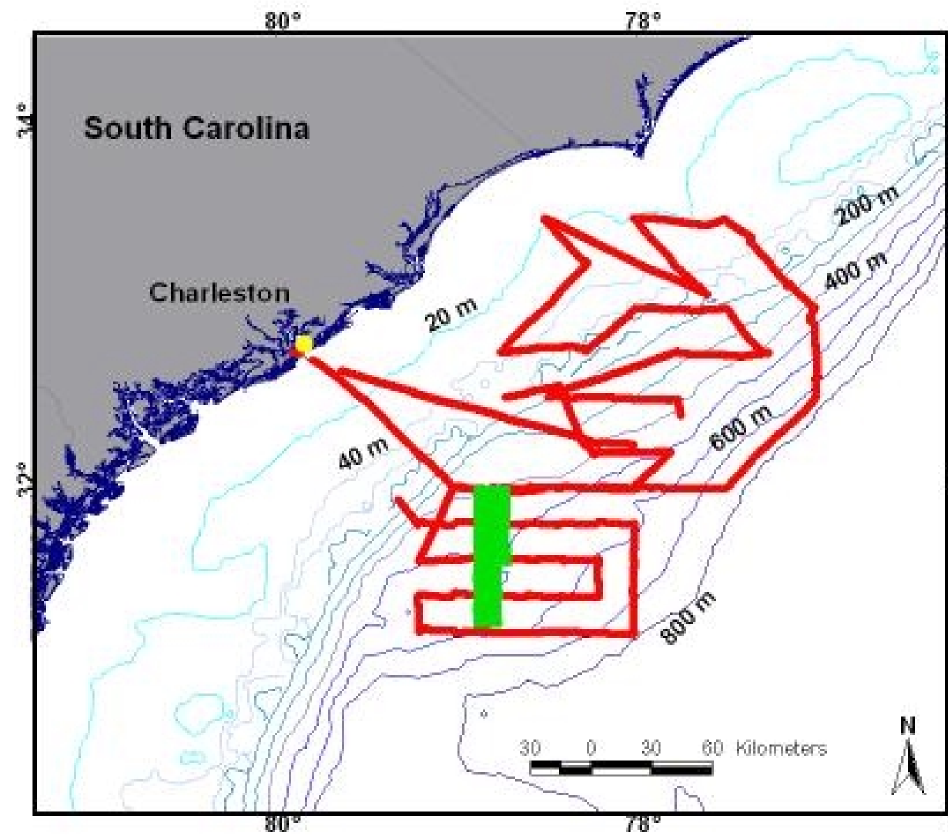


Figure 5. Cruise track of R/V *Palmetto* (line) during hydrographic survey, and area covered by NOAA Ship *Whiting* (polygon) during bottom mapping surveys.

the FPM were monitored during on-line data collection. If the positioning degraded beyond the acceptable limits while on-line, the data were either rejected or smoothed, depending on the extent of the affected data. Coastal Oceanographics HYPACK 8.9 (beta version 00.4 in 2000) software was used exclusively for all data acquisition. Processing of sounding data was accomplished using NOAA HPS (Hydrographic Processing System included in HYDROSOFT 9.4), Mapinfo 4 (Mapinfo 4.9 in 2000), and the HPS-MI MapBasic application.

Additional bottom soundings were taken during hydrographic sampling cruises aboard the R/V *Palmetto*, described below. Soundings were taken continuously and recorded (uncorrected) with GPS coordinates every 200 m along the cruise track (Figure 5). Sampling density was much lower than that from the *Whiting* cruises. Data from the *Whiting* cruises and *Palmetto* cruises were combined for the area of the wreckfish grounds, and used to construct a three-dimensional image of the wreckfish grounds on the Charleston Bump. Data from the oceanographic cruises alone were not useful for constructing three-dimensional images of areas outside the *Whiting* survey area, but will be combined with data from future oceanographic cruises to expand the coverage of the area surveyed by the *Whiting*.

Oceanographic Sampling

Oceanographic, chlorophyll, meteorological, and topographic data were collected aboard R/V *Palmetto* during two cruises in spring of 2000 (Figures 5-7). The main objective of the first cruise (11-14 April 2000) was to take oceanographic measurements and map the bottom topography of the high-relief wreckfish grounds of the Charleston Bump. This cruise covered the area between 31^{o}12' - 32^{o}12'N, and 78^{o}00' - 79^{o}12'W, over depths from 432-784 m. CTD casts were made at 37 regularly spaced stations on a grid [22 x 18.5 km (12 x 10 nautical miles)] that covered the main topographic features of the Charleston Bump (Figure 6). A SeaBird SBE25-03 Sealogger CTD equipped with SBE 3 and SBE 4 sensors (conductivity, temperature, pressure) and SeaTech fluorometer for measuring chlorophyll-a was used.

The main objective of the second cruise was to collect oceanographic and productivity data in the area of the Charleston Gyre, as well as to map bottom topography in this region. This cruise took place from 8-12 May 2000. The station plan (Figures 6 and 7) was designed to include the suspected area of the Charleston Gyre, and to include transects spaced 37 km (20 nautical miles) apart that were perpendicular to the shelf break (e.g. Stations 1-9 on Figure 7). A total of 28 stations was conducted in the area between 32^{o}0' - 33^{o} 30'N, and 77^{o}0' - 79^{o}50'W, over depths from 19-826 m. Stations were spaced 43 km (23 nautical miles) apart along the transects that were normal to the shelf break (Figure 7). Five locations along the northernmost transect of the first cruise were sampled again during the second cruise, in order to determine the changes in oceanographic parameters that possibly could have occurred between cruises. The sampling grid from both cruises combined covered the main topographic features of the Charleston Bump (Figure 6) and the oceanographic features of the Charleston Bump and Charleston Gyre (Figure 7). In addition to CTD casts, continuous (every 200 m along the cruise track) recording of position, depth, sea surface temperature (SST) and fluorometry (Turner Designs Model 10-AU-005-CE fluorometer) was conducted on both cruises.

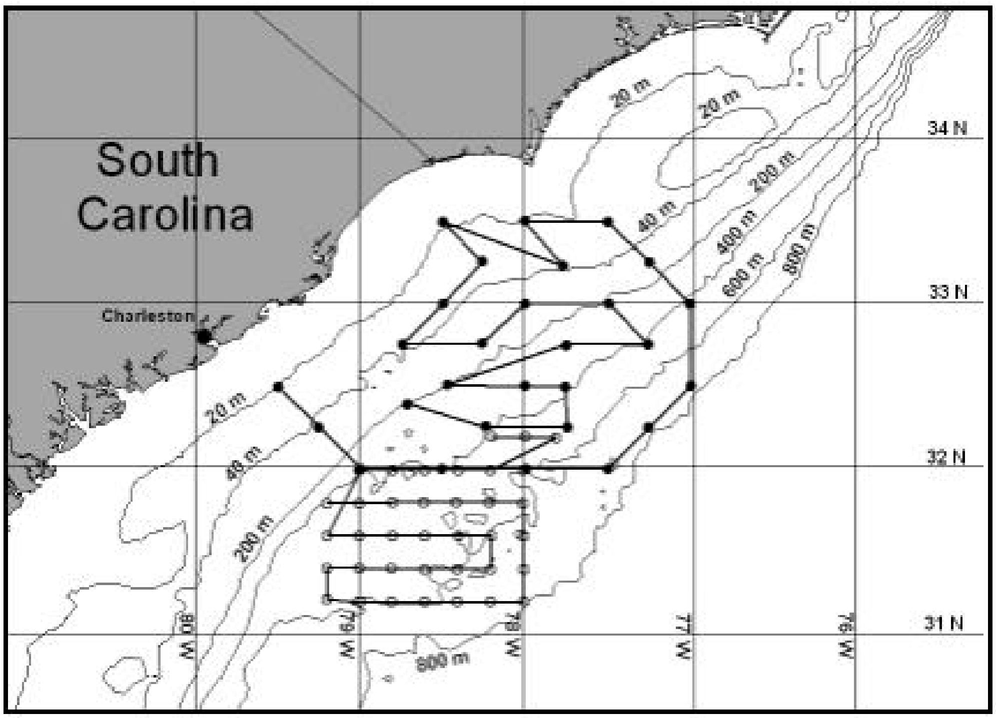


Figure 6. CTD stations occupied during R/V *Palmetto* cruises. Each symbol indicates a CTD cast. Open circles represent stations sampled on the first cruise; closed circles were sampled on the second cruise.

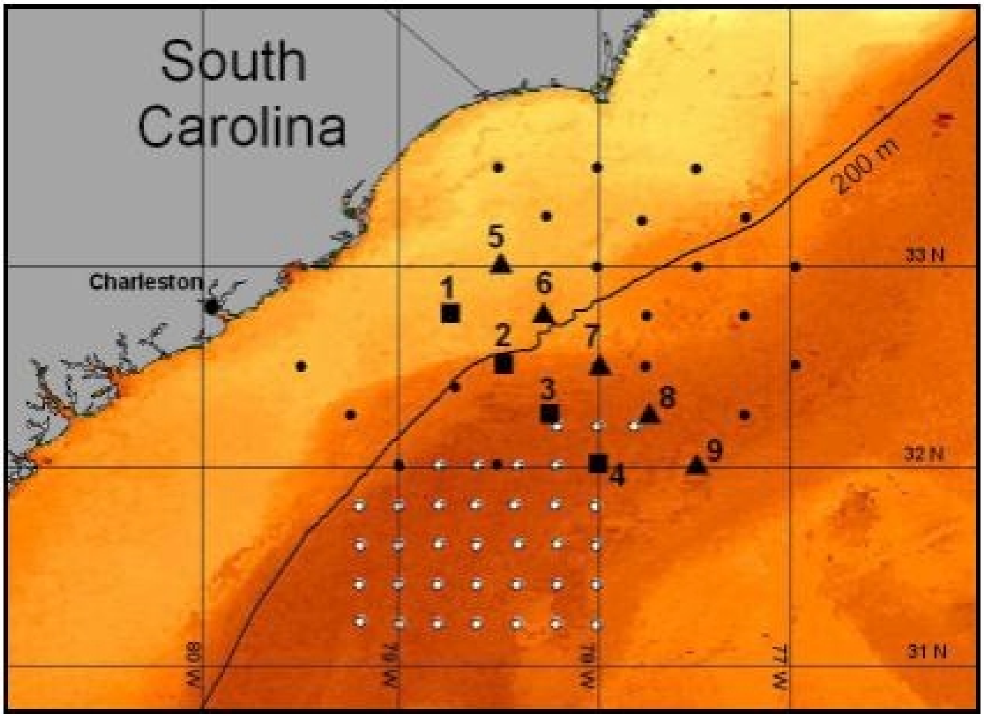


Figure 7. Composite sea surface temperature image (7-d image, ending 15 May 2000). Deflection of the Gulf Stream offshore is clearly visible at about 32°30'N. Note the Charleston Gyre at about 32°45'N, and warm filaments southeast of Charleston and east of the Carolina bays. This is a composite image from about the time of sampling aboard the R/V *Palmetto*. CTD sites sampled are indicated. White circles were sampled on the first cruise and black circles were sampled on the second cruise. Squares and triangles are stations included in the transect analysis (see Figures 12, 14, 16, 18 and 19).

At each station (Figures 6 and 7), the CTD was deployed to measure depth, temperature, salinity and chlorophyll-a from the surface down to 350 m. At each CTD sampling station, 1200 ml of seawater was collected from the surface via an electric pump for chlorophyll-a analysis and to calibrate water-column fluorometry measurements taken by the fluorometer mounted to the CTD. The surface sample was filtered through a 25 mm GF/F microfiber filter under vacuum. The filters were stored at -80^{o}C until analysis. In the laboratory, chlorophyll was extracted from the filter pads by immersion in 90% acetone for 24 h. The samples were then measured on a Turner 10-AU-005-CE fluorometer using the Welschmeyer non-acidification method, and cross-checked on a Turner 10-AU-000 fluorometer.

Surface, 50 m, 100 m, 200m and bottom (to 350 m) measurements of water temperature, salinity, density and chlorophyll-a concentrations were plotted using ArcView Version 3.1 GIS software (ESRI, 1999) and Spatial Analyst Version 1.1 (ESRI, 1998). Vertical profiles of water temperatures along two transects normal to the shelf break (Stations 1-9 on Figure 7) were plotted using Surfer Version 7 (Golden Software, 1999). For stations deeper than 350 m (maximum CTD depth), values at 350 m were combined with bottom data for stations shallower than 350 m to identify the maximum dimensions of the Charleston Gyre and upwellings.

Density (sigma-t) values were calculated according to Fofonoff and Millard (1983). Dynamic height anomalies (dynamic meters) and geostrophic current velocities (m/sec) relative to 350 dbar level (maximum depth of CTD casts) were computed using the dynamic method (Helland-Hansen, 1934, cited in Fomin, 1964). Surface values obtained by the above procedure were compared with the values calculated using conversion to a reference level of 3000 dbar, which is based on the assumption that dynamic height is largely a function of thermocline depth, especially in the regions of cyclonic eddies (Cheney, 1982). Although this method does not reflect the fine structure of the very upper layer, it is still useful in identifying the major circulation patterns.

NMFS Longline Logbook Analyses

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, blue marlin and white marlin. 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, etc.) 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^{o}11' to 35^{o}26'N and 73^{o}48' to 80^{o}30'W).

Satellite Tagging

Tagging of swordfish with “pop-off” tags commenced in April 2000. Twenty-eight swordfish and two sailfish (*Istiophorus platypterus*) were tagged (Table 1).

Swordfish and sailfish were captured aboard a commercial longlining vessel, primarily during late April and early May 2000, in the Gulf Stream waters of the Charleston Bump area (Table 1; Figure 8). We intended to tag only swordfish, but we also wanted to first test the tagging system with a relatively quick-release (5-day) tag. We needed to do this prior to tagging with longer-term tags, and we tagged the first two fish caught with 5-day tags. One of these was a sailfish. We tagged an additional sailfish with a 90-day tag, to further examine movements in this species. Thirty swordfish and two sailfish were tagged.

Fish captured alive and in good condition were brought alongside the vessel and double-tagged with a satellite pop-off tag (Model PTT-100, Microwave Telemetry Inc.) and a conventional streamer tag. The pop-off tags consisted of a satellite transmitter attached to a double-barbed nylon dart tip with a heavy monofilament leader, and were applied with a fiberglass tagging pole with a stainless steel tip (Graves et al., in press). Water column temperature profiles were measured with a CTD deployed from the R/V *Palmetto* working in the vicinity of the tagging locations, at approximately the same time.

The satellite tags were manufactured by Microwave Telemetry Inc. of Columbia MD with preset release intervals of 5 d (2 tags) 30 d (10 tags), 60 d (10 tags), or 90 d (10 tags), and were deployed in alternating order by release time (first the two 5-d tags, then 30, 60, 90, 30, 60, etc.).

