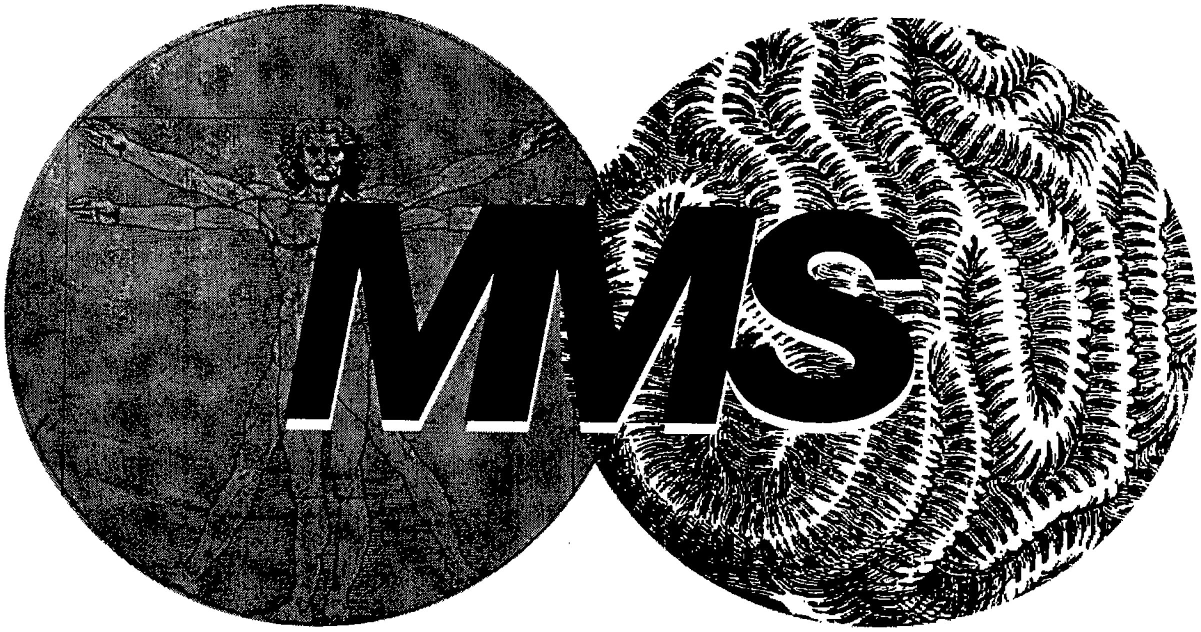
OCS Report
MMS 98-0010

The Flower Garden Banks (Northwest Gulf of Mexico): Environmental Characteristics and Human Interaction



U.S. Department of the Interior
Minerals Management Service
Gulf of Mexico OCS Region

CITATION

Suggested citation:

Deslarzes, K.J.P., ed. 1998. The Flower Garden Banks (Northwest Gulf of Mexico): Environmental Characteristics and Human Interaction. OCS Report MMS 98-0010. U.S. Dept. of the Interior, Minerals Management Service, Gulf of Mexico OCS Region, New Orleans, La. 100 pp.

ABOUT THE COVER

Cover design by Ken Deslarzes and Terry Rankin — The coral pattern symbolizes the coral reef environment of the Flower Garden Banks; the "Vitruvian Man" by Leonardo da Vinci symbolizes human interaction with the environment; and the MMS logo placed over the intersecting symbols represents MMS's mission to "manage the mineral resources of the Outer Continental Shelf in an environmentally sound and safe manner."

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The Flower Garden Banks (Northwest Gulf of Mexico): Environmental Characteristics and Human Interaction

Editor

Kenneth J.P. Deslarzes

Published by

U.S. Department of the Interior
Minerals Management Service
Gulf of Mexico OCS Region

New Orleans
October 1998

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ACKNOWLEDGMENTS

Constructive review comments were generously provided by Gregory Boland (MMS, Biologist, Environmental Assessment Section), Dennis Chew (MMS, Biological and Physical Sciences Unit Chief, Environmental Assessment Section), Joseph Christopher (MMS, Chief, Environmental Assessment Section), Michael Dorner (MMS, Regional Editor), Stephen Gittings (NOAA, Sanctuaries and Reserves Program), Deborah Miller (MMS, Technical Publications Editor, Environmental Assessment Section), and Ted Stechmann (MMS, Biologist, Environmental Operations Section). Wilfred Times (MMS, Visual Information Specialist, Environmental Assessment Section) skillfully produced detailed maps of the Flower Gardens 4-Mile Zone and assisted in the preparation of all final figures. Terry Rankin assisted in the production of the side-scan sonar images. We thank Michelle Morin (MMS, Geographer, Environmental Assessment Section) and Chris Schoennagel (MMS, Petroleum Engineer, Reserves Section) for extracting well completion and water production data within the 4-Mile Zone leases from the MMS Technical Information Management System (TIMS). Janet Diaz (MMS, Environmental Assessment Assistant, Environmental Assessment Section) and Janice Todesco (MMS, Secretary, Production and Development Section) provided valuable support during the preparation of this document.

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INTRODUCTION

Kenneth J.P. Deslarzes

As we enter a period of increased hydrocarbon extraction and lease sales in the Gulf, the Minerals Management Service (MMS) has established the need to reexamine and update what is known about the unique Flower Garden Banks' coral reef resources to assist in its decisionmaking process while addressing oil and gas development within the Flower Garden Banks 4-Mile Zone. This is part of MMS's efforts to foster the long-term well-being of the unique biological communities at these banks. Beyond this immediate need for information, this document also updates various topics concerning the banks--oceanography, meteorology, commercial fishing, recreation, military activities, hydrocarbon development, and potential environmental impacts.

Since 1973, MMS has actively implemented a program of protective activities at the coral reefs of the East and West Flower Garden Banks in the northwest Gulf of Mexico. This program of stewardship will extend into the future. Protective measures including the application of the Topographic Features Stipulation and monitoring efforts have ensured compatibility between an active program of oil and gas development near the banks and the health of this sensitive biological habitat and national treasure. In June 1994, MMS received the Federal Environmental Quality Award from the President's Council on Environmental Quality and the National Association of Environmental Professionals, which recognized MMS's commitment to excellence in environmental protection at the Flower Garden Banks.

The Flower Garden Banks are two remote offshore topographic features. They bear two large and thriving coral reef ecosystems. The U.S. Dept. of the Interior's Bureau of Land Management and MMS pioneered the preservation and long-term monitoring of these unique tropical resources. Having recognized the ecological value and recreational importance of the Flower Garden Banks, MMS has invested millions of dollars in environmental studies since the mid-1970's to identify, describe, map, and protect these important and unique features from potential adverse impacts associated with oil and gas development near the coral reef banks. During the 1990's, the protective 4-Mile Zone surrounding the Flower Garden Banks has been a place of active oil and gas exploration and production. (The MMS restricts oil and gas operations within the 4-Mile Zone surrounding the Flower Garden Banks by requiring the shunting of all drill cuttings and drilling fluids to the bottom through a downpipe that terminates no more than 10 m from the bottom.) The information update provided here is intended to enhance MMS's mission to manage the mineral resources within the Flower Gardens 4-Mile Zone in an "environmentally sound and safe manner."

1. GEOLOGY

Katherine M. Ross, Kenneth J.P. Deslarzes, and Jack Irion

a. Physiography and Structure (after Rezak, 1983; Bright and Powell, 1983)

The East and West Flower Garden Banks are located near the shelf edge, approximately 198 km (107 nmi) due south of Sabine Pass (Fig. 1). The Flower Garden Banks are similar in origin, general structure, and sediment distribution, but differ in the details of structure, physiography, and sedimentology.

The East Flower Garden Bank (EFGB), centered at 27°54.5'N latitude and 93°36'W longitude, is pear-shaped and covers an area of about 67 km^2 (26 mi^2) (Fig. 2). Slopes are steep on the east and south sides of this bank, gentle on the west and north sides. Water depth in the vicinity of the bank ranges from about 18 m (59 ft) in the northeastern part of High Island, East Addition, South Extension (HIES) Block A-388, with some coral heads extending as shallow as 15 m (49 ft), to 136 m (446 ft) in an elongate depression in the north-central part of HIES Block A-389 (USDOC, NOAA, 1992). Total relief on the bank is 116 m (381 ft) (Rezak, 1983).

The West Flower Garden Bank (WFGB) is located 12 km (7 mi) west of the EFGB at 27°52'N. latitude and 93°48'W. longitude. A somewhat larger bank, the WFGB covers about 137 km^2 (53 mi^2) but has a smaller reef on its crest (Fig. 3). The bank is oval-shaped, oriented in a northeast-southwest direction and much more rugged than the EFGB. The crest of the bank lies at a water depth of approximately 20 m (66 ft). Surrounding depths vary from 100 m (328 ft) to the north to 150 m (492 ft) to the south. Total relief on the bank is approximately 130 m (427 ft).

The East and West Flower Garden Banks are bathymetric prominences caused by salt diapirs and are capped by living coral reefs. Bedrock outcrops on the seafloor were caused by the fracturing of the rocks overlying the upward migrating salt diapir. These rocks served as substrates for the initial growth of reef-building organisms. The EFGB has been classified as a young salt dome, and the WFGB as a mature salt dome (Rezak, 1983).

The major fault trends on the EFGB are west-northwest to east-southeast, with minor trends towards the northeast and the southeast (Fig. 4). North-south profiles show the faulting to be step-like, upslope, down-faulting typical of the tensional fractures produced during the domal uplift of sedimentary rocks over salt domes. The large crestal graben has developed partly due to the tensional stresses developed during uplift and by the removal of salt from the crest of the ridge by dissolution. It is expected that faulting will continue as long as salt is being dissolved from the crest of the salt stock (Rezak, 1983).

A brine seep complex found on the EFGB in 1976 consists of interrelated components: brine seep, brine lake, overflow, and canyon with mixing stream (Bright and Powell, 1983; Gittings et al., 1984). The basin containing the brine lake is 60 m (197 ft) from the edge of the bank, 4 m (13 ft) deep, oval-shaped, and 30-50 m (98-164 ft) wide. The brine lake, approximately 25 cm (10 in) deep, occupies part of the eastern and central basin floor at 71 m (233 ft) depth. The lake is irregular in shape with a cuspate "shoreline." Numerous brine seeps occur in the sandy bottoms between the "shoreline" and reef rock wall of the basin.