Each tag contained enough memory to record 60 temperature readings during the attachment interval. The time interval between each temperature record was dependent on how long the tag would be attached to the animal (e.g. 60 temperature readings for a 30-d tag resulted in a temperature record every 12 h). Each temperature reading recorded into memory was an average of temperatures taken hourly since the end of the previous interval (if a temperature is recorded every 12 h, each record is an average of the previous 12 hourly temperature readings). The tags also recorded a single inclinometer measurement during the attachment interval, which gave a general estimate of the angle of the tag relative to vertical throughout the attachment time. Inclination and water temperature measurements gave an indication of the success of each tag, as tags floated vertically in the water when they were released (prematurely, or as programmed), and water temperature data can indicate a diel activity pattern in a vertically-migrating fish such as swordfish. When the release time was reached, electrical current applied to a thin wire promoted rapid corrosion of the linkage and thus released the tag from the fish. The tag then floated to the surface and began transmitting data. Each transmission included the latitude and longitude, real-time sea surface temperature, and current inclination of the tag, as well as a portion of the archived temperature and inclination data stored in memory. The entire archived data set was generally recovered after 5 to 10 satellite contacts with the tag.

Tagging location and pop-off locations were plotted on bottom topography and SST images, with positions geo-referenced using ArcView Version 3.2a GIS software (ESRI, 2000). Bottom topography images were obtained from the National Oceanic and Atmospheric Administration (NOAA) National Geophysical Data Center (NGDS) web site (http://www.ngdc.noaa.gov). SST images from Advanced High Resolution Radiometry (AVHRR) satellites were 7-d composite images assembled from about the date of tag pop-off, and made available courtesy of the Ocean Remote Sensing Group, Johns Hopkins University Applied Physics Laboratory web site (http://fermi.jhuapl.edu/avhrr/).

Table 1. Tag and release data for all swordfish and sailfish tagged during the study. * = sailfish, NC = tag never made contact with ARGOS satellites, NP = tag made weak contact with satellites, no position recorded, LJFL = tip of lower jaw to fork of tail length. Distance traveled is the minimum straight-line distance from tagging point to pop-off point.

Delay	Date (d)	Pop_off (cm) (mo/day)	Tagging Lat (N)	LJFL Long (W)	Tagging Position Date	Lat (N) (mo/day)	Pop-off Long (W)	Pop-off Position Traveled	Distance (km)
			5	04/27	91.4	31o59.3'	78o43.0'	NC	_ _
5*	04/28	127.0	31o59.3'	78o31.4'	05/03	31o12.8'	78o50.9'	98.2	
30	04/28	121.9	31o58.4'	78o29.4'	05/29	32o58.0'	76o48.1'	193.0	
30	04/30	121.9	31o57.3'	78o33.9'	06/14	31o53.9'	78o38.9'	11.0	
30	05/01	101.6	32o00.8'	78o32.9'	06/22	NP	NP	_	
30	05/02	81.3	32o01.1'	78o18.7'	05/31	33o00.8'	73o30.0'	492.4	
30	05/03	127.0	31o56.1'	78o50.0'	06/02	31o37.1'	68o54.4'	920.0	
30	05/03	91.4	32o06.7'	78o43.5'	06/02	33o52.7'	62o45.1'	1486.8	
30	05/03	101.6	32o06.3'	78o42.1'	NC	_	_	_	
30	05/03	86.4	32o05.2'	78o34.9'	06/07	31o09.5'	72o45.1'	563.8	
30	05/06	96.5	32o05.3'	78o45.0'	NC	_	_	_	
30	05/06	165.1	32o09.1'	78o19.0'	06/08	32o15.5'	77o58.3'	35.1	
60	04/30	106.7	31o58.3'	78o37.6'	06/29	39o13.4'	57o44.9'	2040.8	
60	05/01	121.9	31o01.6'	78o40.1'	NC	_	_	_	
60	05/01	106.7	32o00.2'	78o30.6'	07/03	33o21.7'	77o37.1'	173.0	
60	05/02	182.9	32o00.2'	78o16.1'	NC	_	_	_	
60	05/03	91.4	32o01.8'	78o46.9'	06/30	39o33.0'	51o45.4'	2547.0	
60	05/03	91.4	32o06.7'	78o43.3'	NC	_	_	_	
60	05/03	71.1	32o06.1'	78o38.3'	07/03	33o15.7'	76o40.6'	223.7	
60	05/03	91.4	32o04.9'	78o34.3'	NC	_	_	_	
60	05/06	91.4	32o05.0'	78o29.5'	07/07	38o28.3'	72o07.4'	927.8	
60	05/06	66.0	32o09.3'	78o42.2'	07/09	35o43.6'	71o03.4'	810.4	
90	04/30	127.0	31o57.8'	78o35.4'	08/05	36o10.7'	69o12.7'	980.9	
90	05/01	152.4	32o01.5'	78o40.3'	07/30	37o22.4'	73o44.8'	743.5	
90	05/02	-	32o01.8'	78o23.9'	08/10	37o12.5'	71o33.2'	860.3	
90	05/03	91.4	31o56.4'	78o50.1'	08/04	31o07.3'	78o15.2'	107.6	
90	05/03	182.9	32o02.1'	78o45.6'	08/05	31o59.8'	78o32.6'	21.1	
90	05/03	101.6	32o06.3'	78o42.3'	08/05	39o46.9'	52o26.9'	2497.1	
90	05/03	76.2	32o06.0'	78o38.1'	07/31	NP	NP	_	
90	05/03	71.1	31o59.3'	78o30.8'	08/04	28o50.4'	74o02.5'	563.6	
90	05/06	76.2	32o00.8'	78o20.7'	08/06	39o47.6'	45o52.0'	3053.2	
90*	06/19	37.4	32o09.0'	78o42.0'	09/13	34o41.3'	61o49.8'	1581.3	

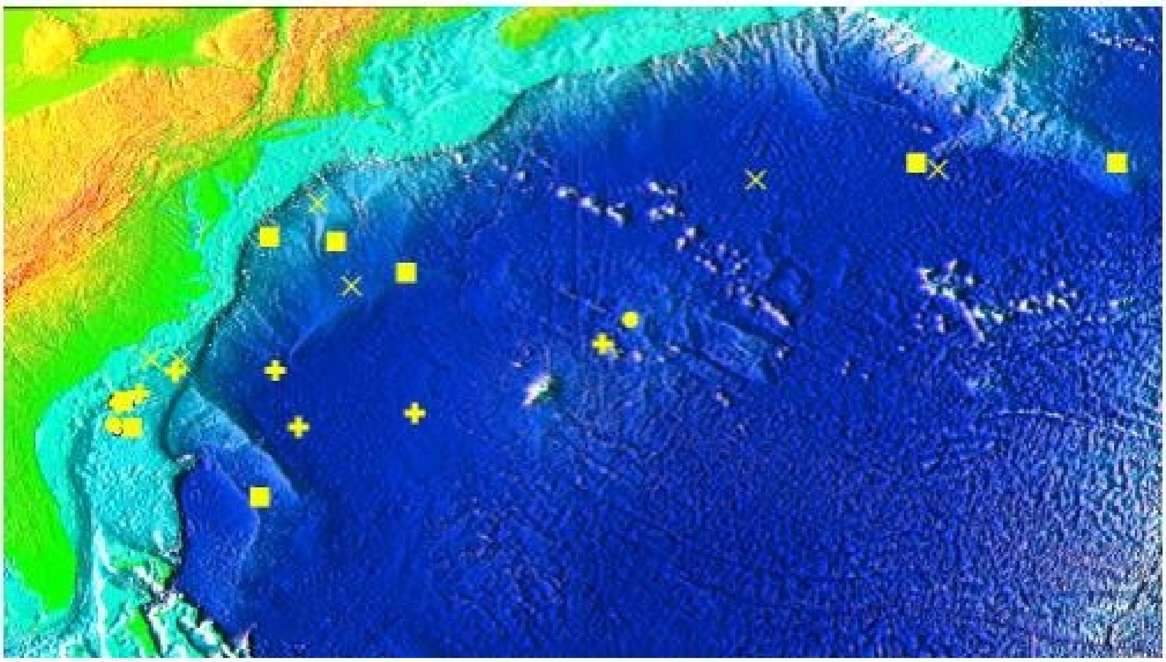


Figure 8. Topographic image of the western North Atlantic showing tagging and release points for all satellite tags in this study. White circles are tagging points. Swordfish tag pop-off points are indicated by yellow plus signs (+) for 30-d tags, yellow crosses (x) for 60-d tags and yellow squares for 90-d tags. Sailfish pop-off points are indicated by yellow circles.

Results and Discussion

Charleston Bump Colloquium and Proceedings

The Proceedings of the Charleston Bump Colloquium are being published as an American Fisheries Society Symposium Volume, Number 25 (Sedberry, 2000). Edits are being made on the final two manuscripts, which should be submitted to AFS before the end of 2000. Sixteen papers, covering geology, oceanography, and fisheries of the Bump will be included in the Proceedings. The contents of the Proceedings will include the following chapters:

"Gulf Stream Physical Oceanography at the Charleston Bump: Deflection, Bimodality, Meanders and Upwelling", by John M. Bane, Jr., Larry P. Atkinson, and David A. Brooks

"Geostationary Satellite Animation of the Gulf Stream at the Charleston Bump", by Richard Legeckis and Paul Chang

"Origin and History of the Charleston Bump--Geological Formations, Currents, Bottom Conditions, and Their Relationship to Wreckfish Habitats on the Blake Plateau", by Peter Popenoe and Frank T. Manheim

"The Charleston Bump: An Island of Essential Fish Habitat in the Gulf Stream", by George R. Sedberry, John C. McGovern and Oleg Pashuk

"Geographic Distribution of Longline Effort and Swordfish Discard Rates in the Straits of Florida and Oceanic Waters of the Continental Shelf, Slope and Blake Plateau off of Georgia and the Carolinas from 1991 to 1995", by Jean Cramer

"Assessments of the Wreckfish Fishery on the Charleston Bump", by Douglas S. Vaughan, Charles S. Manooch III and Jennifer C. Potts

"The Charleston Gyre as a Spawning and Larval Nursery Habitat for Fishes", by John J. Govoni and Jonathan A. Hare

"Trophic Subsidies at the Charleston Bump: Food Web Structure of Reef Fishes of the Outer Continental Shelf and the Upper Continental Slope of the Southeastern United States", by Douglas C. Weaver and George R. Sedberry

"Cephalopods of the Continental Slope East of the United States", by Michael Vecchione

"Benthic Habitats and Associated Fauna of the Upper-and Middle-Continental Slope Near the Charleston Bump", by E.L. Wenner and C.A. Barans

"Understanding Environmental Influences on Movements and Depth Distributions of Tunas And Billfishes Can Significantly Improve Population Assessments", by Richard W. Brill and Molly E. Lutcavage

"Exploitation Related Changes in the Growth and Reproduction of Golden Tilefish, and the Implications for the Management of Deepwater Fisheries", by Patrick J. Harris, Sandra M. Padgett and Paulette T. Powers

"Tagging Techniques Can Elucidate the Biology and Exploitation of Aggregated Pelagic Species", by Kim N. Holland, Steven M. Kajiura, David G. Itano and John Sibert

"Atlantic Blue Marlin and Yellowfin Tuna: Comparative Population Vulnerability to Fishing Mortality", by C. Phillip Goodyear

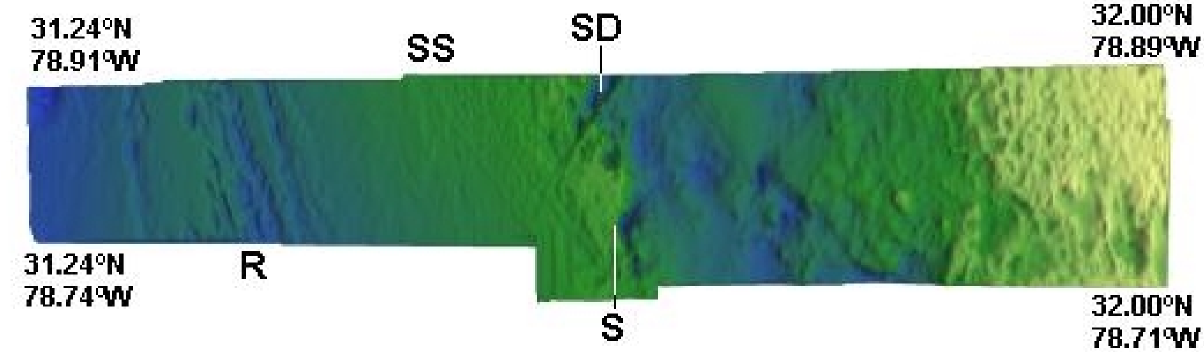
"Landings, Seasonality, Catch per Unit Effort and Tag-Recapture Results of Yellowfin Tuna (*Thunnus albacares*) and Blackfin Tuna (*T. atlanticus*) at Bermuda", by Brian E. Luckhurst, Tammy Trott and Sarah Manuel

"The Charleston Bump: Policy Context and Public Involvement", by John V. Miglarese and Robert H. Boyles, Jr.

The final publication will consist of these papers, and will include 38 tables and 331 figures (40 color).

Bottom Mapping

Bottom mapping analysis is only preliminary, as subsequent *Palmetto* cruises in Year 2 and beyond will add to the database. For this report, we have concentrated on the high-density sampling conducted aboard the NOAA Ship *Whiting*. That survey concentrated on the wreckfish grounds between 78°43' and 78°53' W and shoaling bottom topography to the north of 31°15'N, up to 32°N. The data indicate a northward-inclining ramp, with a series of ridges, scarps and scour depressions (Figure 9). At about 31°15'N, the bottom begins to slope upward toward the north from depths of about 570 m. North of this area, from about 31°20' to 31°25 N is a series of ridges with depths shoaling to 510 m on top of the ridges and 550 m in the valleys between ridges. To the north of the ridges, the bottom is relatively smooth and slopes gradually upward to rough bottom at the top of a system of scarps, at about 430 m depth. Northward of this shoal, the bottom drops precipitously at a series of scarps, dropping down to depths greater than 580 m at the bottom of scour depressions to the north of the scarp. Northward of the scarps, which are important wreckfish habitats, the bottom is very rough, and shoals up to depths of 350 m at the northwest corner of the survey area on the upper continental slope. Catches of wreckfish on fishery research cruises indicate that they are associated with the series of ridges at 31°20' to 31°25 N, and are particularly abundant around the scarps (Popenoe and Manheim, 2000; Sedberry et al., 2000; Sedberry unpublished data). Additional sampling of demersal fishes and submersible observations are needed to evaluate the relative importance of smooth, rough, ridge and scarp habitats on the Blake Plateau in the life history of wreckfish and other demersal fishes.



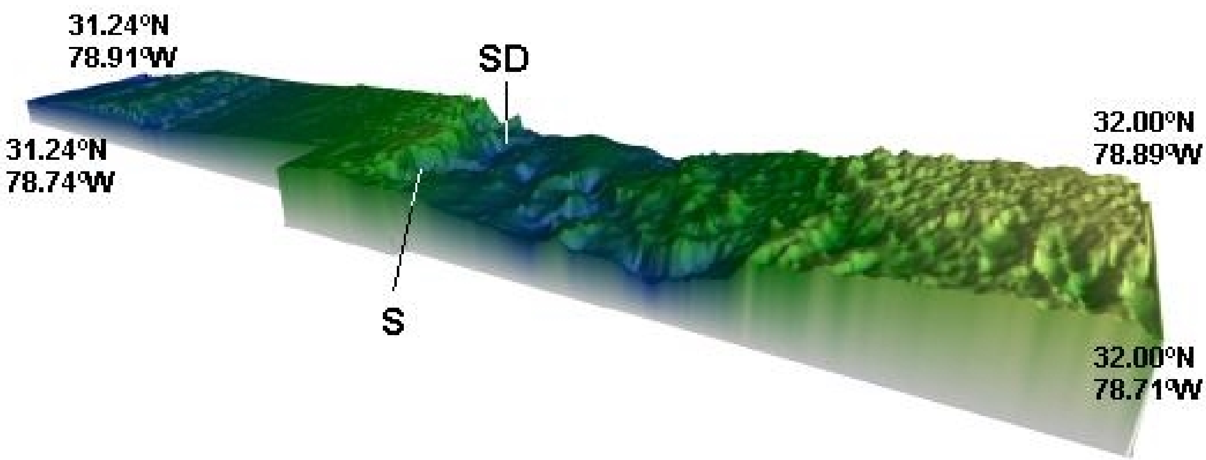


Figure 9. Images of bottom topography from NOAA Ship *Whiting* survey of the Charleston Bump in the vicinity of the wreckfish grounds. The top image is a view "from above", while the lower image is a three-dimensional view of the topography in the area surveyed. The area surveyed corresponds to the shaded polygon in Figure 5 (south is left, north is right). Depths range from 355 to 632 m. R = ridge area, S = scarp area, SD = scour depressions associated with scarps, SS = smooth slope zone. Scarps and ridges are important wreckfish habitats.

Oceanographic Sampling

The results of oceanographic sampling are displayed in series of horizontal and vertical graphs (e.g. Figures 10, 11, 12). Data from both cruises were combined on all horizontal plots, because examination of results from five stations that were sampled during both cruises revealed that there was little change in oceanographic parameters between the cruises. Examination of satellite SST images (http://fermi.jhuapl.edu/avhrr/) also indicated little change between cruises.

Temperature-depth profiles for Stations 1-9 (Figure 7) indicated a rising of the thermocline in areas of suspected upwelling of cooler water, between Stations 2-3 and Stations 6-7 (Figure 10). The main axis of the Gulf Stream was apparent between Stations 2-3 and 7-8.

Surface temperatures progressively increased from about 20.0^{0}C inshore in the Cape Romain area (33^{0}15'N, 79^{0}17W), to 26.0^{0}C offshore in the Gulf Stream and the western Sargasso Sea (Figure 11). Relatively weak horizontal temperature gradients indicated a gradual warming of the surface waters. Isotherms, in general, followed the isobaths more closely on the shelf as compared to isotherm patterns offshore where they were more diffused. Temperatures at 50 m ranged from 19.5^{0}C to 26.0^{0}C. Contrary to the surface distribution, the lowest temperatures were observed both inshore and offshore of the shelf break in the area between 32^{0}30'N and 33^{0}15'N, and they were indicative of upwelling. The intrusion of the upwelled waters onshore was reflected by the temperature minimum which was located on the outer shelf near 33^{0}N. A small pool of colder upwelled waters was also present near the shelf break at about 32^{0}N. Deeper (100 m) distribution patterns of temperature clearly showed upwelled cold waters within the core of the Charleston Gyre, between 32^{0}N and 33^{0}15'N. Temperatures ranged from 15.0^{0}C in the upwelling to 25.0^{0}C in the area of the initial deflection of the Gulf Stream seaward. At 200-m depths, temperatures ranged from 8.5^{o}C at about 32^{o}30'N, within the large upwelling area just to the east of the shelf break, to about 23.0^{o}C at about 32^{o}N farther offshore, in the area of the initial deflection of the Gulf Stream seaward. A broader and better defined Charleston Gyre was present between 31^{o}45'N and 33^{o}15'N. Deepest temperature distributions showed the Gulf Stream main flow, its deflection seaward, and the large elongated cyclonic Charleston Gyre with the upwelling in its cold core. Bottom temperatures on the shelf ranged from 22.0^{o}C inshore to 8.5^{0}C near the shelf break, and from <8.0^{o}C to 19.0^{o}C at 350 m depths offshore. The lowest temperatures offshore were observed in the upwelling area, and the highest 350-m temperatures were within the Gulf Stream deflection.

Temperature contours drawn from surface and subsurface sampling clearly defined the region where the Gulf Stream was deflected by the Charleston Bump at about 32^{o}N (Figure 11). Although somewhat obscured by seasonal warming and wind mixing at the surface, deflection was particularly obvious in deeper waters (e.g. 200 m and bottom plots in Figure 11), corresponding to the deflection observed in SST satellite images (e.g. Figure 4). The initial deflection of the Gulf Stream offshore was observed between 31^{o}45'N and 32^{o}N. A large meander was formed downstream of the deflection, between 31^{o}45'N and 33^{o}15'N. An elongated cyclonic Charleston Gyre was evident in the trough of this meander. The Gulf Stream main front (as defined by 15^{o}C at 200m depth) was deflected offshore about 90 km from the shelf break (Figures 11 and 12).

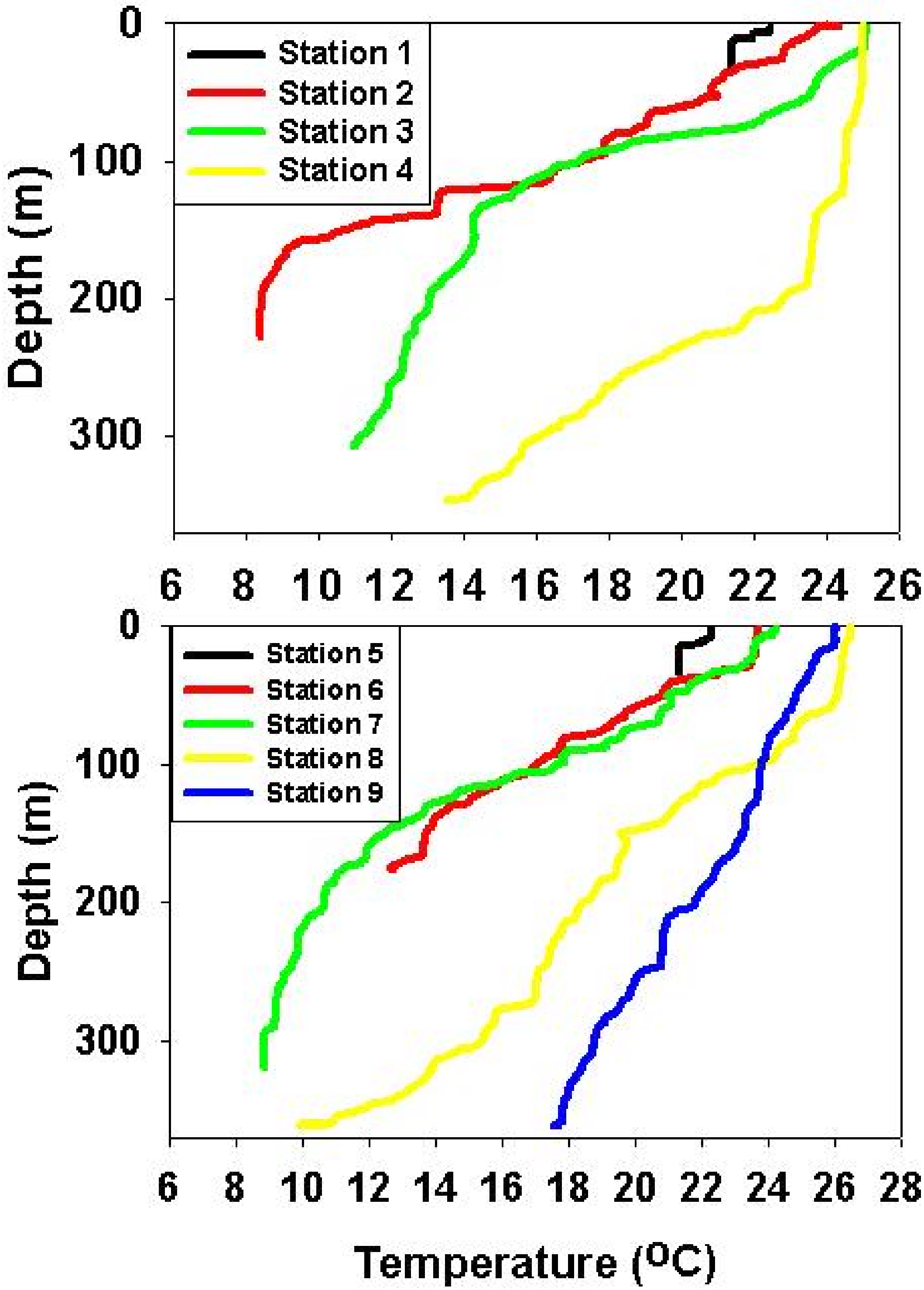


Figure 10. Temperature-depth profiles measured by CTD at Stations 1-4 (top) and 5-9 (bottom). See Figure 7 for station locations. Rising of the thermocline in upwelling areas is evident at Stations 2-3 and 6-7. The Gulf Stream axis is between Stations 3-4 and 7-8.

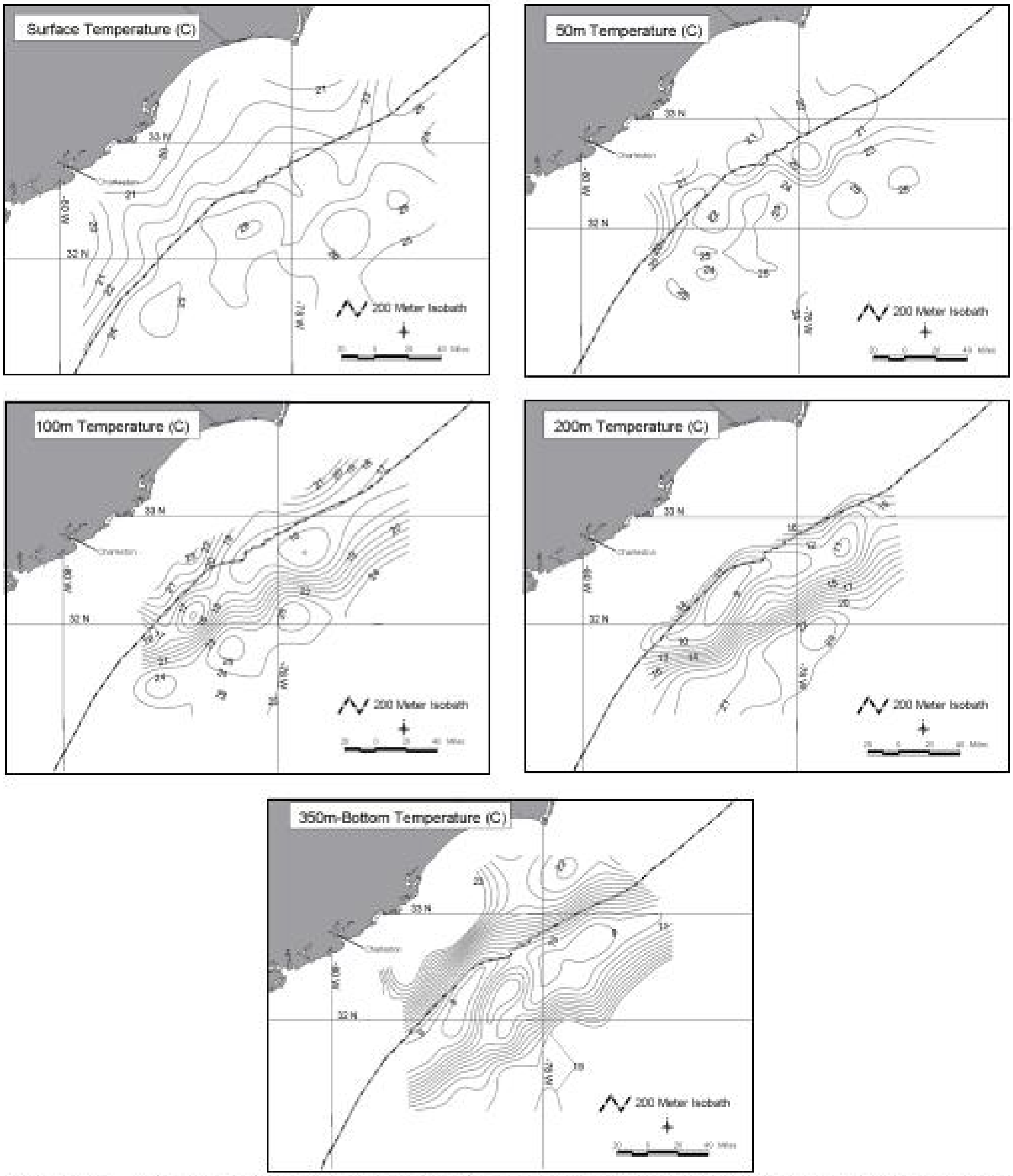


Figure 11. Plots of horizontal distribution of temperature (°C) at the surface, 50 m, 100 m, 200 m, and the bottom (or at 350 m). Note upwelling of cool water that is particularly evident at 100 m depth.

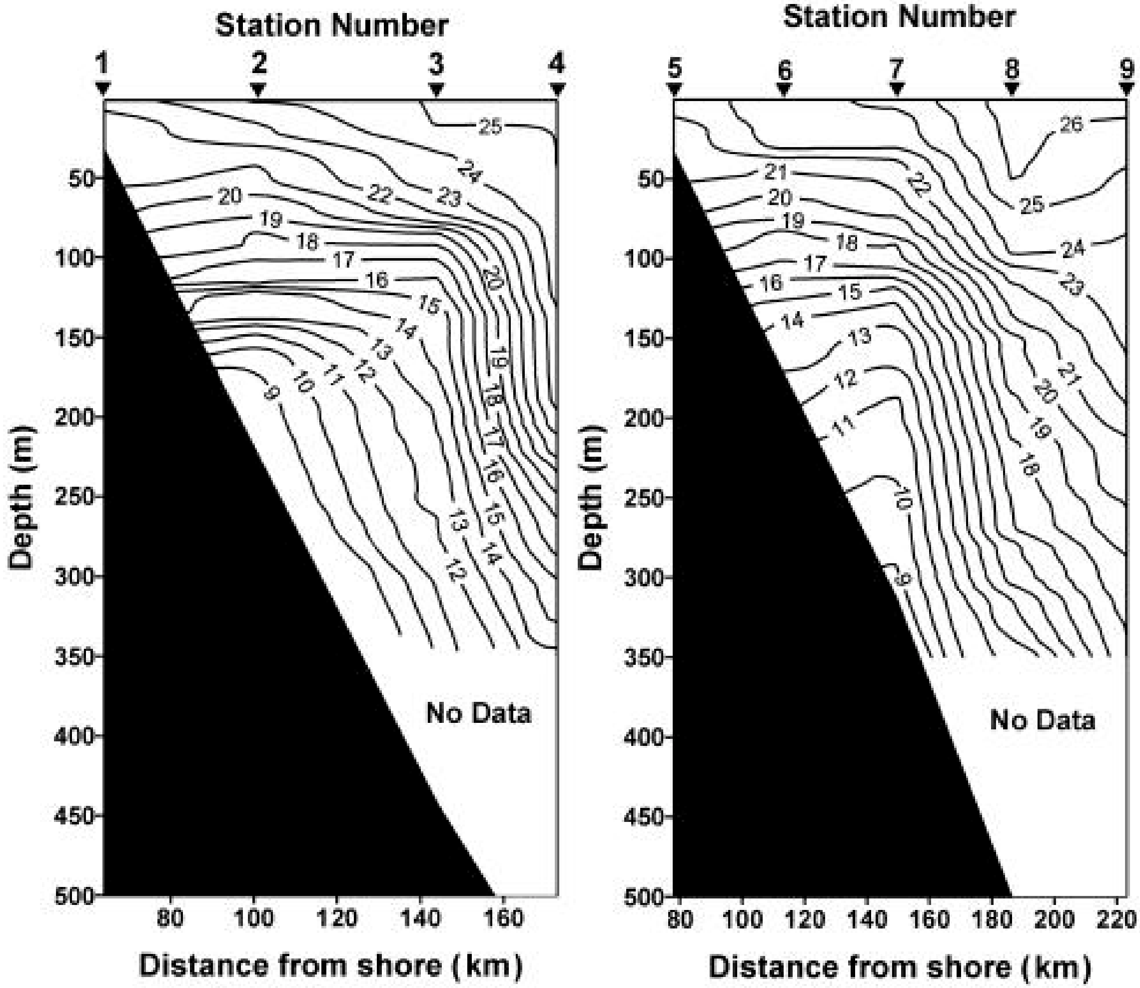


Figure 12. Vertical distribution of temperature (°C) along two transects in the vicinity of the Charleston Gyre, and normal to the shelf edge. Station numbers refer to Stations 1-9 on Figure 7. Upwelling is indicated by doming of isotherms, and the Gulf Stream axis is located between Stations 3-4 and 7-8.