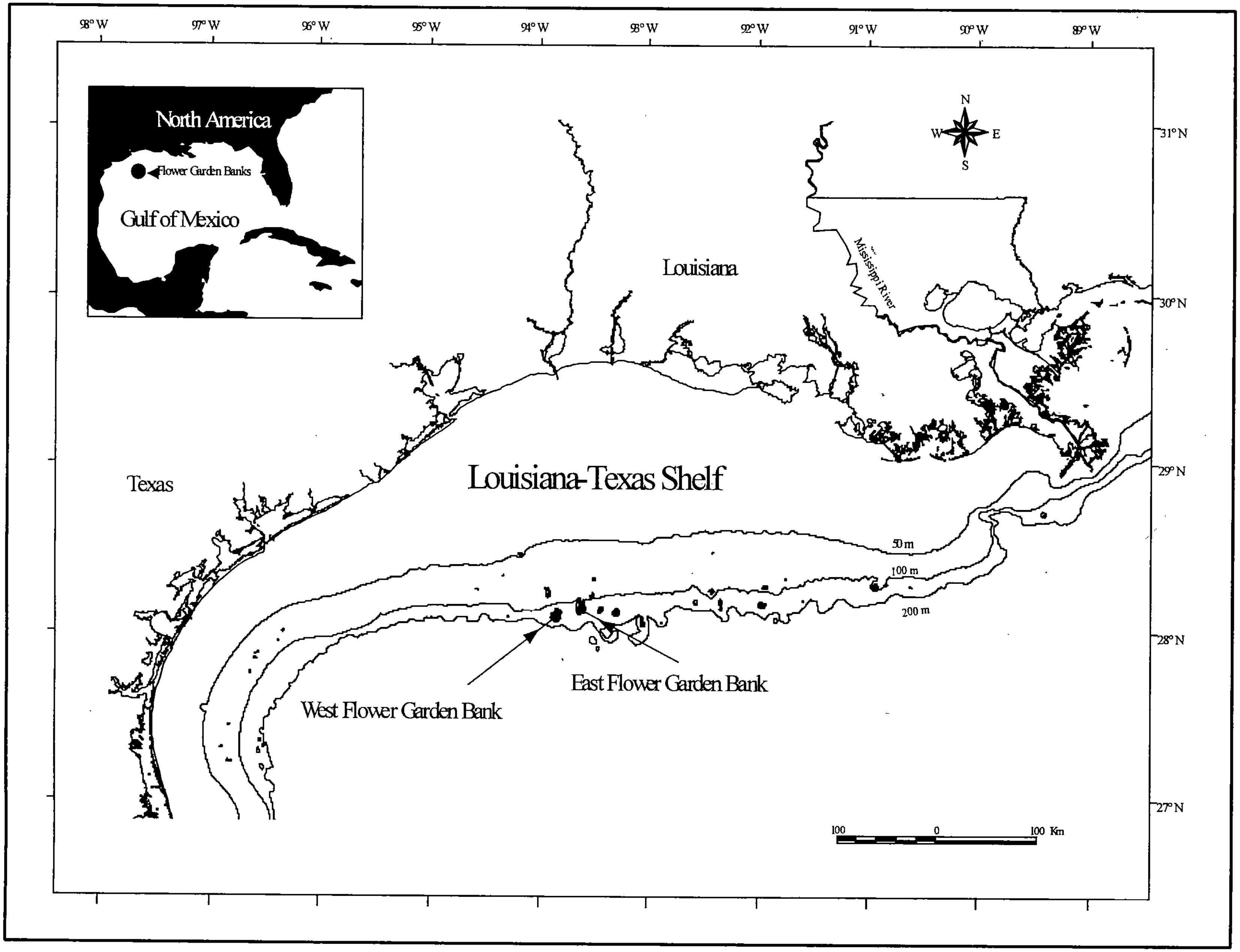

Figure 1. Location map of the Flower Garden Banks, northwest Gulf of Mexico.

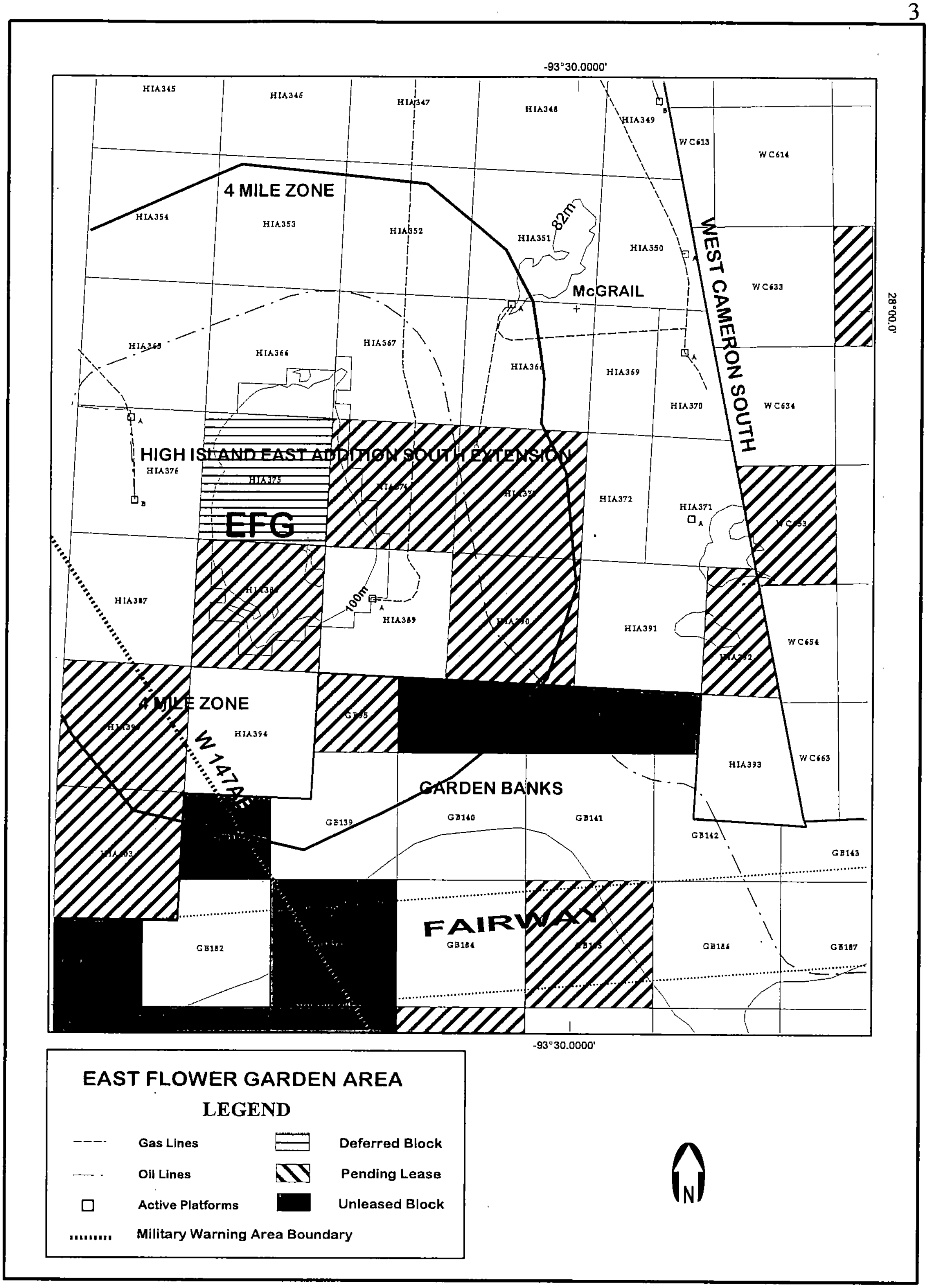

Figure 2. East Flower Garden Bank Area Locations of the "No Activity Zone," the "4-Mile Zone," oil and gas lines, active platforms, unleased blocks, blocks with pending leases, and deferred blocks.

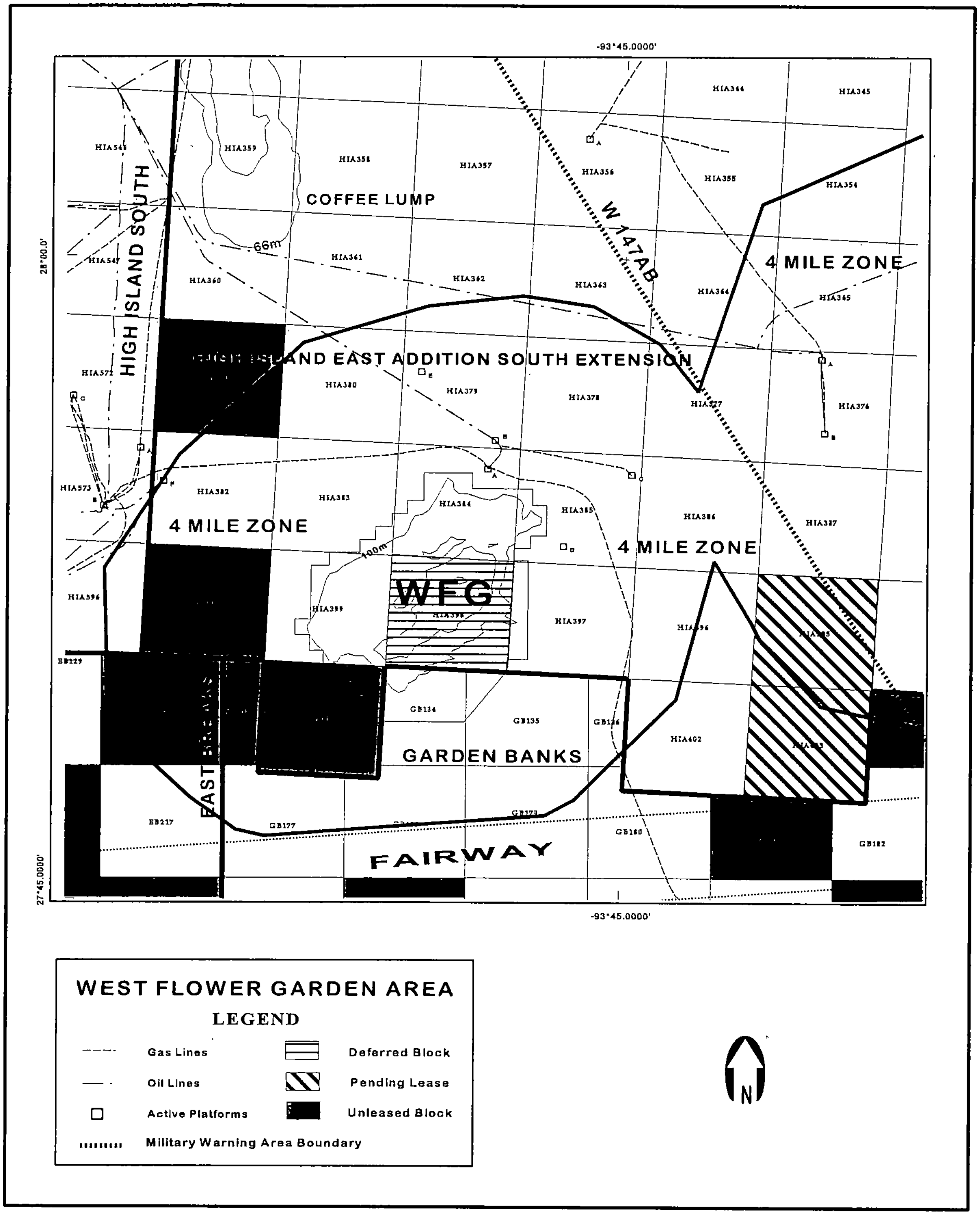

Figure 3. West Flower Garden Bank Area Locations of the "No Activity Zone," the "4-Mile Zone," oil and gas lines, active platforms, unleased blocks, blocks with pending leases, and deferred blocks.

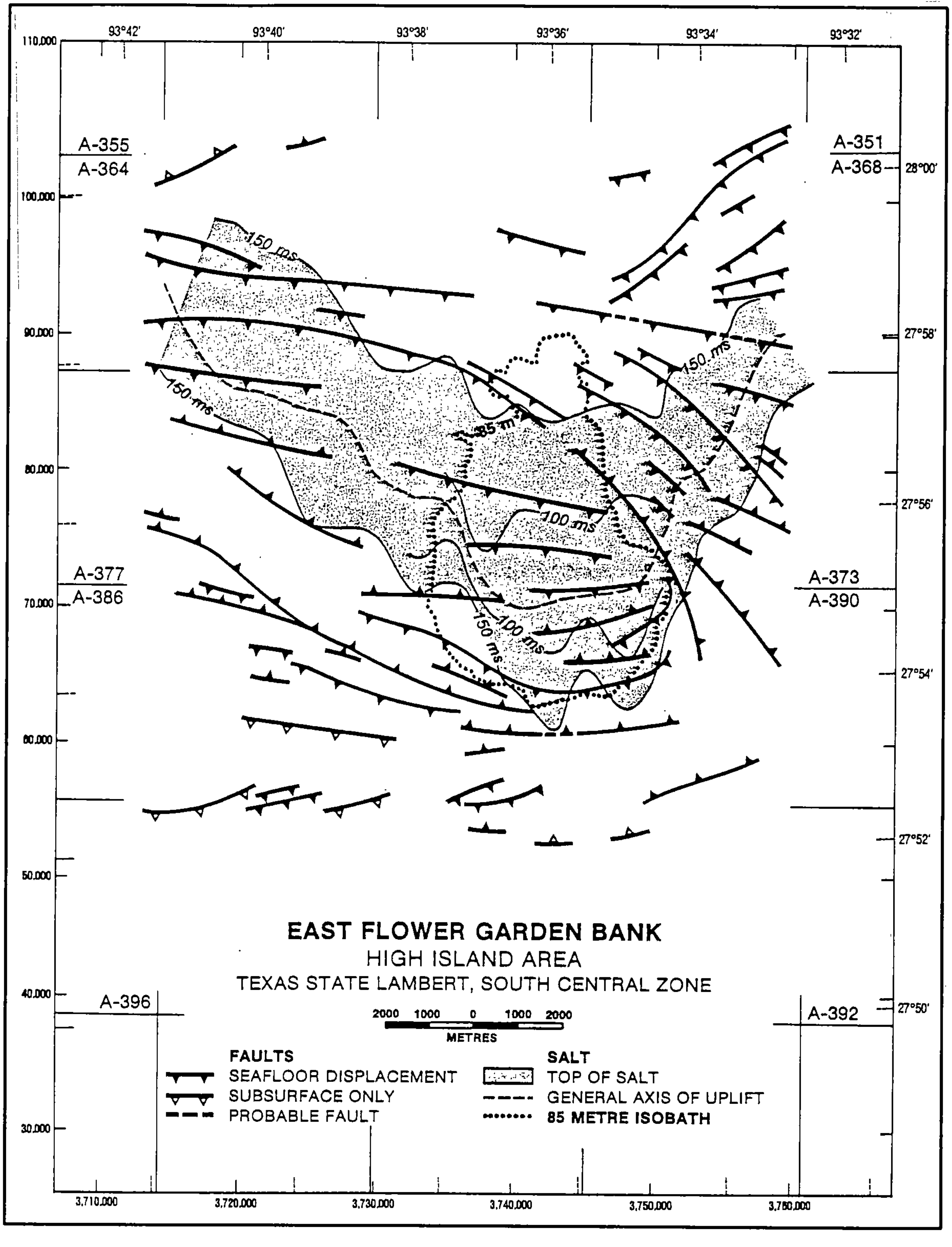

Figure 4. Structure map of the East Flower Garden Bank (after Rezak, 1983). The dotted line delineating the 85-m isobath is given to indicate the shape of the bank proper.

Dendritic rivulets of brine have been observed in sands along the shoreline leading from the seep to the lake. The canyon, approximately 60 m (197 ft) long, extends from the east-southeast margin of the basin to the edge of the bank.

From 1976 to 1980, the residence time of brine in the basin was estimated to be less than one day. The lake, 25-30 m (82-98 ft) long, 15-20 m (49-66 ft) wide, and generally less than 0.25 m (10 in) thick, contained approximately 465 m^3 (3,900 bbls) of brine. The overflow rate of brine from the lake into the canyon, calculated by current meter and direct measurement of outflow cross-section area, was approximately 355-717 m^3/day (2,977-6,014 bbls/day). Residence time was therefore 0.65-1.3 days. The depth of the brine lake and the overflow rate appeared unchanged during the 4-year observation period. Based upon measured outflow of the brine lake and the salinity of brine in the lake (salinity > 200), calculations show that the amount of solid salt being removed from the crest of the salt diapir ranged from a minimum of 10,765 m^3/yr (90,289 bbls/yr) to 21,710 m^3/yr (182,088 bbls/yr). As other smaller seeps are known to exist at the EFGB, this is a minimum range for the removal of solid salt.

The natural removal of such large volumes of solids beneath the crest of the bank would eventually create sizable caverns beneath the cap rock and the overlying substrate. Collapse of the crest of the reef or other patterns of the bank into these caverns would depend upon the strength of the cap rock and the overlying reef. If these structures are weak, collapse would be gradual, keeping pace with the removal of salt. However, if either the cap rock or overlying substrate is strong, the caverns may attain considerable sizes before failure occurs and the collapse becomes catastrophic (Bright and Powell, 1983).

Chemically, the brine has a higher density than seawater, is anoxic, and contains exceptionally high levels of dissolved hydrocarbon gases (methane, ethane, and propane) and hydrogen sulfide. The density differential inhibits mixing of the lake brine with overlying seawater. Because of the lack of mixing, chemical characteristics of water above and below the interface differ drastically over a vertical distance of less than 2 cm (0.8 in), e.g., salinity; 36.7 vs. 200.

Local relief on the WFGB is much greater than at the EFGB. Although the structure of both banks is the result of normal faulting, more movement has apparently occurred along the faults at the WFGB. Although no brine seeps have been observed at the WFGB, the chief source of these structural differences may be the greater amount of salt removal at the WFGB.

The structure of the WFGB is typical of a mature salt diapir in which crestal faulting has occurred. The crestal graben at the WFGB, which extends from the southeast corner of HIES Block A-399 to the southeast corner of HIES Block A-384, exhibits much greater relief than the crestal graben at the EFGB. The WFGB has an abundance of normal faults. The numerous bathymetric prominences on the bank represent horsts that stand above the surrounding graben (Fig. 5; Rezak, 1983).

The living reef on the WFGB lies in the north-central portion of HIES Block A-398. Rising from depths of 40 to 50 m (131-164 ft), it crests at about 20 m (66 ft). Extending from near the base of the reefs towards the northeast and the south is a broad terrace that extends to depths of 60-70 m (197-230 ft). The surface of this terrace is characterized by

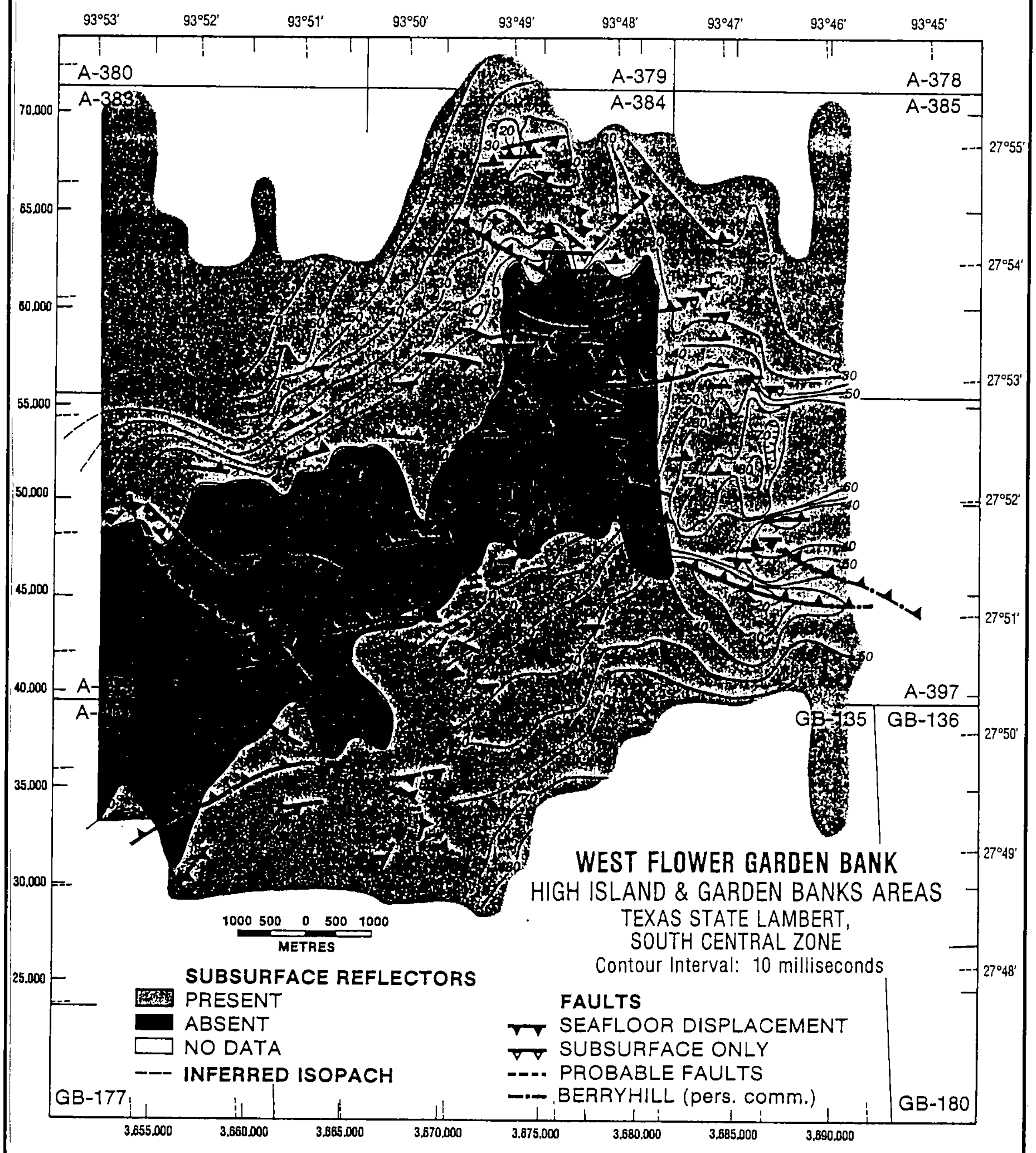

Figure 5. Structure map of the West Flower Garden Bank (after Rezak, 1983).

large waves of sediment consisting primarily of sand from the coral debris facies and gravels of the *Gypsina - Lithothamnium* facies. The gravel waves are oriented normal to the isobaths. Below these depths are numerous lineations (faults and outcrops of tertiary bedrock covered by drowned reefs) and patch reefs scattered to depths as great as 170 m (558 ft). Most of the patch reefs above 90 m (295 ft) appear to have formed during the last rise of sea level (Rezak, 1983).

b. Sedimentary Facies (after Rezak, 1983; Bright and Powell, 1983)

Sediment distribution at the Flower Garden Banks is illustrated in Figure 6. The sediments of the two banks differ markedly in origin from the sediments of the open shelf surrounding the banks. Bank sediments are all derived from the skeletons of organisms that are living on the banks. The sediments in the open shelf surrounding the banks are sands and muds eroded from the North American continent and mechanically transported to the Gulf of Mexico by rivers (Mississippi, Atchafalaya, Trinity, Sabine, and Brazos Rivers). These sands and muds do not occur at depths shallower than 75 m (246 ft) at the Flower Garden Banks. The sediments above the 75-m (246 ft) level are all coarse sands and gravels and the rocky limestone structure built by the corals and other reef-dwelling organisms. The loose sediments around the reef reflect the depth zonation of the biological communities present on the two banks. Table 1 illustrates the relationship between the biological zones and the sediment facies.

As indicated in Table 1, the sediment facies are related to the biological zonation and hydrological conditions at each bank. However, the distribution of the sediment does not coincide with the boundaries between biotic communities, partly due to the downslope movement of loose sediment by the force of gravity and partly due to the use of soft-bodied organisms in delineating the biotic zonation. In Table 1, for example, the lower boundary of the Algal-Sponge biotic zone is based upon the lower depth limit of *Neofibularia,* a sponge that also grows in the upper part of the *Amphistegina* sand facies. The distribution of the living, lime secreting, skeletal organisms points to a downslope direction of sediment transport on the banks. This, in combination with the fact that there is no land-derived mud in the bottom sediments above a depth of 75 m (246 ft), substantiates the conclusion from water and sediment dynamics studies that the currents flow around the banks rather than up and over them (the nepheloid layer rarely rises to depths of 75 m [246 ft]). Any fine sediments, such as occur below the 75 m (246 ft) depth, would be trapped in the irregular topography of the living reefs or *Gypsina - Lithothamnium* facies if they were ever carried to the top of the reef by either physical or biological processes.