Vertical distribution of temperature (Figure 12) along two selected transects in the vicinity of the Charleston Gyre (see Figure 7), also indicated major features such as the Gulf Stream axis and its main front (western wall as identified by 15^{o}C at 200 m depth). Upwelling of the deep cold waters between the western wall and the continental slope are clearly identifiable on vertical plots, as a doming of isotherms (Figure 12). The Gulf Stream main front and the Gulf Stream axis were located between Stations 2-3, and 7-8. Some sloping of the isotherms downward on the inshore side of the upwelling indicated weak southward flow within the western side of the Charleston Gyre. A broad and gradual Gulf Stream front on the Sargasso Sea (offshore) edge was evident between Stations 8-9 (note that current velocities decreased as compared to Stations 7-8 in Figure 19).

An upwelling of deep cold water was located within the core of the Gyre. This water rose into the euphotic layer from at least 400 m depth, based on surface dynamic height differences (Tomczak and Godfrey, 1994). Thermal structure of the cold core suggests that the Gyre was formed at least 3-4 months prior to our sampling (Cheney, 1978).

Surface salinities ranged from 33.75 psu inshore to 36.35 psu offshore (Figure 13). The lowest values were observed south-southwest of Cape Fear, and east-northeast of Charleston SC, indicating seaward spreading of lower salinity terrestrial runoff. Salinities at 50 m ranged from 35.80 psu inshore, to 36.5 psu far offshore. Lowest values were south of Cape Fear. Overall, 50-m salinities were relatively high, and they varied little throughout the area. Salinity distribution at 100 m exhibited two distinct locations where values were lower than in surrounding areas. These pools of low salinity indicated a presence of upwelled waters. Both were just offshore of the shelf break. One was between 32^{o}30'N and 33^{o}N; the other was located between 31^{o}45'N and 32^{o}15'N. Salinity values ranged from slightly less than 36.00 psu in the southern low-salinity pool to 36.85 psu far offshore, indicating presence of the subsurface Sargasso Sea waters. Salinity distribution at 200-m depths also clearly showed the large area of the low-salinity upwelling just offshore of the shelf break. It occupied the area between 31^{o}45'N and 33^{o}N. Apparently, the two low-salinity pools seen at 100 m have the same source at the deeper levels. Salinity values ranged from <35.20 psu in the upwelling, to 36.80 psu far offshore, in the area of the initial deflection of the Gulf Stream. This high-salinity water is representative of the subsurface Sargasso Sea waters. The deepest salinity measurements also identified a very large area of low-salinity upwelling between 31^{o}45'N and 33^{o}15'N. Salinity values ranged from about 34.75 psu in the southern area of the upwelling, to about 36.75 far offshore. It is interesting to note that the lowest-salinity water at 350-m depths also had very low temperature (7.8^{o}C). Temperature-salinity (T/S) relationships suggest that this water has a signature of the Antarctic Intermediate Water that was advected northward along the Blake Plateau. Atkinson (1983) also reported a presence of this water type in the area.

Vertical distribution of salinity along the two transects (Figure 7) was similar to temperature patterns, but only at the depths below 100 m, where distribution reflected the oceanographic features described above. Low salinity upwelled waters are depicted by doming of isohalines (Figure 14). Gulf Stream waters with salinities 35.8-36.4 psu at depths from 100-350 m were found between Stations 3-4, and 7-8. In addition, high-salinity (up to 36.8 psu) subsurface Sargasso Sea waters were located at depths of 75-200 m between Stations 8-9. A shallow pool of low-salinity shelf waters was present between Stations 1-2. With an exception of this pool, there was very little salinity difference along both transects in waters shallower than about 75 m. Similar horizontal distribution of salinity throughout the area was found at 50 m (Figure 13).

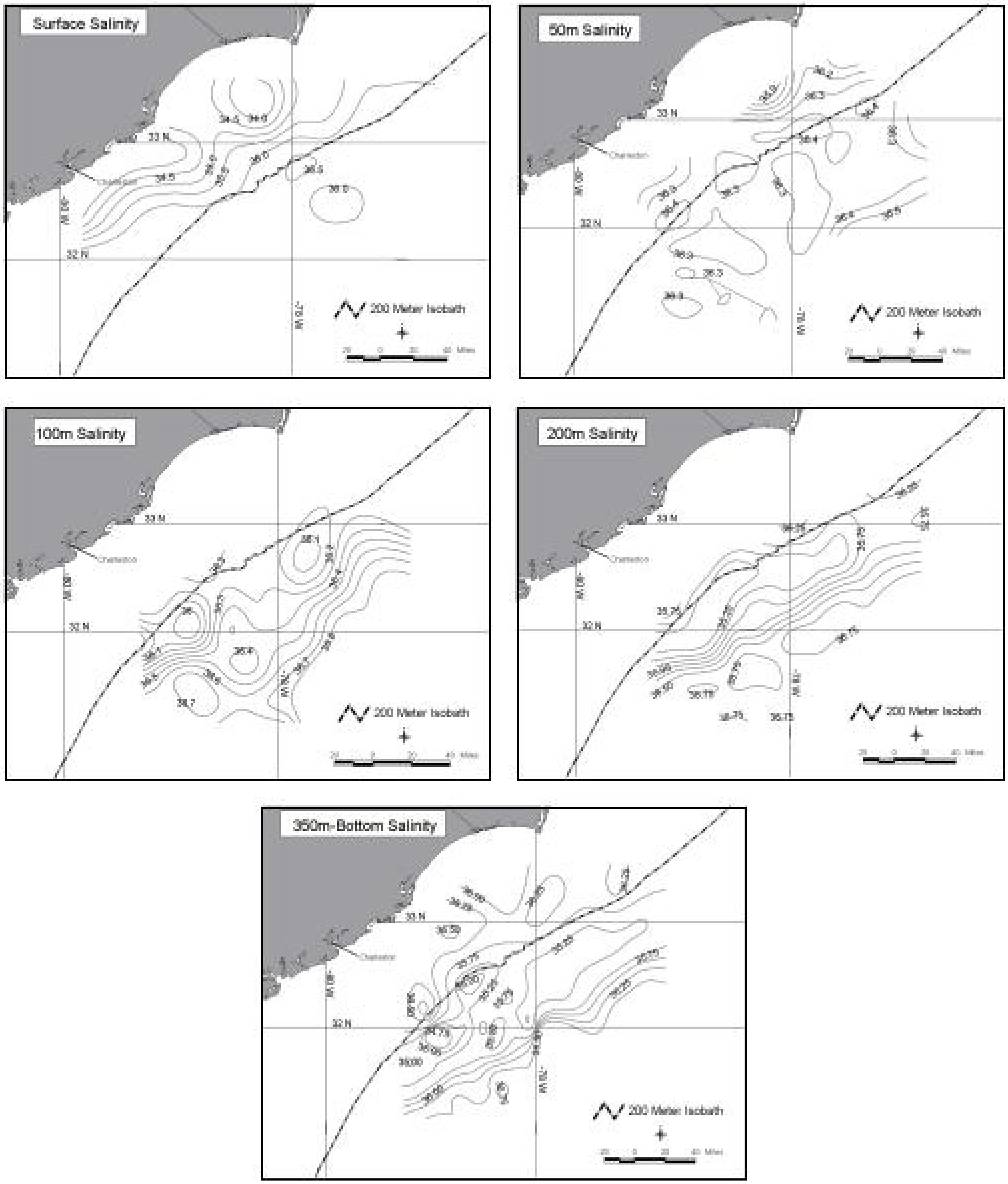


Figure 13. Horizontal distribution of salinity (psu) at the surface, 50 m, 100 m, 200 m, and the bottom (or at 350 m).

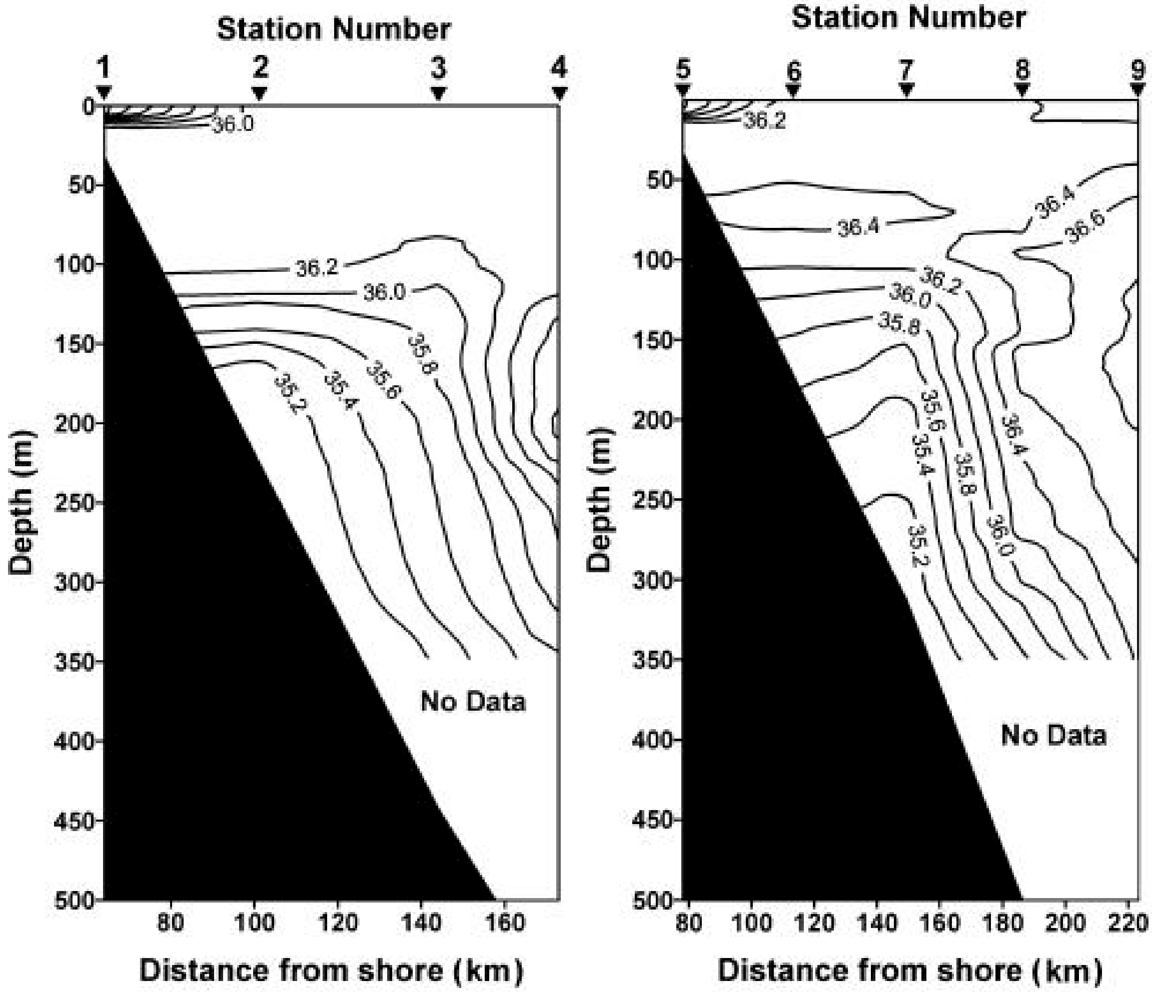


Figure 14. Vertical distribution of salinity (psu) along two transects in the vicinity of the Charleston Gyre, and normal to the shelf break (see Figure 7). Station numbers refer to Stations 1-9 on Figure 7. High salinities indicate Gulf Stream flow; lower salinities indicate upwelling of cold, lower salinity water. The Gulf Stream axis is between Stations 3-4 and 7-8,

In general, density (sigma-t) distribution patterns were similar to temperature patterns, especially below the surface (Figure 15). Surface sigma-t values ranged from 23.15 to 24.95. In general, densities were lowest inshore and highest near the shelf break. High values near the shelf break were apparently associated with the upwelling of deep waters and their advection onto the outer shelf at 40-75 m depths. Density values decreased again seaward of the shelf break. Although not clearly defined at very surface due to seasonal heating and wind action, cyclonic circulation was nevertheless suggested around high surface values near the shelf break in the area between 32°30'N and 33°15'N. Offshore spreading of the coastal waters was evident on the shelf east-northeast of Charleston SC, and off northern Long Bay. Sigma-t values at 50 m ranged from 23.75 to 25.85. Again, the highest values were observed near the shelf break between 32°30'N and 33°15'N. Unlike the surface patterns, the upwelling of dense deeper waters and cyclonic circulation around it were better detectable in this area from sigma-t distribution at 50-m depth. The intrusion of the upwelled waters onshore was also identified by the density maximum located on the outer shelf at about 33°N. Smaller upwelling was also present at 32°12'N. Density values at 100 m ranged from 24.25 to 26.85. An inshore-offshore spreading of isopleths, with an extended distribution along the shelf break, was clearly visible between 32°N and 33°15'N and indicated the cyclonic Charleston Gyre with dense upwelled deep waters in its core. The highest densities were in the upwelling, and the lowest were offshore in the area of the Gulf Stream initial deflection seaward at about 32°N. Sigma-t values at 200 m ranged from 25.25 to 27.25. A long and wide cyclonic Charleston Gyre with dense upwelled deep waters in its core was even better organized at this depth, between 31°45'N and 33°15'N. The highest densities were in the upwelling, with a maximum at about 32°30'N; the lowest values were in the area of the Gulf Stream initial deflection at about 32°N, similar to the 100-m sigma-t distribution. The bottom (to 350 m) sigma-t values were similar to temperature patterns and demonstrated the magnitude of the Charleston Gyre, and the upwelling during the study period. Bottom values on the shelf ranged from 24.25 just to the east of Cape Romain at about 33°N, to 26.50 near the shelf break, and from 26.35 to 27.50 at 350 m offshore. Again, the highest densities were within the upwelling, and the lowest 350-m densities were in the area of the initial defection of the Gulf Stream seaward.

Vertical distribution of sigma- t was almost identical to the temperature patterns (Figure 16). All major features described in temperature section (above), were also identifiable in sigma-t distribution. Dense upwelled deep waters with sigma- t values > 27.2 were indicated by doming of isopycnals.

Surface chlorophyll-a values ranged from <0.1 :g/l to >1.1 :g/l (Figure 17). The highest values were observed near the shelf break at about 32°N, and they were clearly associated with the highest point of the upwelling of the deep, nutrient-rich waters into the near-surface layer in the center of the cold core of the Charleston Gyre. With an exception of this location, surface chlorophyll-a values were <0.2 :g/l throughout the area. Chlorophyll-a distribution at 50 m showed very high values compared to the surface, along the shelf break and just inshore and offshore of it, between 31°45'N and 33°15'N. Apparently, the upwelled waters were reaching the 50 m level over a much larger area than that in which they were reaching the surface. Chlorophyll values ranged from about 1.0 :g/l offshore, to over 9.0 :g/l near the shelf break at 50 m. Chlorophyll-a distribution at 100-m showed that the highest values were near the shelf break between 33°N and 33°15'N, and were associated with the upwelling. Relatively high values up to about 7 :g/l, were also evident offshore at 32°15'N, and they were near the deflected Gulf Stream main front (western wall). Chlorophyll values at 100 m ranged from about 1 :g/l to 13 :g/l.

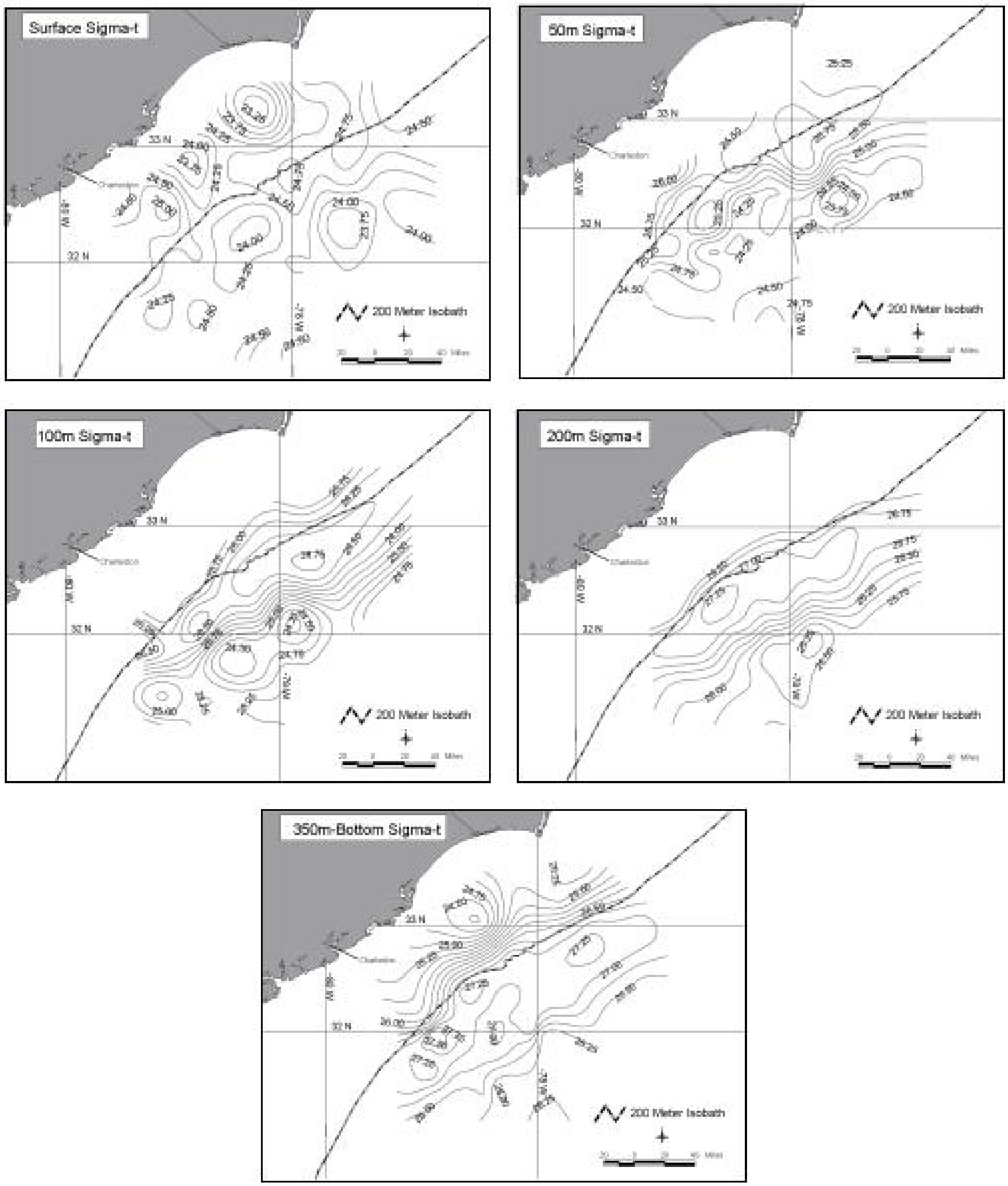


Figure 15. Horizontal distribution of density (sigma-t) at the surface, 50 m, 100 m, 200 m, and the bottom (or at 350 m). The upwelled water in the core of the Charleston Gyre is clearly visible at all subsurface levels.

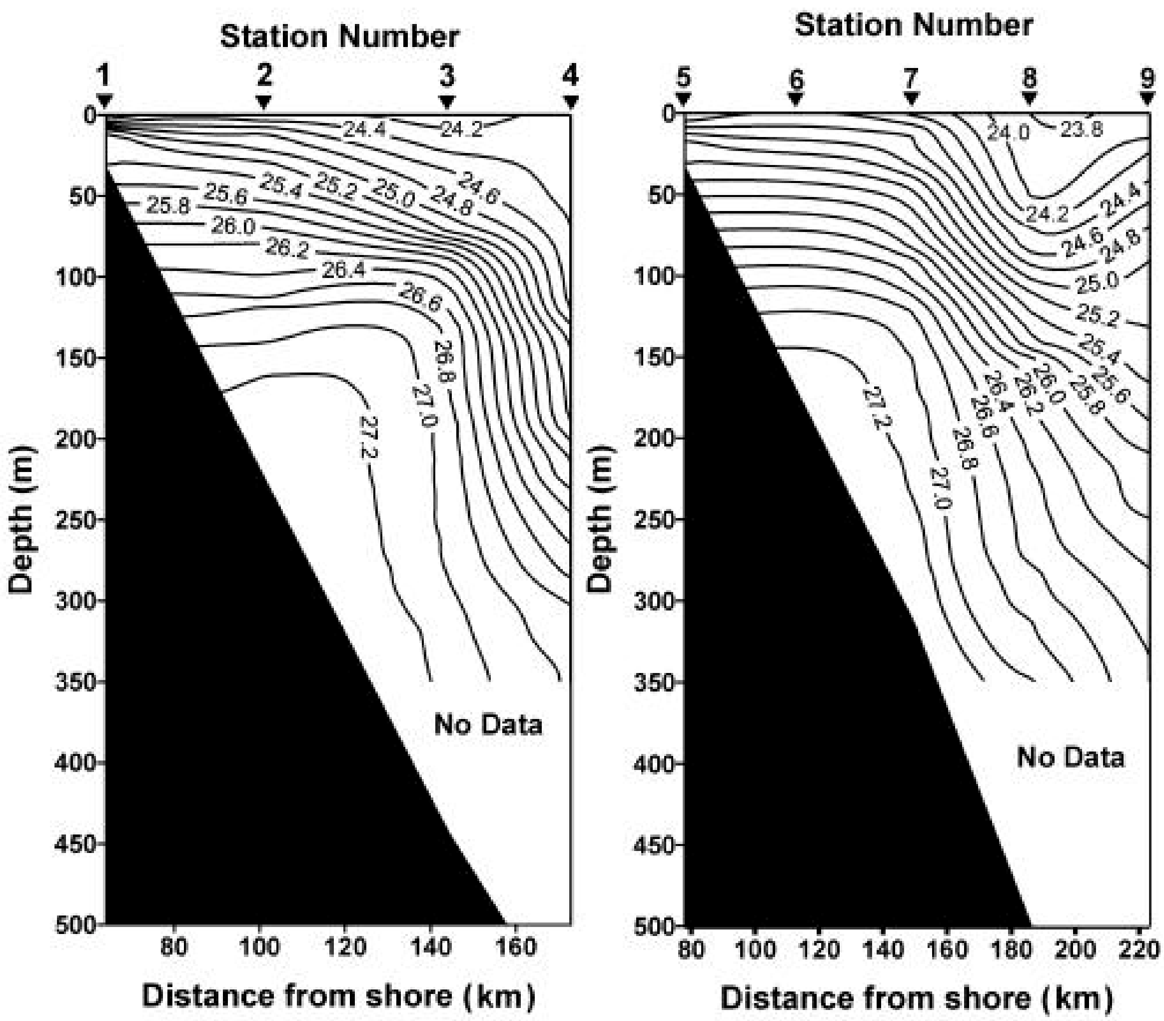


Figure 16. Vertical distribution of density (sigma-t) along two transects in the vicinity of the Charleston Gyre, and normal to the shelf break (see Figure 7). Station numbers refer to Stations 1-9 on Figure 7. The upwelling of dense deep water is clearly visible near the continental slope by the doming of isopycnals. The Gulf Stream axis is between Stations 3-4 and 7-8.

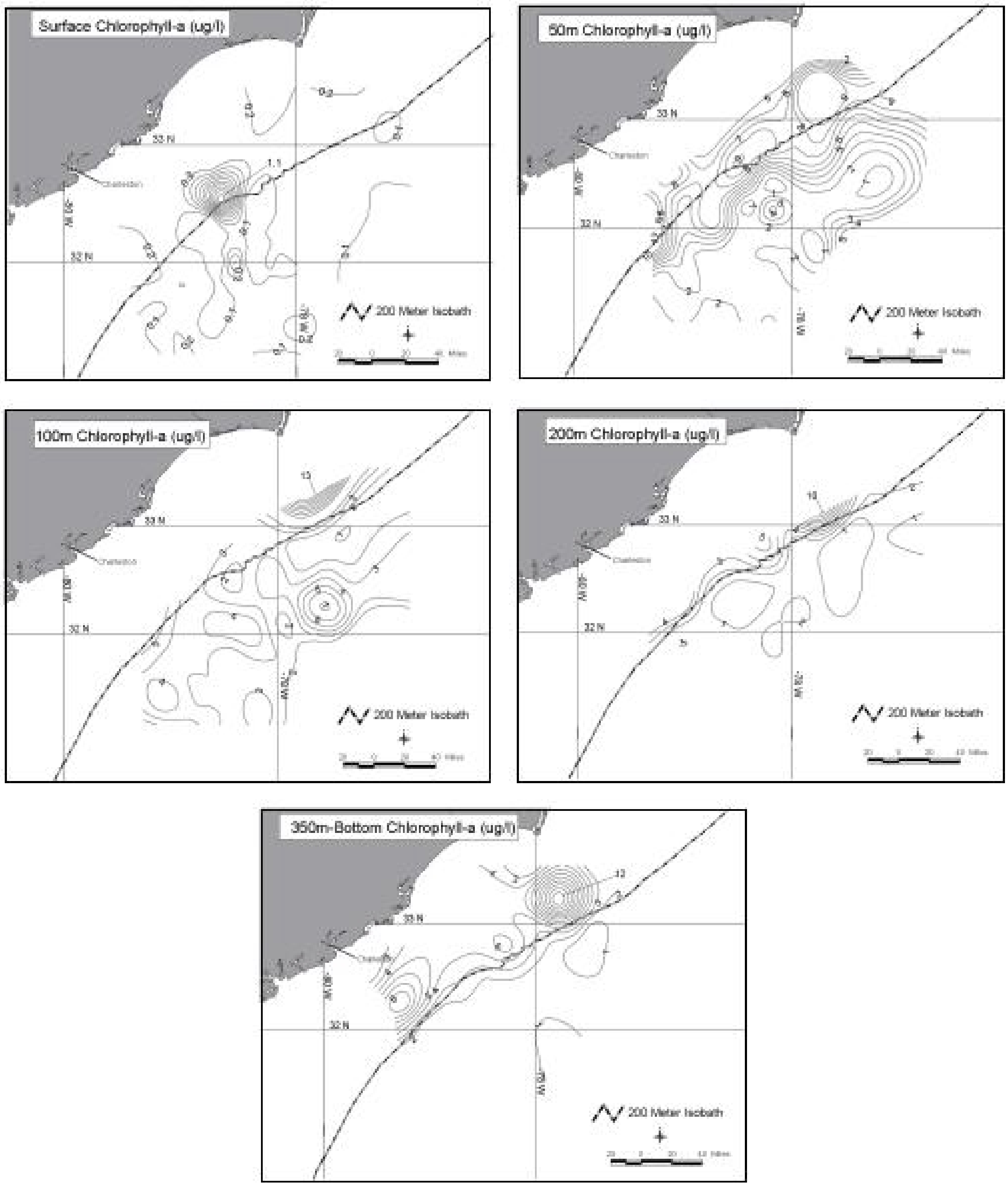


Figure 17. Horizontal distribution of chlorophyll-a (µg/l) at the surface, 50 m, 100 m, 200 m, and the bottom (or at 350 m). Note high concentrations of chlorophyll-a associated with areas of upwelling of cold deep water (see Figure 11).

Chlorophyll-a levels diminished with increasing depth. At 200 m, chlorophyll-a exhibited much lower values offshore, as compared to 100-m level. Again, the highest values were observed near the shelf break between 33^{o}N and 33^{o}15'N. Values ranged from 1 :g/l to about 10 :g/l. Contrary to 100-m chlorophyll-a distribution, offshore values were very low at the 200-m level, even in the upwelling area, apparently in response to extremely low light at this depth. At the 350-m level, chlorophyll-a values offshore were very low due to restricted light. On the bottom at the outer shelf, which is within the euphotic zone, two distinct areas of the high chlorophyll-a concentrations were present. One such area was between 33^{o}N and 33^{o}15'N, and the other was between 32^{o}N and 32^{o}20'N. Those areas were near the northern and southern limits of the intruded upwelled waters, where thermocline descended to the bottom. Chlorophyll-a values ranged from about 1 :g/l at 350 meters offshore, to over 12 :g/l in the northern area of high chlorophyll-a concentration.

Vertical distribution of chlorophyll-a clearly shows its association with the upwelling of the nutrient-rich deep waters into the euphotic layer (Figure 18). The highest concentrations were observed along both transects within the doming of the thermocline (Figure 12) and pycnocline (Figure 16), from 100 m depths offshore to maximum chlorophyll values at 50 m near the shelf break. High values were observed within the temperature range of 18-21^{o}C, and the chlorophyll maximum (>9 :g/l) occurred at Station 2 and Station 6, in both cases at 20^{o}C, at 50m depth.

Areas of upwelling and high chlorophyll-a densities coincide with high abundance of larval fishes. Ichthyoplankton studies have shown that high concentrations of larvae of economically valuable species are associated with upwelling along the shelf edge between 32-33^{o}N. Larvae of king mackerel (*Scomberomorus cavalla*), bluefish (*Pomatomus saltatrix*) and menhaden (*Brevoortia tyrannus*) are more abundant in the areas of upwelling described above, than in other regions of the SAB (Yoder et al., 1981; Collins and Stender, 1987; Govoni and Hare, 2000). It is likely that larvae of other fishes utilize this upwelling area as well, and the shelf edge is an important spawning ground for reef fishes that may utilize this highly productive region (Powles, 1977; Sedberry et al., 2000).