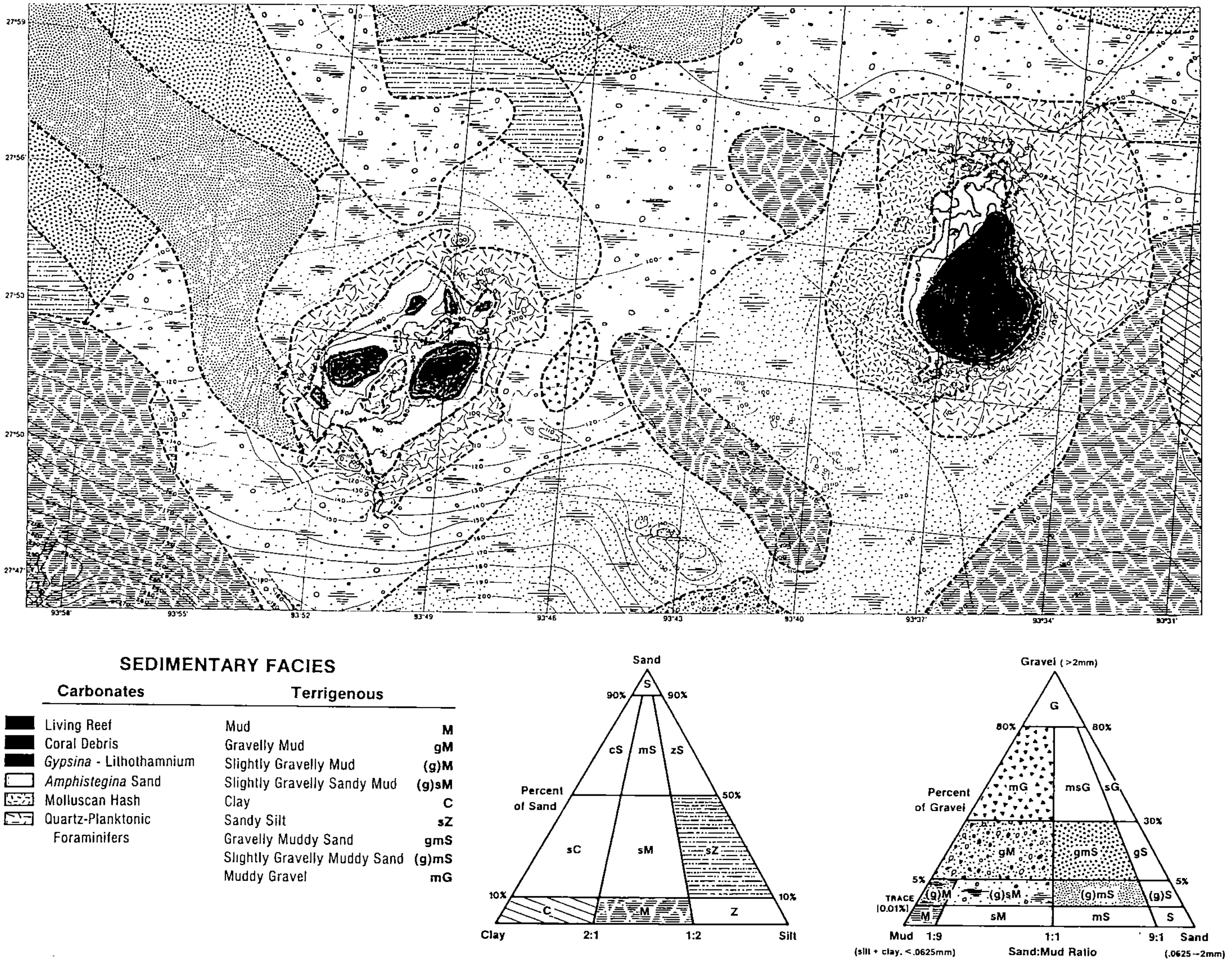

Figure 6. Sediment facies at the Flower Garden Banks (after Rezak, 1983).

Table 1. Relationship Between Sediment Facies and Biological Zones at the East Flower Garden Bank (after Rezak, 1983).

Sediment Facies	Depth (m)	Biological Zone	Depth (m)
1. Coral Reef	15-50	1. *Montastrea-Diploria-Porites*	15-36
a. Living Reef	15-45	2. *Madracis*	28-46
b. Coral Debris	25-50	3. *Stephanocoenia*	36-52
2. *Gypsina-Lithothamnium*	50-75	4. Algal-Sponge	46-88
3. *Amphistegina* Sand	75-90	5. Transition	88-89
4. Quartz-Planktonic Forams	90+	6. Nepheloid	89
5. Molluscan Hash	90+		

c. Petroleum Geology

The prospective horizons of the northwestern continental shelf are of Miocene, Pliocene, or Pleistocene age. The environment of deposition of the continental shelf and slope in the northern Gulf of Mexico are two of the most significant factors controlling hydrocarbon production. Sediments deposited on the outer shelf and upper slope have the greatest potential for bearing hydrocarbons because this environment is the optimum zone for encountering the three ingredients necessary for the successful formation and accumulation of oil and gas: reservoir rock, source beds, and traps.

There are approximately 975 fields on the Federal OCS of the Gulf of Mexico. Of these, 742 produce primarily gas and 157 produce primarily oil. In the remaining 76, production or productivity has not yet been determined. Production depths range from about 300 to 6,700 m (984-21,983 ft). The MMS's publications show that 9.683 billion barrels of oil and condensate and 117.4 trillion cubic feet of gas had been produced from Federal OCS lands as of December 31, 1995 (USDOI, MMS, 1996a).

In the Western Planning Area of the Gulf of Mexico Region (where the Flower Garden Banks are located), proven reserves are predominantly gas. Pleistocene reservoirs account for 33 percent, Pliocene reservoirs for 1 percent, and Miocene reservoirs for 66 percent of the remaining proven gas reserves. In the Central Planning Area, both proven oil and gas reserves are significant. For oil, Pleistocene reservoirs account for 34 percent, Pliocene reservoirs for 30 percent, and Miocene reservoirs for 36 percent of the remaining proven reserves. For gas, Pleistocene reservoirs account for 38 percent, Pliocene reservoirs for 20 percent, and Miocene reservoirs for 35 percent of the remaining proven reserves. The other 7 percent remaining proved gas reserves are from Oligocene, Cretaceous, and Jurassic reservoirs (USDOI, MMS, 1996a).

Hydrocarbon reserves on and around the Flower Garden Banks occur in the Pleistocene trend, and there have been seven proven fields discovered in this area. Five of the seven are classified as gas fields and even though the other two fields are classified as oil fields, they both contain notable amounts of natural gas (nearly half of the reservoirs in these two fields are gas reservoirs). Six of the seven fields have produced hydrocarbons, and all of the six have produced significant amounts of gas.

d. Geohazards and Hydrocarbon Development

Within the northern Gulf of Mexico, major geohazards to oil and gas development are associated with seafloor geologic features that result in seafloor instability. These hazards present many operational limitations to the exploration and development of oil and gas. Seafloor instabilities present limitations and necessitate adaptations in the siting, structural engineering, and routing of pipelines, exploratory drilling, and production platforms. Three conditions prevail on the Gulf of Mexico continental shelf that cause unstable conditions on the seafloor: (1) salt movement, which may result in salt domes, faults, steep slopes, gas seepage, and sediment slumping; (2) sediment overloading and differential compaction, causing growth faults and differential subsidence; and (3) rapid sedimentation in deltaic areas, which results in unconsolidated, fine-grained, often gas-charged sediments.

Because the East and West Flower Garden Banks are bathymetric prominences caused by salt diapirism, unstable conditions related to salt movement can be expected. The central graben at the EFGB (over 1.5 km in diameter and 5 m deep at the 50-m isobath), for example, has developed partly due to the tensional stresses during uplift and the removal of salt from the crest of the ridge by dissolution. As long as the formation of the crestal graben and resultant faulting are likely to continue at the EFGB, Rezak and Bright (1981) concluded it would be unwise to place any permanent structures on the bank. As the WFGB is a mature salt diapir in which crestal faulting is not likely to occur, similar concerns are not warranted for this bank.

Since the Flower Garden Banks overlie a known area of shallow gas deposits in the Pleistocene trend, which stretches for hundreds of miles along the outer edge of the continental shelf, the area may be predisposed to blowouts. A gas blowout occurred 3,609 m (1,100 ft) from the WFGB on HIES Block A-397, on February 2, 1984, during cementing operations on the No. 1 well location. No pollution or drill mud spillage was detected and the semisubmersible rig was back in full operation by February 24, 1984.

In accordance with NTL 83-3 and prior to the installation of any structure or pipeline, the grantee is required to provide MMS's Field Operations a shallow hazards survey report on the immediate area of the proposed activity in order to locate, identify, and assess the potential geologic hazards and engineering constraints that may exist (USDOI, MMS, 1996b). Most structures and equipment used for mineral exploration and development can be designed to withstand the stresses of the continental shelf environment if adequate information is available. Studies developed under the former Bureau of Land Management's Environmental Studies Program have been especially directed toward areas where more detailed geologic information was needed for intelligent management of the OCS mineral leasing program. Additional information concerning potential geologic hazards will be addressed on a site-specific basis for proposed activities within the 4-Mile Zone.

e. Remote-Sensing Survey

The MMS conducted a high-resolution, sidescan-sonar survey of the high-diversity reefs of the East and West Flower Garden Banks at depths less than 36 m (118 ft) (September 7-12, 1997). The purpose of the survey was to obtain representative images of the coral reefs, investigate for human-induced damage to the seafloor, and evaluate the instrument's future usefulness to biological and geological analyses of the Flower Gardens and other Banks. The primary instrument employed for the survey was a 600-kilohertz (kHz) Marine Sonics side-scan sonar. The side-scan sonar uses sound waves to image the seafloor by processing their reflected rate of return. By using a high-frequency sound source, the seafloor is "pinged" more densely, resulting in a high-resolution image. Lower frequencies, such as the 100-kHz sonars that are more commonly used in the Gulf, result in lower resolution images but have greater ranges. The maximum range of the 600-kHz system is 75 m to each side of the line of travel.

Approximately 50 percent of the area contained within the 30-m isobath at both banks was surveyed. This required approximately five hours of survey time. The presence of mooring buoys on the banks resulted in data gaps as the vessel towing the instrument swerved to avoid passing too close to the mooring lines.

The survey was conducted along preset tracklines spaced 0.04 nautical miles (nmi) or 74 m apart and oriented north-south. The survey area at the WFGB measured approximately 0.5 nmi (926 m) north-south and 0.2 nmi (370 m) east-west. The EFGB survey area measured approximately 0.75 nmi (1.4 km) north-south and 0.2 nmi (370 m) east-west. Positioning was done using a Trimble NT200D differential geopositioning system (DGPS) with a published accuracy of ± 10 m (33 ft). In addition to providing helmsman guidance, the DGPS also provided positioning data to the sidescan instrument, which used it to control scroll and ping rate to maintain constant aspect ratio of the sonar. The sidescan images were linked to the positioning data and were saved to the hard drive of a computer that formed the operating platform of the system for post-survey analysis and image analysis and manipulation.

The survey resulted in over 67 megabytes (MB) of data and 59 images, each representing 1,000 scan lines of data. Each saved image represented an area of the seafloor measuring approximately 190 m (630 ft) long and 100 m (330 ft) wide. A combined total area of approximately 1.13 km^2 (0.44 mi^2) was imaged around both banks.

The side-scan survey resulted in detailed images of the massive hermatypic reefs and numerous interspersed sand flats and channels that occupy the Flower Gardens (Figs. 7 and 8). These images also contain views of the NOAA/MMS long-term monitoring sites, each measuring 100 by 100 m, their centers marked by Buoy #5 at the WFGB and Buoy #2 at the EFGB (Figs. 9 and 10). These data could be useful in studying the geological history of the banks, particularly in searching for evidence of relict spur and groove formations. Also of interest were the numerous and relatively large schools of fish visible on the edges or drop-off areas of the banks (Fig. 11). Repeated observations of schooling fish could help assess the locations of favored habitats for schooling and help estimate fish biomass. No definite evidence of human-induced damage to the reefs was observed during the survey, although

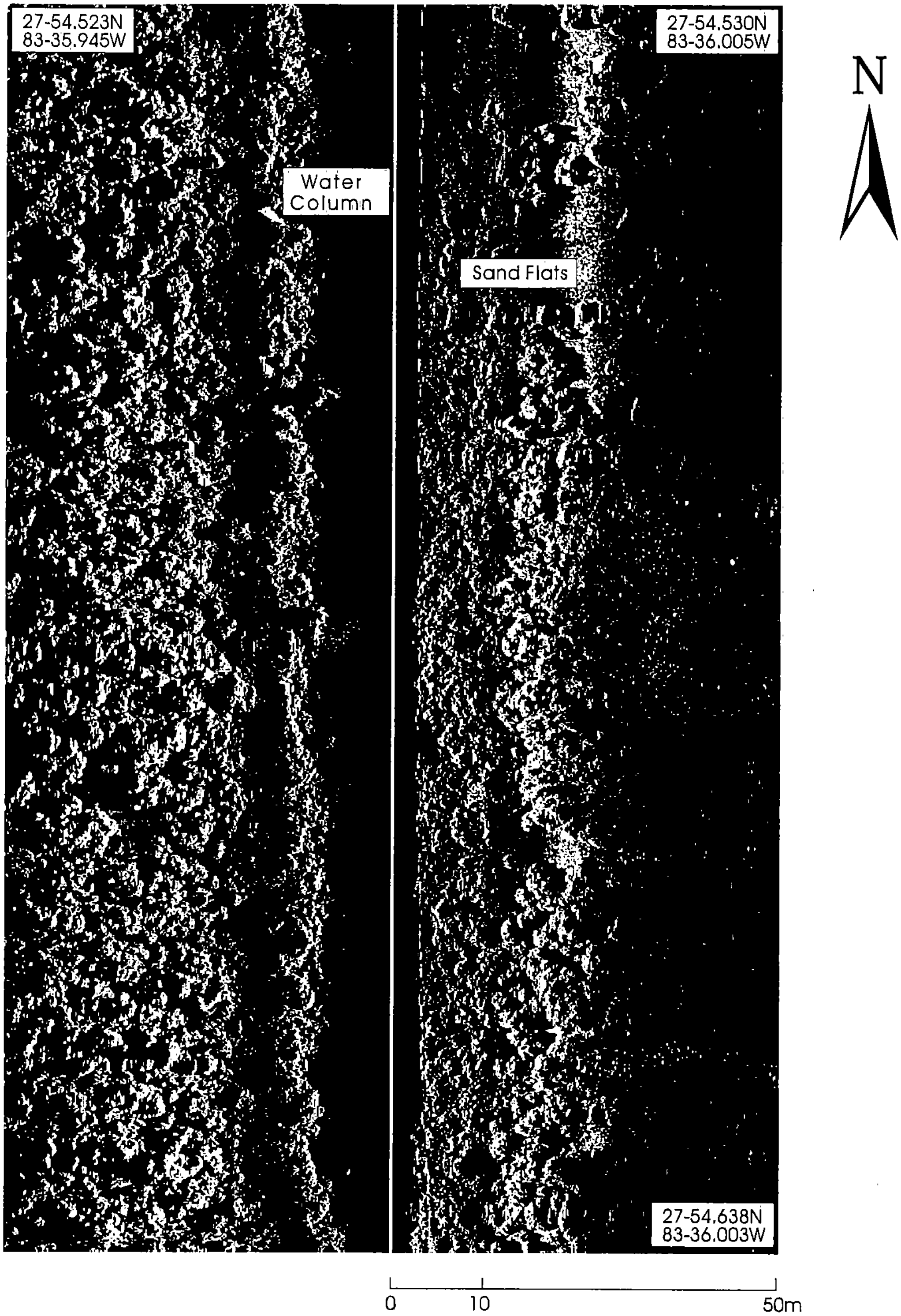

Figure 7. Sidescan-sonar image of a portion of the East Flower Garden Bank showing coral heads, a sand flat, and sand channel.

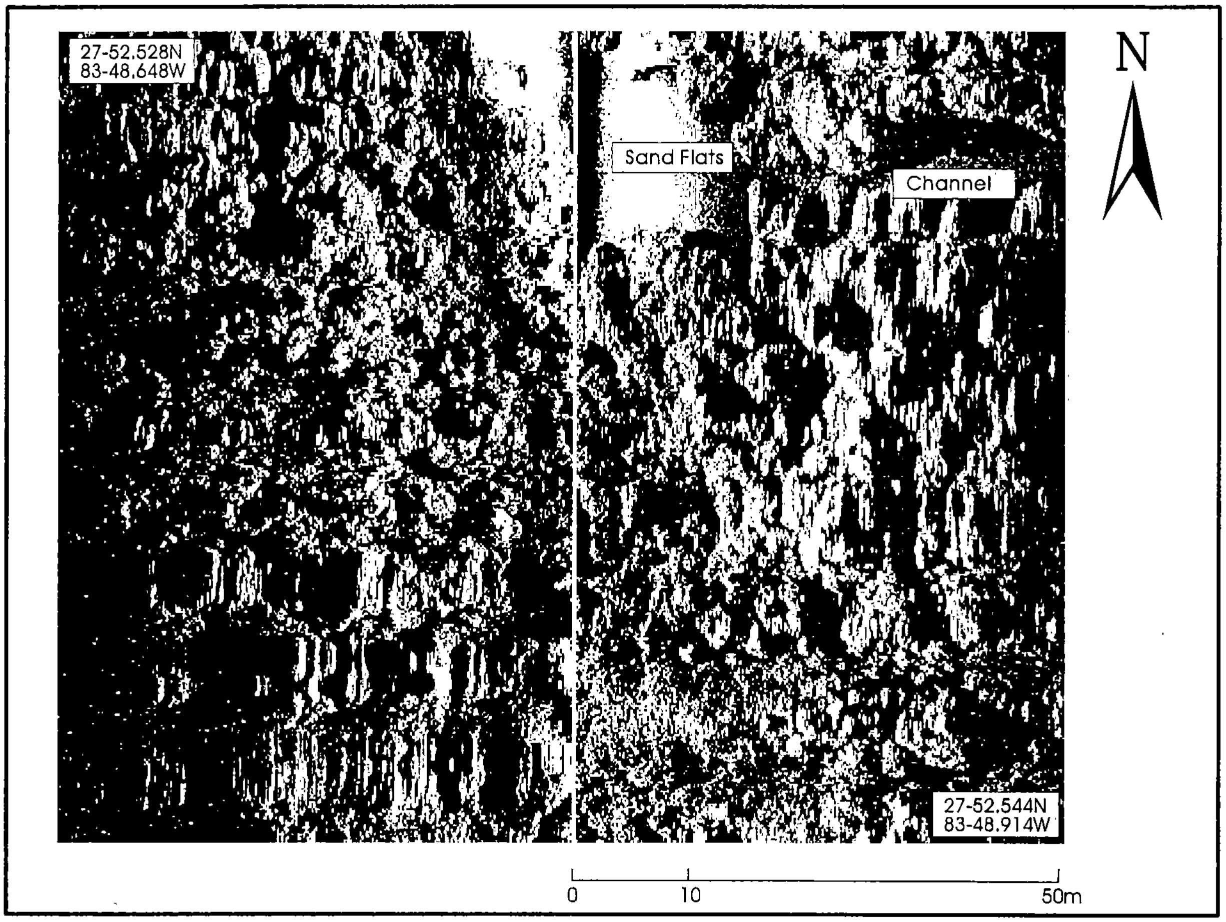

Figure 8. Sidescan-sonar image of a portion of the West Flower Garden Bank showing coral heads, a sand flat, and sand channel.

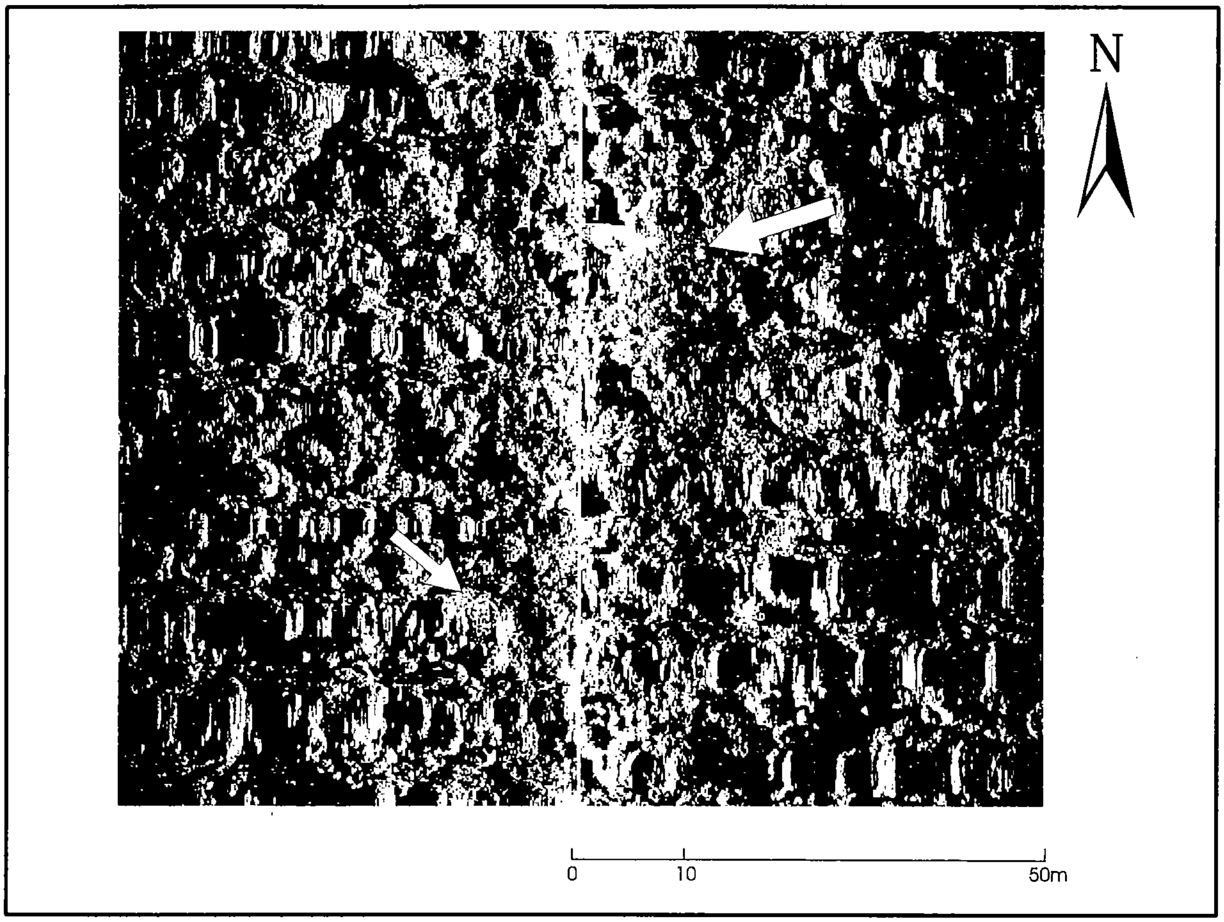

Figure 9. Sidescan-sonar image locating the West Flower Garden Bank long-term monitoring site (100x100 m) investigated since 1988 by MMS/NOAA-funded studies and general location of a known anchor-damaged portion of the reef. (Larger arrow points to the Buoy #5 mooring coordinates, which mark the center of the monitoring site [27°52'30.6"N, 93°48'54.1"W]; smaller arrow points to possible anchor-damaged area.)