Surface geostrophic velocities calculated for the two selected transects (Stations 1-9, Figure 7) across the Charleston Gyre using the traditional dynamic method (Helland-Hansen, 1934) and a conversion method (Cheney, 1982) had drawbacks. In the dynamic method, a choice of the reference level was limited by 350 dbar (maximum depth capacity of the CTD used). The conversion method did not account for the fine structure of the very upper layer. Nevertheless, both methods produced similar results, especially for the Gulf Stream flow. After a comparison of the surface velocities obtained using both methods, the Helland-Hansen (1934) method was applied in computation of the vertical distribution of geostrophic current velocities (m/sec) along the two selected transects (Figure 19). Cheney's method was used for obtaining a general surface circulation patterns (dynamic topography, in dynamic meters) for the entire area (Figure 20). The Gulf Stream main flow, its deflection seaward, the cyclonic Charleston Gyre, and the upwelling of deep waters into the euphotic layer are clearly defined (Figures 19 and 20). Gulf Stream velocities were the highest near the surface between the Stations 3-4 (up to 1.3 m/sec), and between Stations 7-8 (up to 0.9 m/sec). The upwelling areas were indicated by the minimal horizontal flow (Figure 19). The "zero" line was located between Stations 1-2 and Stations 6-7. Currents on the both sides of the upwelling moved in opposite directions: northeast in the Gulf Stream, and southwest within the inshore side of the Charleston Gyre.

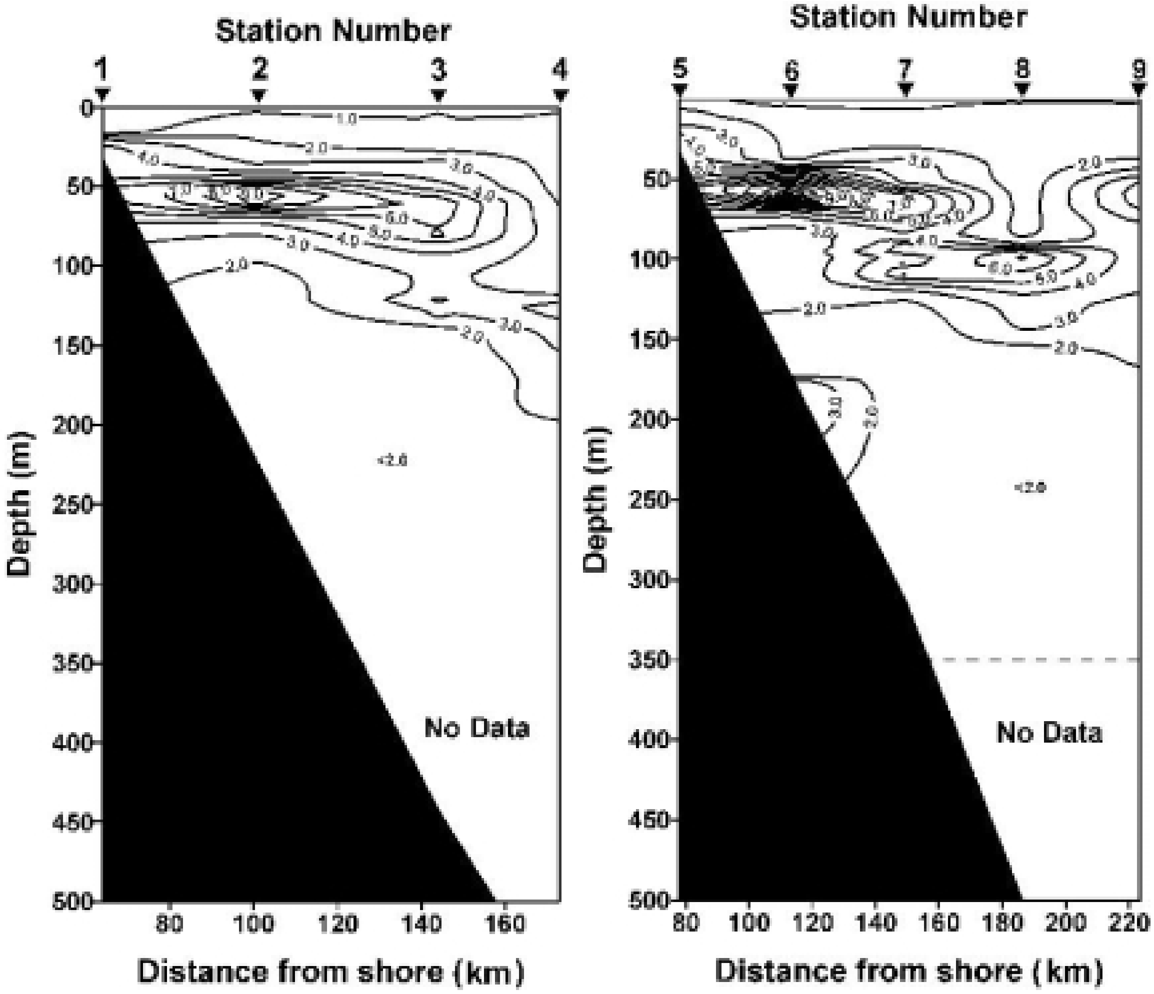


Figure 18. Vertical distribution of chlorophyll-a concentrations (µg/l) along two transects in the vicinity of the Charleston Gyre, and normal to the shelf edge (see Figure 7). Station numbers refer to Stations 1-9 on Figure 7. Subsurface maximum chlorophyll concentrations were located within the doming thermocline between 50 and 75 m depth just offshore of the shelf break, near the peak of upwelling (see Figure 12).

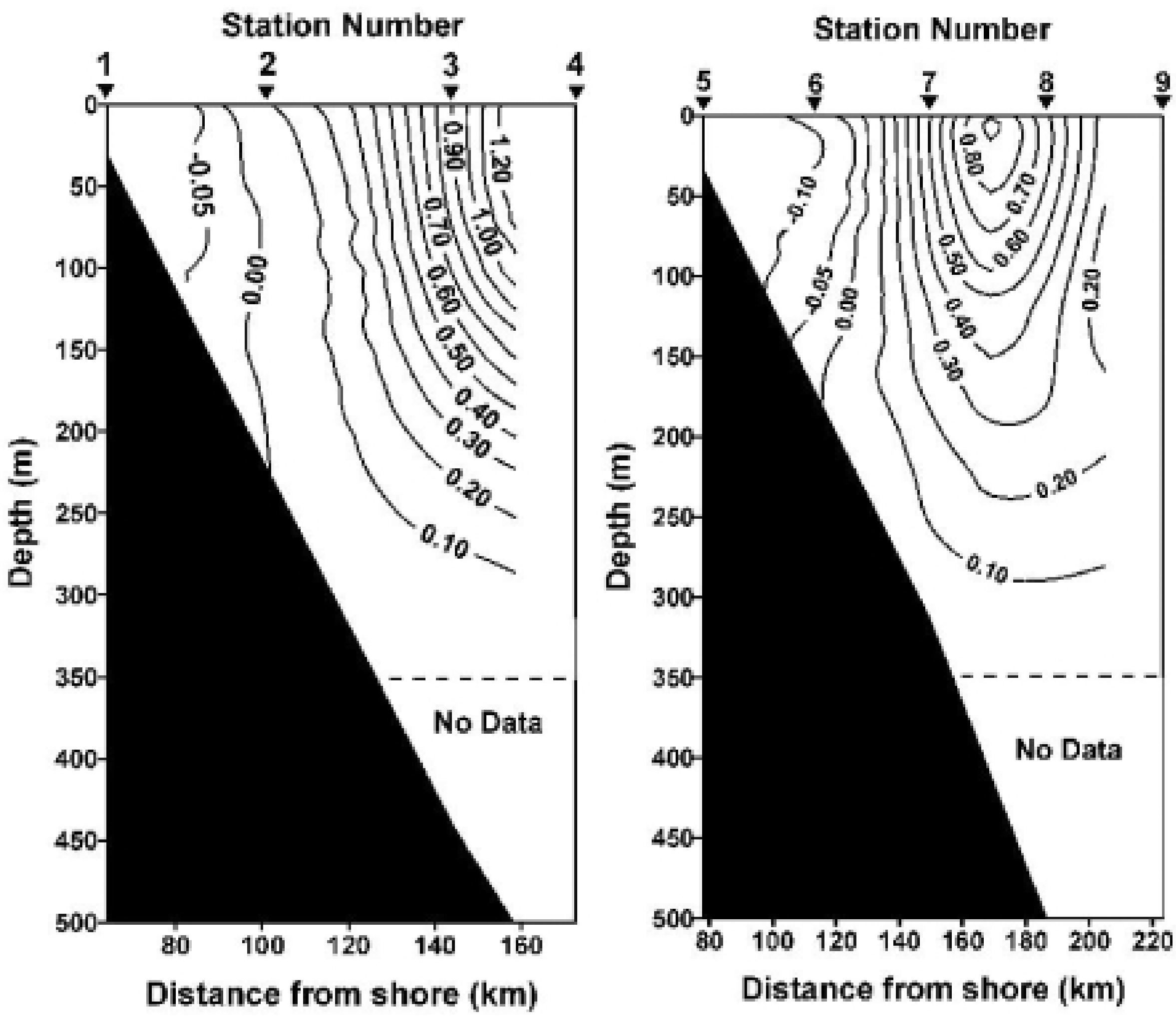


Figure 19. Distribution of geostrophic current velocities (m/sec) determined by dynamic method (Helland-Hansen 1934) for data from transects indicated in Figure 7. Positive values indicate flows into the plane of the figure (northeastward) and negative values indicate flow out of the plane of the figure (southwestward). Maximum positive values indicate the main axis of the Gulf Stream and negative values indicate return flows associated with the Charleston Gyre. Zero values indicate the approximate location of the core of the Charleston Gyre. Station numbers refer to Stations 1-9 on Figure 7.

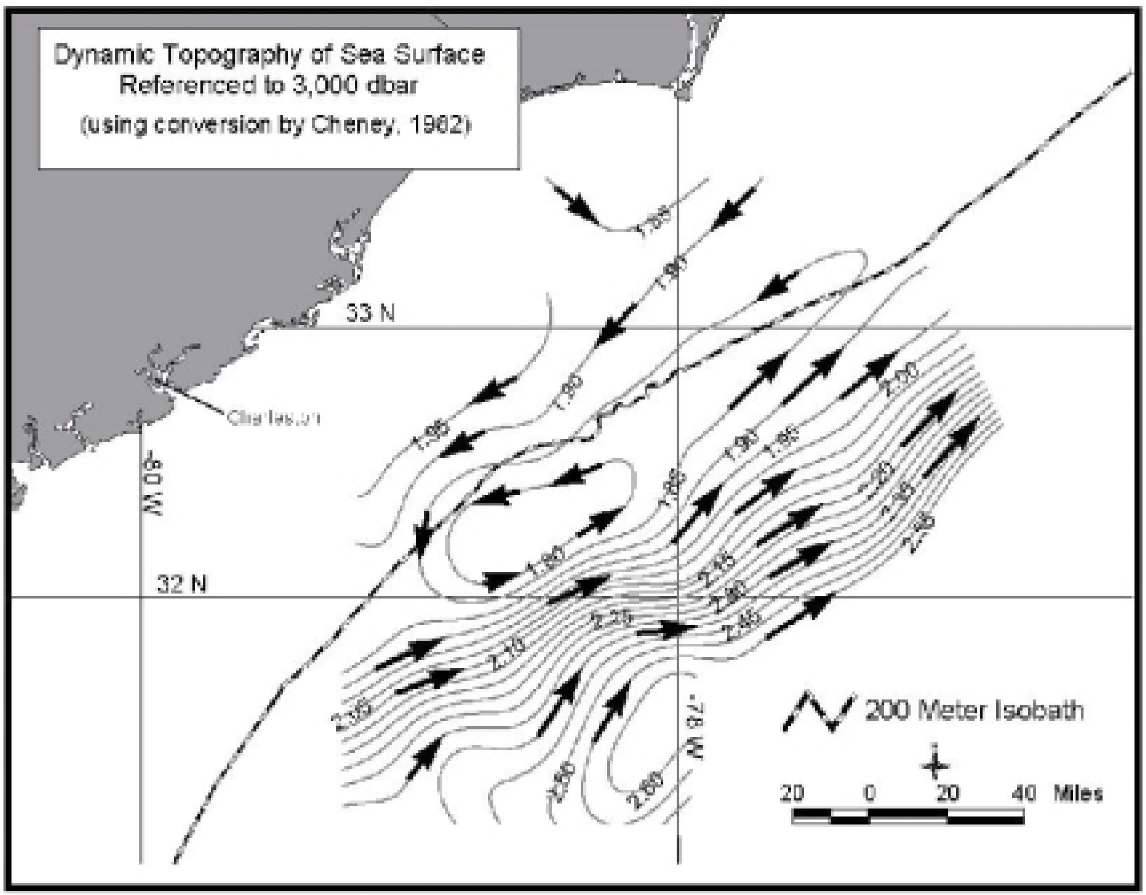


Figure 20. Major circulation patterns determined from dynamic height method. Contours represent dynamic sea surface height anomalies, in dynamic meters. The elongated cyclonic Charleston Gyre with a core between 32°N and 33°N is evident.

NMFS Longline Logbook Data

NMFS logbook data 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 21). 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 22). 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 non-frontal 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 23).

Because of concern for overfishing of swordfish, the high occurrence of non-targeted sport billfishes (marlins and sailfish) that must be discarded, as well as concerns with bycatch of turtles, birds and other 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). NMFS concluded that while "pelagic longline activity in the Charleston Bump area results in bycatch of small swordfish throughout the year, over 70 percent 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

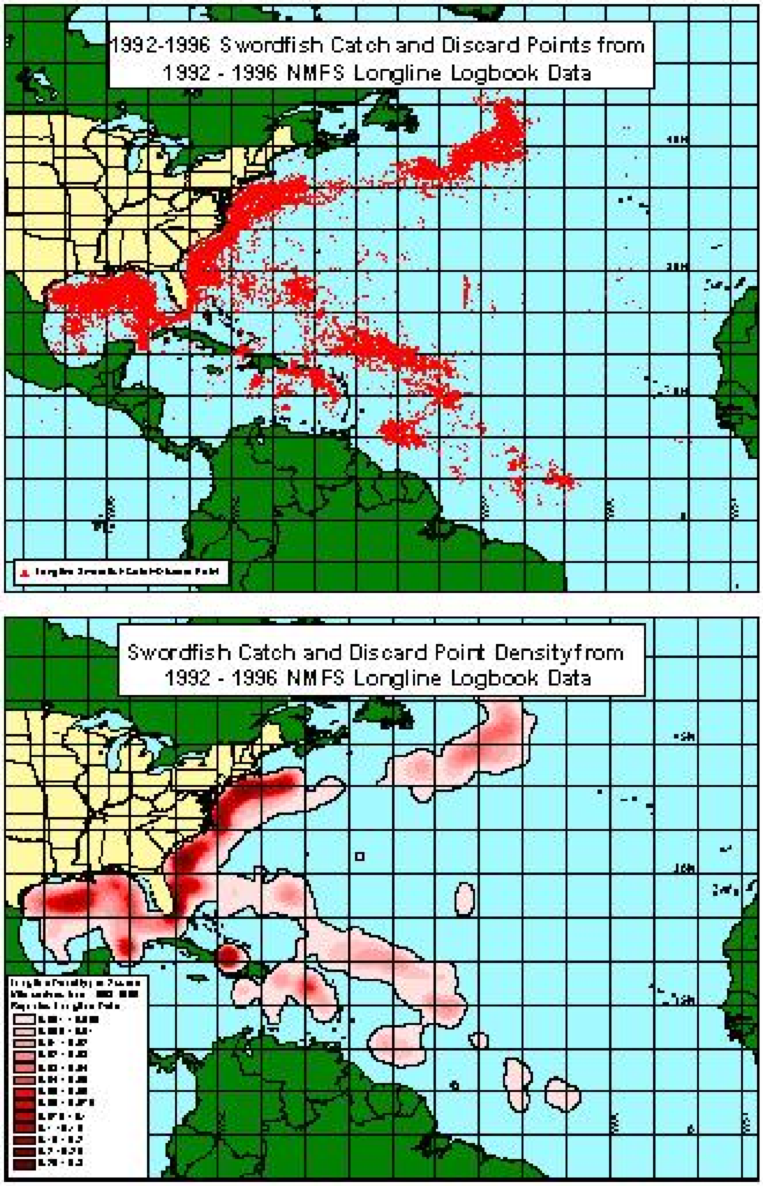


Figure 21. Location (top) of longline set points for sets that caught (kept or discarded) swordfish, and density analysis (bottom) of points (number of sets per square mile) from 1992-1996 NMFS longline logbook data.