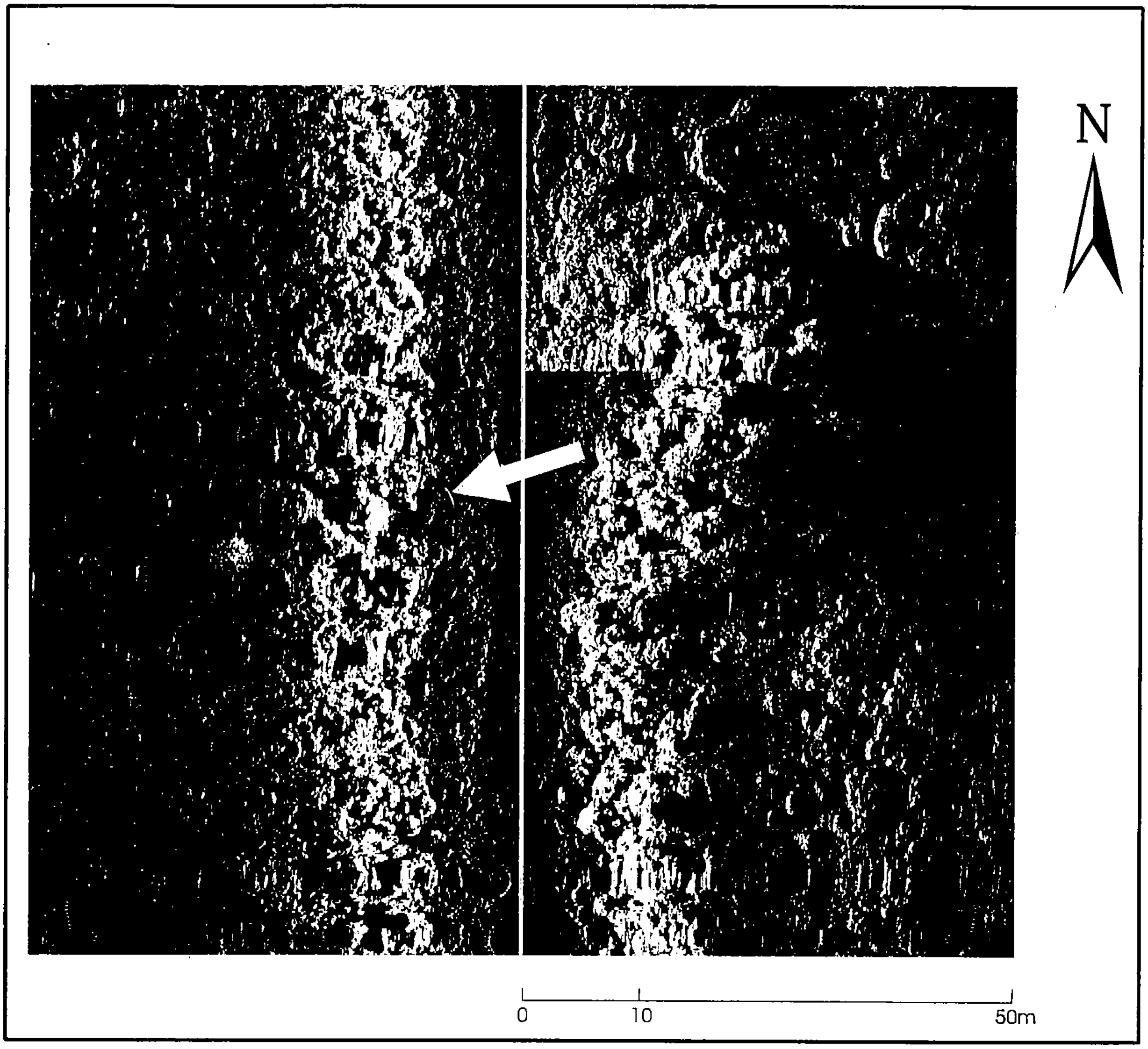

Figure 10. Sidescan-sonar image representing the East Flower Garden Bank long-term monitoring site (100x100 m) investigated since 1988 by MMS/NOAA-funded studies. (Arrow points to the Buoy #2 mooring coordinates, which mark the center of the monitoring site [27°54'31.9''N, 93°35'49.0''W].)

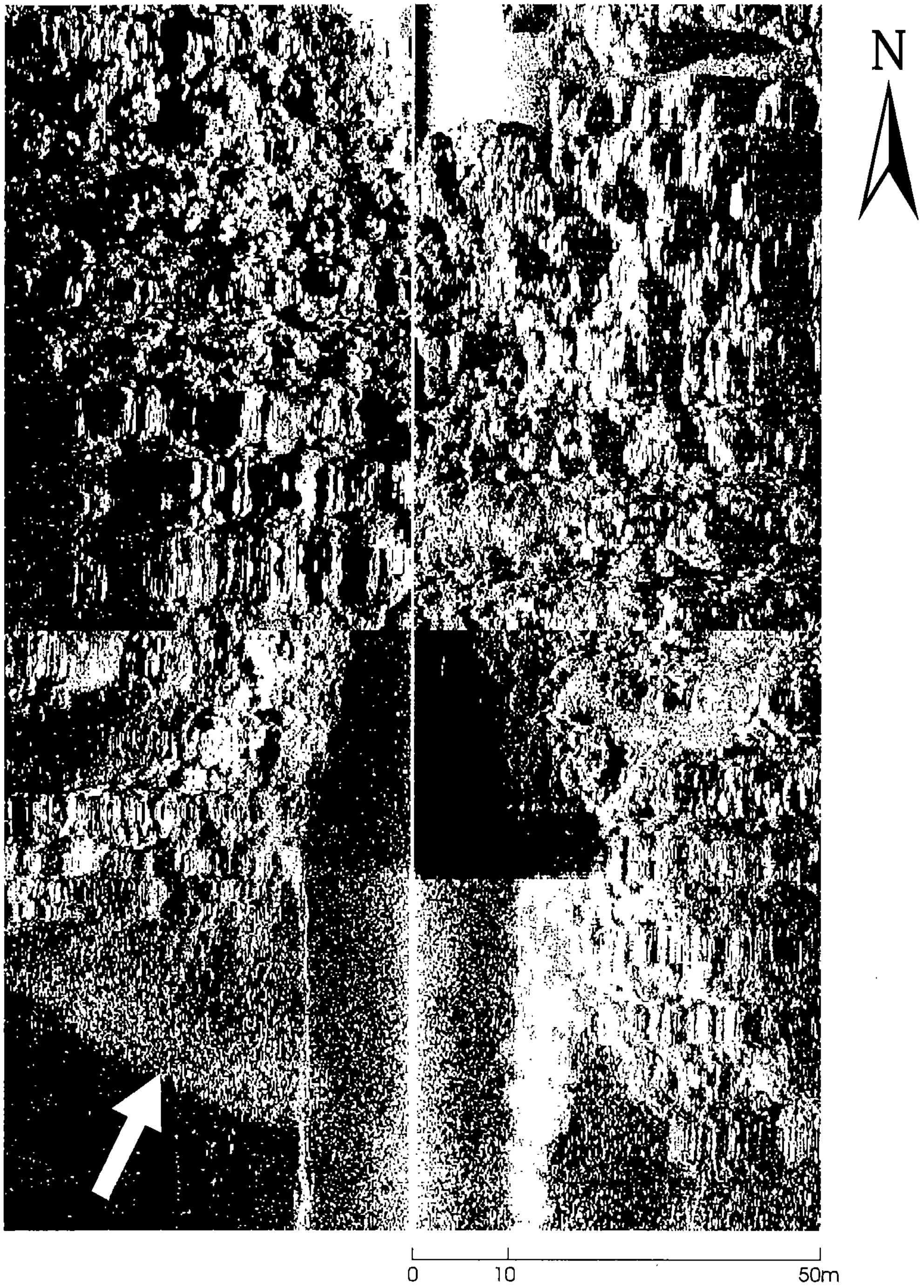

Figure 11. Sidescan-sonar image exhibiting schools of fish at the southwest drop-off area of the West Flower Garden Bank high-diversity reef (arrow points to fish).

this instrument should prove useful in documenting such occurrences. A known area of damage at the WFGB is located 50 m (164 ft) southwest of Mooring Buoy #5. It was difficult to pinpoint this anchor damage against the background "clutter" of irregular coral formations (Fig. 9). Anchor scars do show up very clearly on smooth (mud) bottoms using this method. It is suspected that, against this kind of background, the damage would have to be substantial or in some way distinctive from the naturally occurring irregularities of the coral-covered seafloor (e.g., fan-shaped chain scars or linear anchor scars).

2. PHYSICAL OCEANOGRAPHY

Alexis Lugo-Fernández

This section summarizes prevailing climatological and oceanographic conditions around the Flower Garden Banks. This information was derived from past and recent observations and does not necessarily reflect instantaneous observations at a given time or point. During the past decade several major studies (e.g., Gulf of Mexico Physical Oceanography Program, GulfCet, LATEX Program) have provided new insights and data on the physical oceanography around the banks. This new information suggests that the physical oceanography of the Flower Garden Banks last presented in USDOI, MMS (1984) should be updated. These data represent average conditions and ranges that could serve as valuable background information for other disciplines. The summary is organized in three broad categories: hydrography (temperature and salinity), water levels (tides, and storms), and circulation. More details on hydrography, circulation, nutrients, and marine optics can be found in Lugo-Fernández (in review).

a. Hydrography

Water Temperature

Solar heating is the primary control of water temperature and produces diurnal, seasonal, vertical, and horizontal variations. Diurnal and seasonal variations are caused by the well-known changes in solar energy distribution. The vertical and horizontal temperature gradients arise because of the rapid absorption of solar energy, large heat capacity of water, and depth variations. Variations at other time scales are induced by currents (e.g., upwelling and advection) or interannual variations.

Sea surface temperature (SST) around the Flower Garden Banks displays a strong seasonal variation that can be detected throughout the upper half of the water column. The climatological SST varies from a minimum in February ($T \sim$ 19-20 °C) to a maximum in July/August ($T \sim$ 29-30 °C). These values yield an amplitude of 9-11 °C. A climatological SST annual amplitude (30 years of observations) is ~ 9.3 °C (Bottomley et al., 1990). Temperature measurements near the shelf edge yield an amplitude of 10 °C (Science Applications International Corporation, 1989). The weekly variation of local SST (11 years of satellite data) is about 5 to 6 °C in winter and about 2 to 3 °C in summer (Gittings et al., 1992a). Notice that the annual amplitude is larger than weekly temperature variations which distinguish the Flower Gardens from tropical areas. Interannual variations occur and temperatures of over 30 °C have been observed (McGrail, 1983; Science Applications International Corporation, 1989; Gittings et al., 1992a). Shorter time variations (scales of days to weeks) of 2 to 4 °C also have been observed (Gittings et al., 1992a; Continental Shelf Associates, Inc., 1997). Horizontally, SST exhibits a strong cross-shelf gradient in winter, 14 °C near the coast to about 20 °C near the banks (Science Applications International Corporation, 1989; Nowlin et al., 1998). Near the shelf edge, sharp SST gradients or fronts are seen in satellite images from October to May. These fronts are associated with warm Loop Current (LC) eddies or other causes (Science Applications International Corporation, 1989). A frequency analysis shows that about 5 percent of the time eddy fronts occur near the banks, while other types of fronts occur 20 percent of the time in the area (Science Applications International Corporation, 1989). These data also suggest that shelf waters leave to deeper regions through the Texas-Mexico shelf edge between 23 and 26 degrees north. In summer, June to September, the Gulf of Mexico sea surface becomes isothermal and the SST is near 30 °C everywhere. This condition severely limits use of satellite images to evaluate current patterns.

Subsurface water temperature also undergoes seasonal changes but the amplitude and timing of the variations change with depth. For example, at 30 m the minimum average temperature is about ~1 °C cooler than the SST. Both minima occur simultaneously; the maximum temperature at 30 m, however, is ~2-3 °C cooler than the SST and occurs later (August or September). At 91 m, the annual temperature range is ~2 °C. The average minimum temperature (~2 °C cooler) coincides with the surface minimum. Two temperature maxima at 91 m of ~21 °C occur in April and November (Robinson, 1973). Two thermographs operating since 1990 on each bank (depths of 19 and 24 m) revealed that from 1993 to 1995 (Continental Shelf Associates, Inc., 1997) the annual temperature range was 12 °C (18-30 °C) and exhibited a similar timing of seasonal change when compared to the SST. Thus, both reefs experienced a temperature pattern similar to the SST. Deeper in the water column, the temperature regime changes. The near-bottom temperature exhibits an offshore gradient, with cooler water near the coast in winter. In fact, the winter temperature distribution shows a band of warmer water (T~19 °C) near the banks. In summer, the offshore gradient is stronger because of the strong warming near the coast, but near bottom water temperature around the banks remains around 18 °C (McGrail, 1983). Vertical temperature gradients separate the upper mixed layer, the thickness of which also varies seasonally, from deeper water. Data in McGrail (1983) show a minimum thickness in April (ca. 20 m) that increases monotonically to a maximum thickness of about 70 m in December/January. Data from the LATEX-A program (Nowlin et al., 1998) show a mixed layer in winter at about a 100-m depth created by surface cooling and mixing by strong winds. In summer, a combination of heating and light winds produces a shallow mixed layer. Another mechanism that regulates and maintains minimum water temperature around 20 °C is advection of warm water by Loop Current warm core eddies near the shelf break (Nowlin et al., 1998).