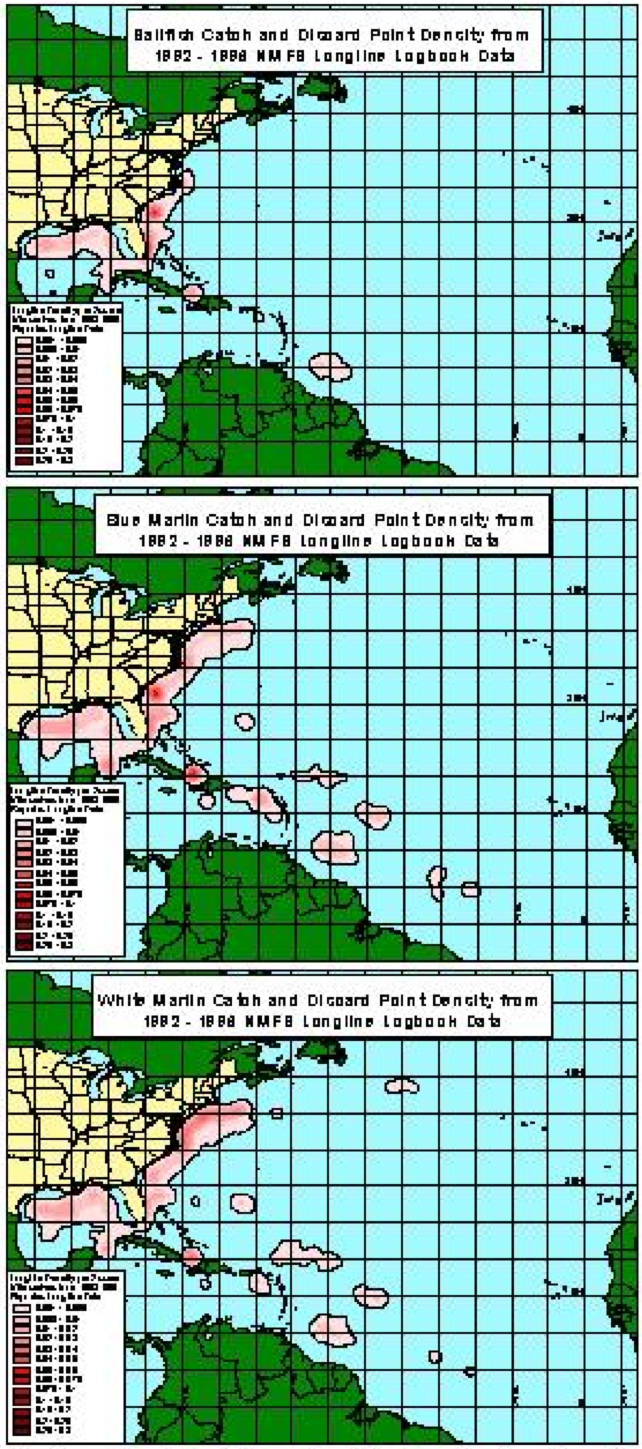


Figure 22. Density of longline set points for sets (number of sets per square mile) that caught sailfish (top), blue marlin (middle) or white marlin (bottom), from 1992-1996 NMFS longline logbook data.

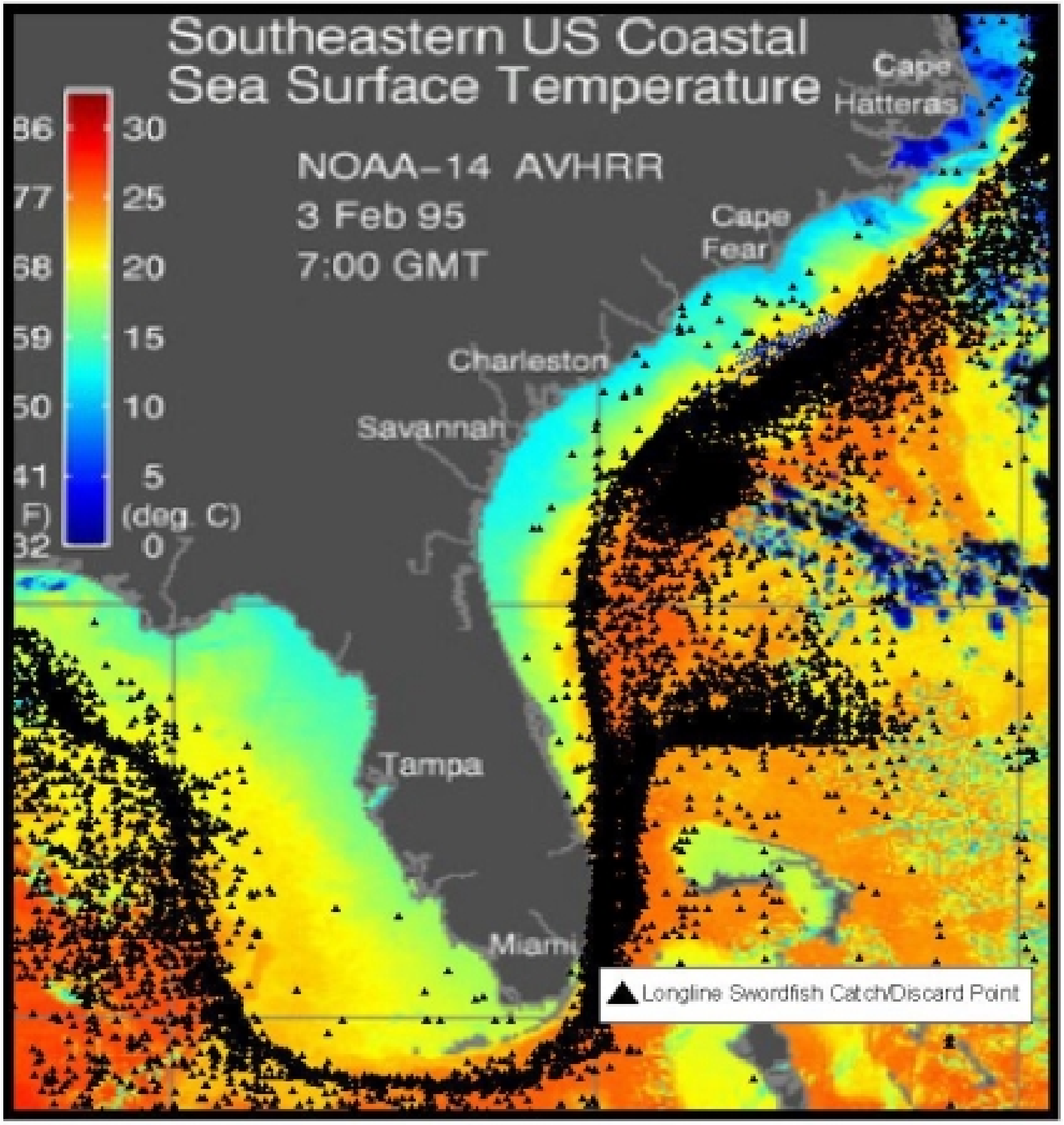


Figure 23. Sea surface temperature image and longline set points where swordfish were captured, indicating a concentration of effort on the Charleston Bump and the Charleston Gyre.

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; NOAA, 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 22) and sea turtles. NMFS will monitor fishing activity to determine whether a larger 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, 1966; Cramer, 2000). Cramer (1996, 2000) found the highest proportion (relative to legal-sized fish) of undersized discards off the Carolinas 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 non-targeted 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 22), 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 gamefish 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.

Satellite Tagging

Of the two sailfish tagged, one tagged just north of the main scarp on the Bump moved toward that scarp in 5 d (Figures 8, 24). The other moved far offshore, northeast of Bermuda, in 90 d.

The swordfish tagged for this study ranged in size from 71 to 183 cm (mean = 106.4; s.d. = 31.4) lower jaw fork length (LJFL; Table 1). Of the 30 swordfish tagged, one 5-d tag did not report. That fish was not in as good a condition as most, and may have died and sunk to the bottom, thus imploding the tag. Of the other 29 satellite tags deployed on swordfish 23 released successfully and made contact with the Argos system (Figure 8). Three tags demonstrated weak or sporadic contact with the satellites, and the full archived temperature data set was not recovered.

Tags that released after 30 d showed that those fish moved mainly to the east, towards Bermuda (Figure 25). Of these, the fish that moved the farthest was located near the Muir Seamount (Figure 8), 260 km northeast of Bermuda, or 1490 km east-northeast of the Charleston Bump. Tags that popped off after 60 d showed some further movement to the north and northeast, and some of these fish were found near other seamounts or near submarine canyons (Figures 8 and 25). One was found near Wilmington Canyon (930 km from tagging site). Tags that popped off after 90 d showed that these fish were also found near submarine canyons (Norfolk Canyon, 750 km from tagging site) and others were following the Gulf Stream to the northeast, and were found along the "north wall" of the Gulf Stream (Figures 8 and 25).

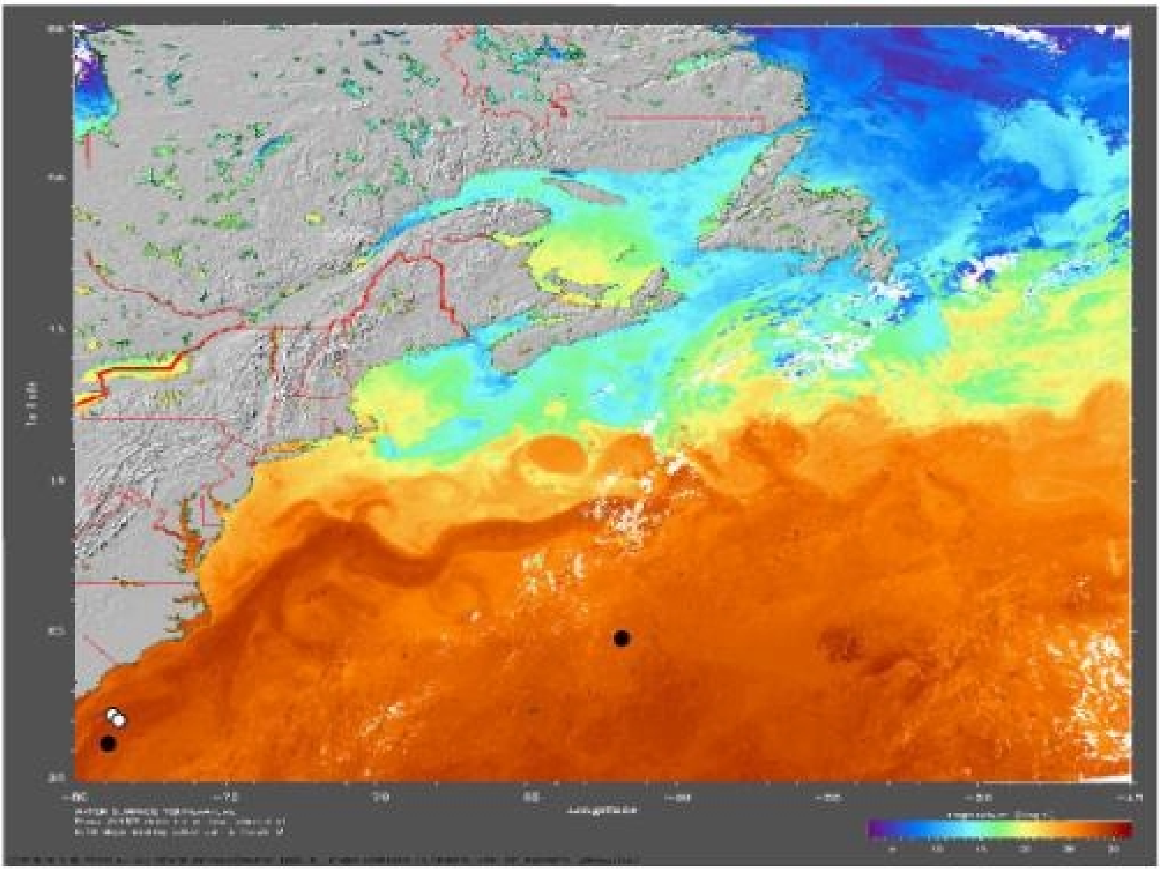


Figure 24. Seven day composite SST diagram for 7 July 2000 showing tagging and release points for the two sailfish tagged. Note the offshore deflection of the Gulf Stream by the Charleston Bump in the tagging area.

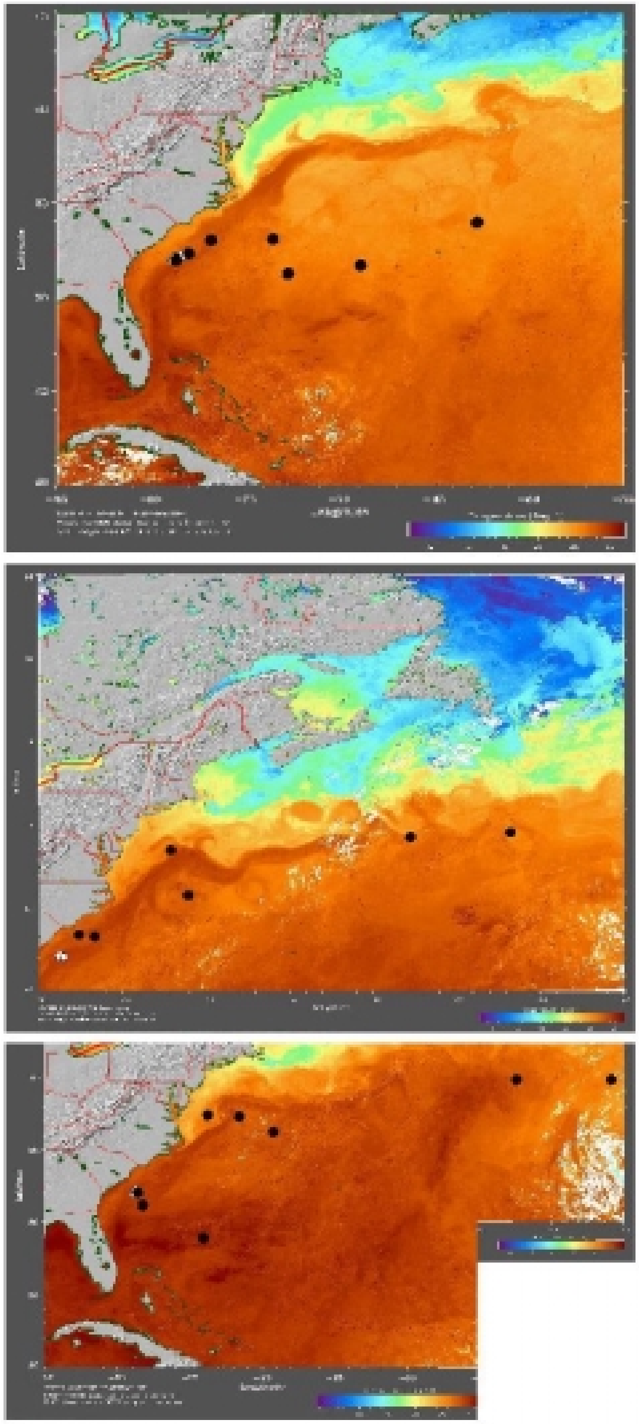


Figure 25. Movements of swordfish in relation to SST features. Top: 7-d composite SST diagram for June 5 2000 showing tagging and release points for 30-d satellite tags. Note the offshore deflection of the Gulf Stream by the Charleston Bump in the tagging area. Middle: 7-d composite SST diagram for July 10 2000 showing tagging and release points for 60-d satellite tags. Bottom: 7-d composite SST diagram for August 21 2000 showing tagging and release points for 90-d satellite tags.

Four swordfish apparently did not move away from the Charleston Bump, even after 90 d (two of the four). These fish may have ranged away from the Bump during the time at large, but were in the vicinity of the tagging location when the tags popped off, indicating that some swordfish prefer the area of the Charleston Bump. Most swordfish, however, moved great distances from the tagging site. The longest minimum straight-line distance (from tagging point to pop-off point) was 3053 km, covered in 90 d (about 34 km/d). The fastest fish moved 1487 km in 30 d (about 50 km/d). Although the tagged fish ranged in length from 71 to 183 cm LJFL, there was no statistical relationship between distance traveled and size of the fish (ANOVA, $R^2 = 0.11$, $n = 20$, $P = 0.159$).

Archived temperature data from 30-d tags indicated daily movements through water temperatures between 10°C and 28°C (Figure 26). Tags with longer times-at-large (60 and 90-d) recorded a temperature average only once every 24 h or 36 h, so the temperatures reported by these tags did not demonstrate as great a variation between readings as did the 30-d tags. The archived temperature data also indicated (by archiving temperatures that were consistent with continuous recording of sea surface temperatures) that seven tags were either shed from the fish prematurely, or the fish died and surfaced prior to the tag release date (data not shown).

Temperature-depth profiles collected in the area of tagging at about the same time (Figure 10) were variable, reflecting the dynamic nature of currents in the area where the Gulf Stream is deflected offshore by the Charleston Bump. This complicated the use of the temperature data for estimation of the depth of swordfish diel migrations. The profiles indicated that forays into water as low as 10°C may have required dives of as little as 150 m, or greater than 350 m, depending on the exact location in the tagging area.

Archived temperature and inclination data indicated that satellite pop-off tagging of swordfish was successful in most cases. Varying patterns in the temperature data should be expected, as swordfish move vertically through different temperature regimes. Variability patterns in temperature data that showed a diel pattern would indicate an active swordfish migrating vertically from warm surface waters to cooler waters at depth. The temperatures archived in each tag varied according to the time period between temperature recordings. For example, a 12-h temperature averaging and archiving period (such as in the 30-d tags) should demonstrate averages that alternate between warm and cold, as this time scale would record and average temperatures for every half of a diel cycle. The temperature averages recorded by a 60-d tag (once every 24 h) should thus be fairly constant, as each temperature reading is an average of the values of water temperatures inhabited by the fish for a full diel cycle. It would also be expected that a 90-d tag, which records an average temperature once every 36 hours, should show the same general pattern of alternation between warm and cold readings as a 30 d tag, but the variation between subsequent recordings would not be as great, since temperature averages were recorded every one and a half diel cycles (the full diel cycle averages will have a buffering effect on the variation from the half diel cycle). Tags of all three deployment lengths demonstrated temperature data very similar to these expectations. As a result, the 30-d tags provided the most insight into the diel migration of swordfish. Carey (1990), used acoustic telemetry to demonstrate the diel migration patterns of swordfish, which consisted of a rise to the surface at sunset to waters as warm as 27°C, followed by dives to as low as 5°C at sunrise. Our data from satellite tags indicated swordfish preferred average temperatures of around 10°C during the day, and rose to near surface waters of up to 28°C at night, which was consistent with the findings of Carey (1990). Considering that the temperature measurements of the former study are discrete, and of the later are averages, the results are quite similar.

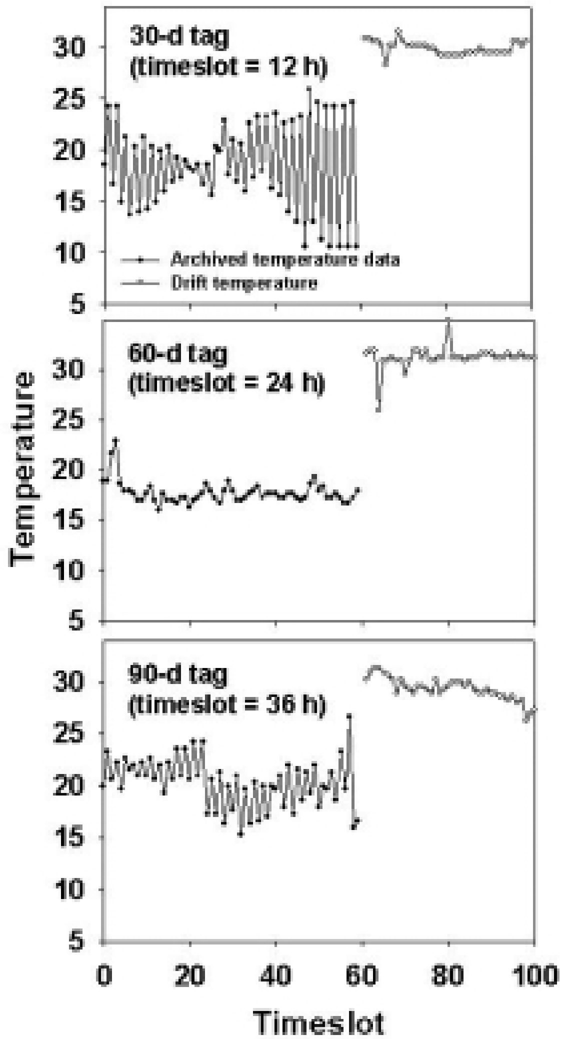


Figure 26. Temperature data recorded by pop-off tags.
Top: archived temperature data (closed circles) and drift temperatures (open circles) reported after release from a 30-d satellite tag. The archived temperature data demonstrates the pattern expected for an individual with a diel vertical migration pattern. The difference between the two data sets indicate that the tag remained attached to the fish the entire time at large.
Middle: archived temperature data from a 60-d satellite tag. The overall consistency of temperatures lower than that of surface water temperatures in the tagging region fits the expected pattern for a tag archiving average water temperature surrounding a vertically migrating organism approximately every 24 h.
Bottom: archived temperature data from a 90-d satellite tag. The reported temperatures fit the expected pattern for a tag archiving water temperature averages surrounding a vertically migrating organism approximately every 36 h.

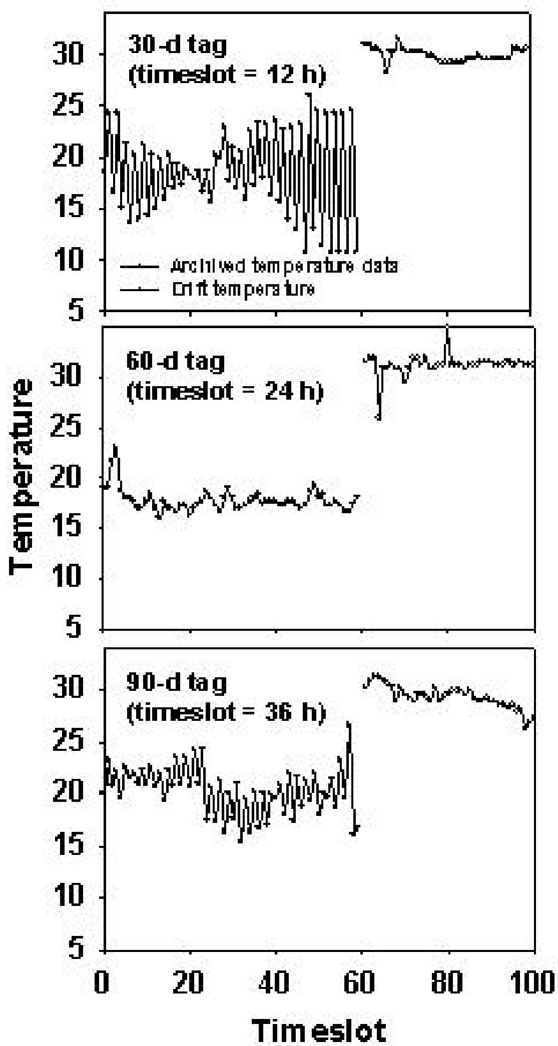


Figure 26. Temperature data recorded by pop-off tags.
Top: archived temperature data (closed circles) and drift temperatures (open circles) reported after release from a 30-d satellite tag. The archived temperature data demonstrates the pattern expected for an individual with a diel vertical migration pattern. The difference between the two data sets indicate that the tag remained attached to the fish the entire time at large.
Middle: archived temperature data from a 60-d satellite tag. The overall consistency of temperatures lower than that of surface water temperatures in the tagging region fits the expected pattern for a tag archiving average water temperature surrounding a vertically migrating organism approximately every 24 h.
Bottom: archived temperature data from a 90-d satellite tag. The reported temperatures fit the expected pattern for a tag archiving water temperature averages surrounding a vertically migrating organism approximately every 36 h.

The results of this study indicate that the pop-off satellite technology originally developed for bluefin tuna works on swordfish as well. However, a previous study on bluefin tuna (Block et al., 1998) demonstrated a much lower tag failure rate (5%) than the current study (21%). This is the first time satellite tags have been used on a species that makes such deep diel migrations. It is therefore possible that swordfish may occasionally exceed the 650 m depth limit of the satellite tags (at which the tag is crushed by hydrostatic pressure). Even if this maximum depth is not reached, the frequent and substantial changes in pressure resulting from the daily migrations demonstrated by swordfish may fatigue the tag casing during the attachment interval, leading to occasional leakage and failure.

Swordfish migration appears to be complex and multidirectional, as there was no definite trend towards fish moving progressively farther away from the tagging location with increased time of tag release. While the longest straight-line travel (3053 km) was demonstrated by a fish with a 90-d tag, two other 90-d tags reported from within 100 km of the tagging location. In fact, all three tag groups demonstrated a broad range of distances traveled from the tagging location. These results are at odds with previous studies using conventional tags. Beckett (1975) reported a maximum distance of 288 km between tag and recapture points based on 13 tag returns from swordfish tagged in Canadian waters. These fish were recaptured in subsequent years following tagging, but at around the same time of year they were tagged, which suggests that the fish were recaptured near the same point in their seasonal migration, rather than being resident at the tagging site.

Swordfish appear to be attracted to complex high-relief bottom structure and complex thermal structure consisting of fronts where warm Gulf Stream waters meet cooler shelf, slope and Labrador Current waters. The topographic relief of the Charleston Bump is an area of high swordfish catch frequency (Figures 21 and 23; Cramer 1996; Cramer 2000), and higher catches have been noted along the western wall of the Gulf Stream in the vicinity of thermal fronts (Podestá et al., 1993). Our tagging data indicate that some swordfish remained in the vicinity of the Charleston Bump, probably attracted to the great topographic relief (exceeding 100 m of steep scarps in depths from 375 - 700 m) and numerous thermal fronts generated by deflection of the Gulf Stream and subsequent formation of meanders, frontal eddies, gyres and upwelling of cooler waters. Because the Charleston Bump results in increased frequency and abundance of thermal fronts, the Bump provides additional habitat for swordfish. Swordfish that moved away from the Charleston Bump were frequently found associated with seamounts, submarine canyons, and the Gulf Stream front as the Stream turned eastward across the North Atlantic.

The Charleston Bump appears to be an important habitat for swordfish, and also functions as a stepping stone along the path of seasonal migration of the swordfish. Satellite tagging technology is increasing in sophistication and the amount and kinds of data that can be archived and transmitted. Additional studies, including satellite tagging of swordfish with tags having deeper capabilities, and that are able to store data on depth and ambient light, are needed to further define the activity patterns and migratory behavior of swordfish and other highly migratory species in the western North Atlantic.

Conclusions

The Charleston Bump influences major circulation patterns in the South Atlantic Bight, and thus influences fishes and their life histories and distributions. During this study, deflection of the Gulf Stream offshore was observed between 31°45'N and 32°N. A large meander with a wavelength of about 250 km was formed downstream of the deflection, between 31°45' and 33°15'N. An elongated cyclonic Charleston Gyre was evident in the trough of the meander. The Gulf Stream main front (i.e. its western wall as defined by 15°C at 200 m depth) was deflected about 90 km from the shelf break. An upwelling of deep cold water was located within the core of the Gyre. This water rose into the euphotic layer from at least 400 meters, based on surface dynamic height differences. Thermal structure of the cold core suggests that the Gyre was formed at least 3-4 months prior to our sampling in April-May 2000, and it was relatively stationary since February 2000.

Chlorophyll-a concentrations were clearly associated with the upwelling. The highest values were observed within a doming of the thermocline and pycnocline. Maximum subsurface chlorophyll-a concentrations were located between 50 and 75 m depths just offshore of the shelf break; a surface maximum occurred just inshore of the shelf break at 32°30'N, near the highest point of the upwelling in the center of the Charleston Gyre. The highest bottom values were located on the outer shelf (40- 75 m depth) within the southern and northern limits of the Gyre where the thermocline descends to the bottom. All high values of chlorophyll-a were within euphotic layer.

The Charleston Bump Complex functions as essential fish habitat (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 swordfish in the vicinity of the Bump. 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.

Satellite pop-off tagging of swordfish indicated that most tagged fish were not resident on the Bump, but moved great distances and were associated with bottom features such as submarine canyons and ridges, or with oceanographic fronts. Some swordfish were found in the vicinity of the Charleston Bump up to 90 days after tagging.

Limited data from historical ichthyoplankton surveys indicate that thermal fronts created by the Charleston Bump are areas where larval swordfish are often caught, and that high concentrations of larval fishes are associated with upwelling generated by the Charleston Bump. 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.

While essential fish habitat (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. Consideration of deepwater EFH has been limited to deepwater coral (e.g. *Lophelia prolifera, Oculina*) banks occurring primarily in the Straits of Florida. In spite of the concentration on shallow habitats, the South Atlantic Fishery Management Council (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. 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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Appendix 1

Charleston Bump Colloquium Program and Abstracts