Salinity

Sea surface salinity (SSS) also varies seasonally, vertically, and horizontally, reflecting changes in the general circulation and river discharge. Nowlin et al. (1998) present a detailed analysis of the seasonal salinity variation on the shelf. The primary offshore source of salty water is the subtropical underwater mass with a characteristic salinity of over 36.2 at water depths of 50-100 m (164-329 ft). Higher salinities or less diluted subtropical water is advected from the core of LC warm eddies, and these interact with the shelf break near the banks. In spring, the mean SSS varies offshore due to the influence of river discharge in nearshore areas. Near the shelf break SSS is over 35, but increases to over 36 near the bottom. Summer SSS is low inshore and east of 95°W. West of this longitude, isohalines run offshore across the entire shelf and increase toward Texas. Near the banks, SSS is between 33 and 34, reflecting the subtropical underwater origin. Near the bottom, salinities increase offshore up to 28.5°N. South of 28.5°N salinity remains above 36. During fall the average SSS is relatively high near the coast, 29-30 vs. < 20 in spring, and increases offshore to higher than 36. Bottom salinities are over 36 near the shelf break. Measurements made at the banks by McGrail (1983) were always between 35.5 and 36.5 from surface to bottom. More recent measurements by Gittings et al. (1992a) varied from 35 to 36.5, and one sample from 1 m depth indicated 33.4. Elevated salinity values (37-38) reported by Continental Shelf Associates, Inc. (1997) seem unusual.

b. Water Levels

Tides

Tides near the Flower Garden Banks are mixed diurnal (Barry A. Vittor & Associates, 1985). The diurnal K1 (luni-solar) component has a uniform amplitude and phase over the Gulf of Mexico (Zettler and Hansen, 1972; Reid, 1988). The diurnal K1 component represents a Helmholtz mode driven by synchronized volume transport at both entrances. The semidiurnal M2 (principal lunar) component represents a wave with negligible amplitude in the mid-Gulf, increasing to more than 10 cm near the coast and traveling cyclonically (Reid, 1988). Sea-level data from the LATEX-A program (Nowlin et al., 1998) were analyzed for tidal motions of five components: three diurnal (K1; O1 [principal lunar]; P1 [principal solar]) and two semidiurnal components (M2; S2 [principal solar]). The results show that the diurnal components have a nearly uniform phase over the entire shelf, and K1 and O1 have amplitudes of ~15 and ~14 cm, respectively, while P1 has a smaller amplitude of ~5 cm. Results for the diurnal components contain some bias by contributions from wind and solar heating diurnal motions on this shelf. Results for the semidiurnal components show cyclonic propagation and amplitude magnification at mid-shelf. The M2 component amplitude is about four times the S2 amplitudes over mid-shelf. The Conrad Blucher Institute, Division of Coastal Observations, Corpus Christi, maintains a water level station at the Flower Garden Banks (Flower Garden Station 028) as part of its Texas Coastal Ocean Observation Network (TCOON). The raw water level data from January 1995 to January 1997 show an annual cycle that peaks in September-October and decreases to a minimum in January-February, and an annual variation of the tidal range (Fig. 12). The raw data also suggest a second but lower peak in summer. Monthly mean water levels from Galveston (Pier 21) show the annual cycle with a clear maximum in September-October and minimum in January-February, and a suggestion of the secondary maximum in April-May (Hicks et al., 1983). Further analysis of the raw water level data at the Flower Gardens shows a typical mixed diurnal tidal cycle, two big lows and a smaller low in between over a 24-hour period, and tidal ranges that vary over the year from 0.1 m to 0.7 m. Comparison of the annual air

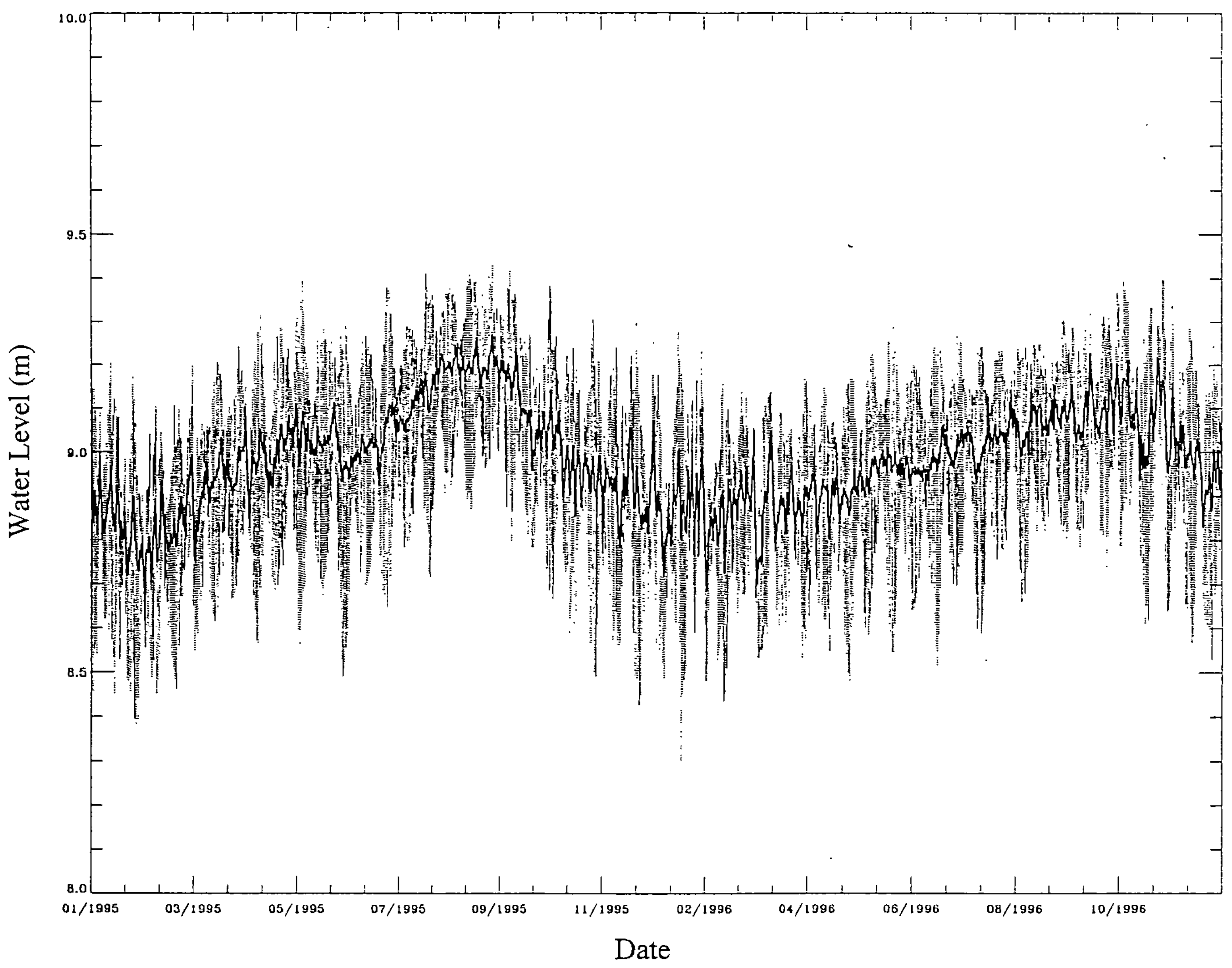

Figure 12. Water level data (unfiltered) at the Flower Garden Banks from January 1995 to January 1997. Data provided by the Conrad Blucher Institute—Division of Coastal Observations, Corpus Christi, Texas.

temperature and water levels at the banks suggests that the annual cycle probably includes effects of thermal expansion/contraction of the water column.

c. Circulation

Cochrane and Kelly (1986) proposed a mean circulation for the Louisiana-Texas (LATEX) shelf consisting of cyclonic non-summer (September-May) flow and anticyclonic summer (June-August) flow. The cyclonic cell consists of downcoast (Louisiana to Texas) nearshore flow and upcoast flow near the shelf break. In summer, the nearshore flow reverses, but the shelf edge current continues upcoast. The Flower Garden Banks are found near the edge of the LATEX shelf, which places them within the year-round upcoast mean flow. All processes affecting the shelf edge's current variability and transport also affect the banks (Fig. 13). Thus, it is important to understand these processes to make informed management decisions affecting the Flower Gardens.

A series of moorings set from the inner shelf to the upper slope at 94°W (Science Applications International Corporation, 1989) revealed a mean current pattern and agrees with Cochrane and Kelly's model. While agreeing with the proposed mean-shelf circulation at seasonal time scales, the dataset is not large enough to demonstrate statistical significance. In the outer shelf and upper slope, currents above 100 m were easterly at 1-8 cm/s. Below 100 m the flow was westerly at 3-6 cm/s. A surprising result was the predominant offshore flow at all depths on the outer shelf and upper slope. These data provide no clear evidence of influence from deepwater processes in the region. However, the salinity values suggest oceanic influence at the shelf break (Nowlin et al., 1998). The temperature information also suggests that LC eddies interact with the shelf edge by advecting warm water onto the outer shelf (Nowlin et al., 1998).

Thirty months of current data and several hydrographic cruises on the LATEX shelf from the mouth of the Rio Grande River to the Mississippi Delta (Nowlin et al., 1998) provide the most comprehensive and recent circulation data on this area. As can be seen from the mean current patterns, stream function analysis, and current kinetic energy changes, the shelf is divided into inner and outer provinces by the 50-m isobath. At the Flower Gardens, the average alongshore current at 10 m is mostly upcoast at 10 cm/s, but decreases with depth to ± 3.5 cm/s near the bottom. Average cross-shelf currents near the shelf edge vary ± 1 cm/s. At annual time scales, the 10-m alongshore currents are directed upcoast in summer but experience reversals in non-summer periods. Near the bottom these currents decrease to ± 3 cm/s. The cross-shelf currents show no discernible patterns at annual time scales, but decrease from ± 6 cm/s at 10 m to ± 1 cm/s near the bottom. Cross-shelf currents exhibited the greatest variability near Texas, suggesting the influence of LC eddies near the shelf edge. The findings of this program can be summarized as: (1) large interannual and intraseasonal variability of the currents exists; (2) a net mean eastward current at the shelf edge is caused by eddies; and (3) cross-isobath currents are frequent and strong (Fig. 14).

These findings confirm the results of Oey (1995), which suggested from a numerical model output that the shelf edge current is driven by the LC intrusions and resulting patterns of convergences and divergences, and LC eddies. The wind effect on this current is through

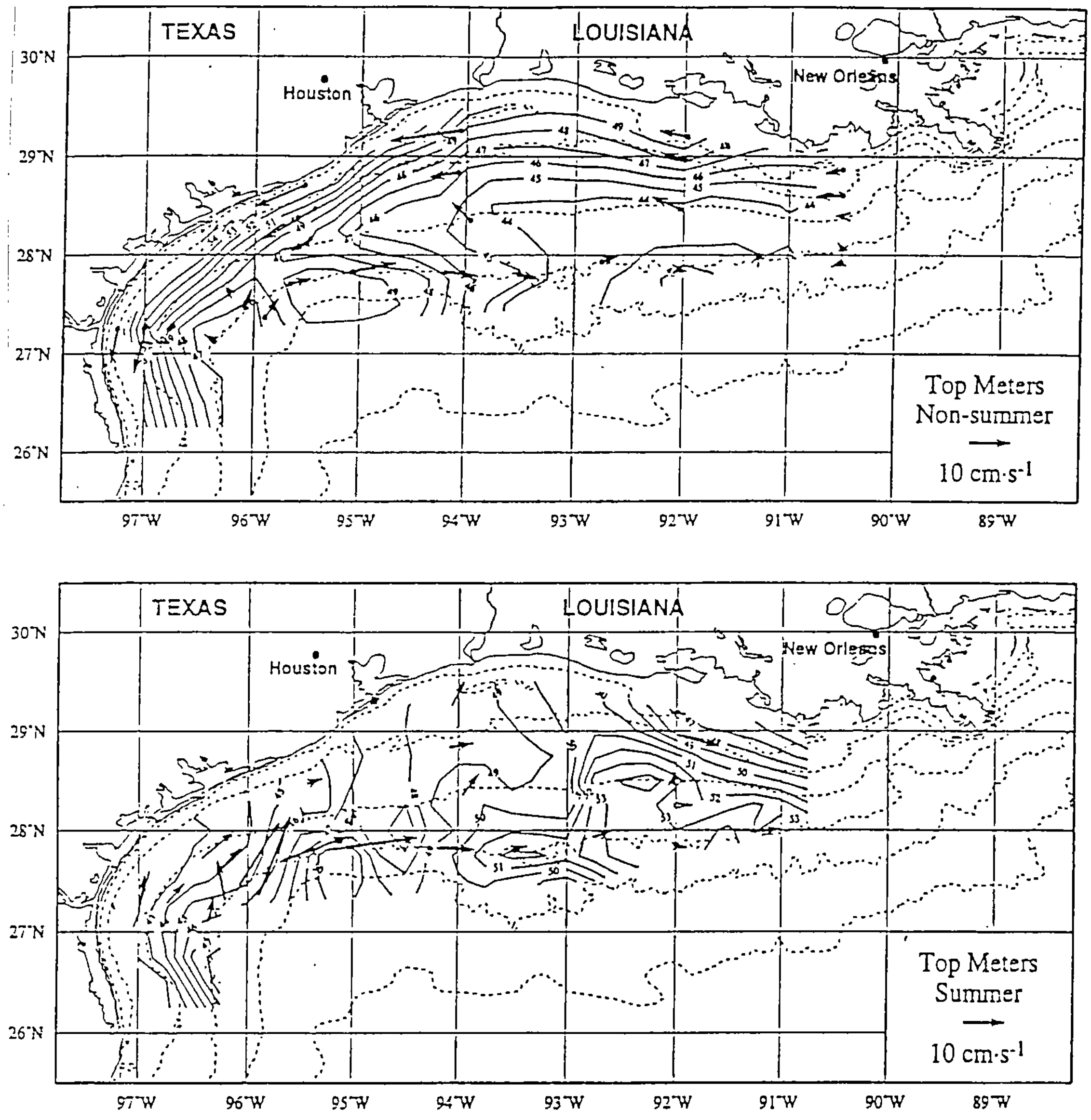

Figure 13. Mean surface geopotential relative to 200 db showing the nonsummer and summer circulation pattern in the Louisiana-Texas Shelf. Arrows represent 10-m average currents for nonsummer (September-May) and summer (June-August) during April 1992 through November 1994 (from Nowlin et al., 1998).

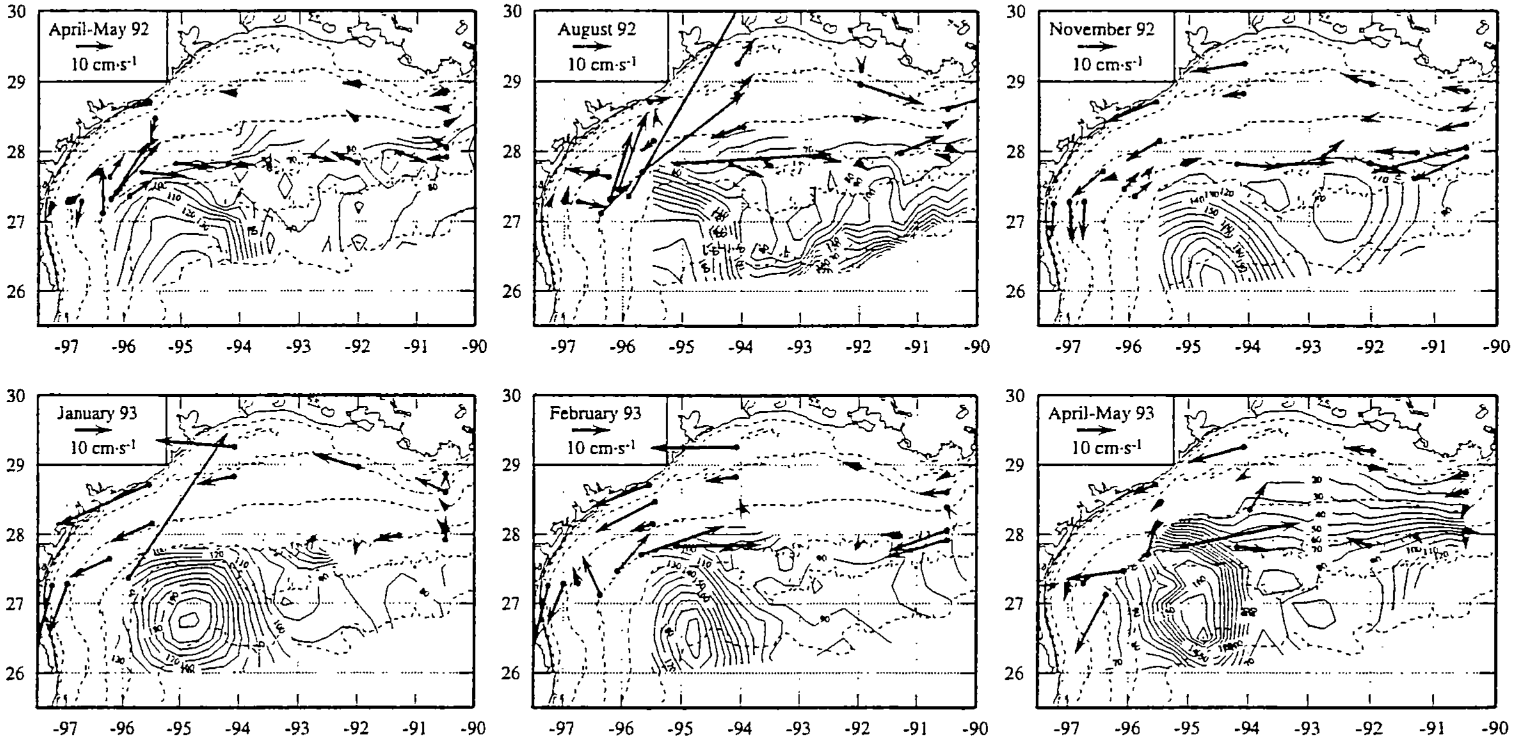

Figure 14. Topography of the 20 °C isotherm based on LATEX A, LATEX C, and GulfCet measurements for six periods from April 1992 through May 1993. Arrows represent 10-m average currents for the period plus 14 days preceding the period (from Nowlin et al., 1998).

the seasonally modulated wind stress curl. This shelf-edge current, while agreeing with Cochrane and Kelly's model, is not part of a cyclonic cell, but results from interactions between LC eddies and shelf break.

Mass transport is a very important quantity. The alongshore transport across a box containing the banks averages about 0.4 Sv (1 Sv = 10^6 m^3/s) in summer and decreases to about 0.2 Sv in non-summer; the record mean transport is less than 0.1 Sv. Cross-shelf transports are 0.2 Sv in summer, 0.1 Sv in non-summer, and 0.1 Sv for the record mean (Bender and Reid, submitted). These transport values agree with the results of Oey (1995).

The above information has shown that LC eddies interact with and drive the shelf-edge current. The Science Applications International Corporation's (1989) systematic observations of LC eddies in the Gulf of Mexico revealed cyclones or cold water eddies of 100 km in diameter in the northern slope (water depths of 200-2,000 m) of the Gulf as well. The large LC warm eddies (Fig. 15) are shed every 11 months on average (Vukovich, 1995) and travel in a southwest direction. Recent observations (Berger et al., 1996) document the existence of an active slope field of warm and cold eddies spanning a wide range of scales. The 100-km cyclones move up and down the slope, depending on what side of a large LC anticyclone they happen to be. Besides large anticyclones and cyclones, smaller eddies (cyclones and anticyclones) of scales of an order 30-50 km diameter commonly reside on this slope (Fig. 16). The interaction of counter-rotating eddies appears to be the dominant mechanism for water exchange between the shelf and upper slope. The smaller eddies can mask the effects of larger eddies on the shelf edge currents at subtidal frequencies.

Sahl et al. (1993) discussed hydrographic and nutrient data to show that the along-shelf current at the shelf break can induce Ekman bottom upwelling, creating high nutrient concentrations in near-surface waters. Onshore flux of warm-eddy water that contains low concentrations of particles brings fewer materials across the shelf edge. Offshore flux by cyclones and counter-rotating eddies creates large particle fluxes because the shelf waters are particle rich. Exchange of nutrients by cross-shelf transport may not be affected (Sahl et al., 1997) because most transport occurs near the surface where nutrient concentrations are low; deeper in the water column, most transport is along isobaths even though nutrient concentrations are higher. The cyclone-anticyclone pair (Fig. 17) affects productivity in the upper slope by two mechanisms: raising cold, nutrient rich water to the photic zone and removing nutrient rich water from the shelf (Fargion et al., 1996). Thus, eddies are not only the main driving forces of currents at the shelf break, but they also affect watermass properties, heat, and particle transport. The results also show that shelf-edge currents are not seasonal but are intermittent over time scales of weeks (Berger et al., 1996).

Tidally driven currents have been analyzed in detail by the LATEX-A program using an extensive mooring array that provides current data over the entire shelf (Nowlin et al., 1998). The data show that, near the Flower Garden Banks, the tides contribute ~10 percent of the current energy available in the 8- to 40-hr periods. The root-mean-squared current amplitude of all tidal constituents analyzed near the banks is only about 3 cm/s. The greatest tidal current is the K1 component and near the banks it equals the O1 component with a current amplitude of nearly 1-2 cm/s. The tidal currents exhibit strong vertical shear and rotate

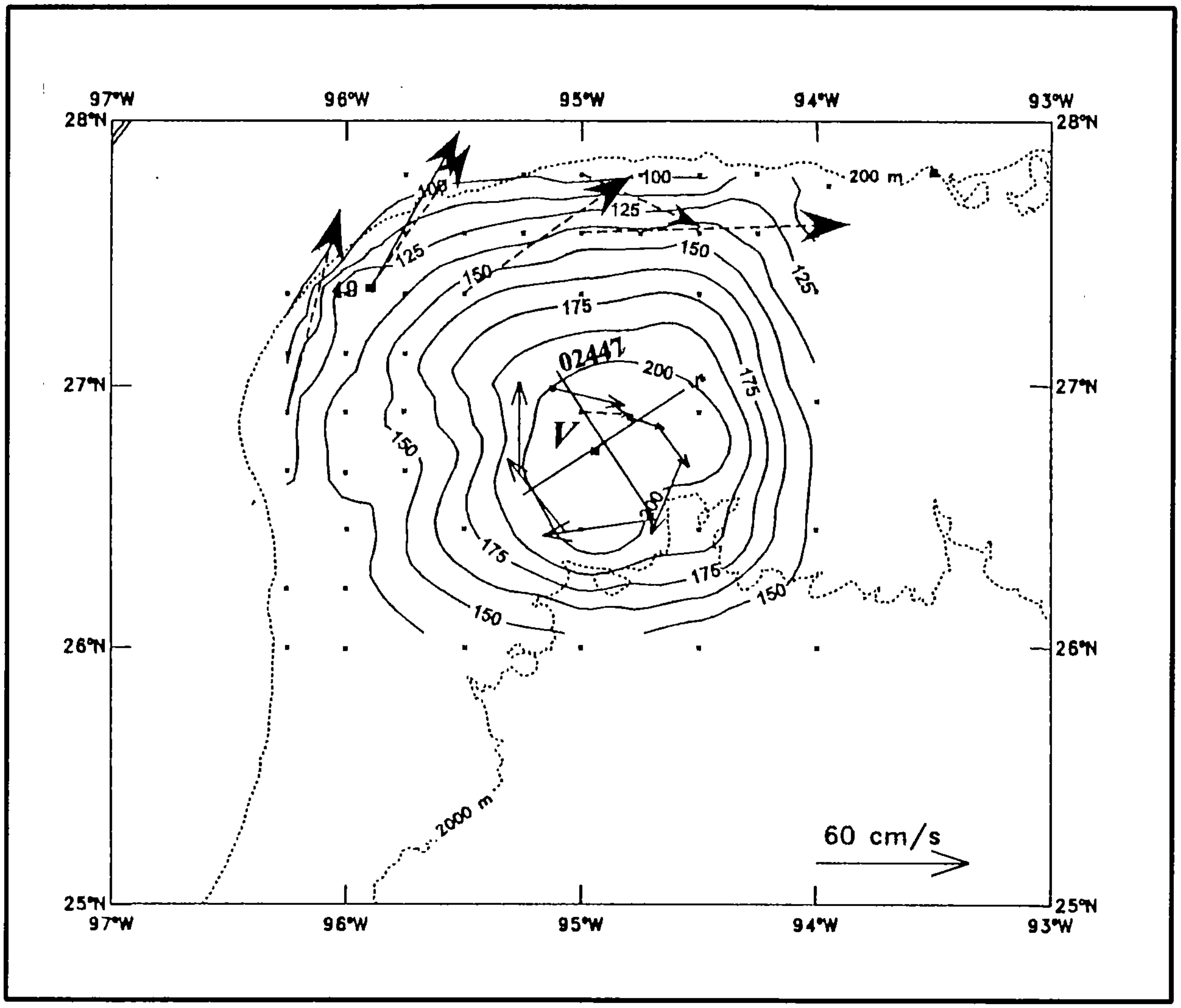

Figure 15. Topography of the 20 °C isobath based on LATEX C data for Eddy V. Arrows near the center are daily mean currents derived from Drifter 02447. Solid and cashed arrows from the squares represent daily low-passed current averages at 12 and 100 m in January 5, 1993, from LATEX A Measurements. From Berger et al. (1996).

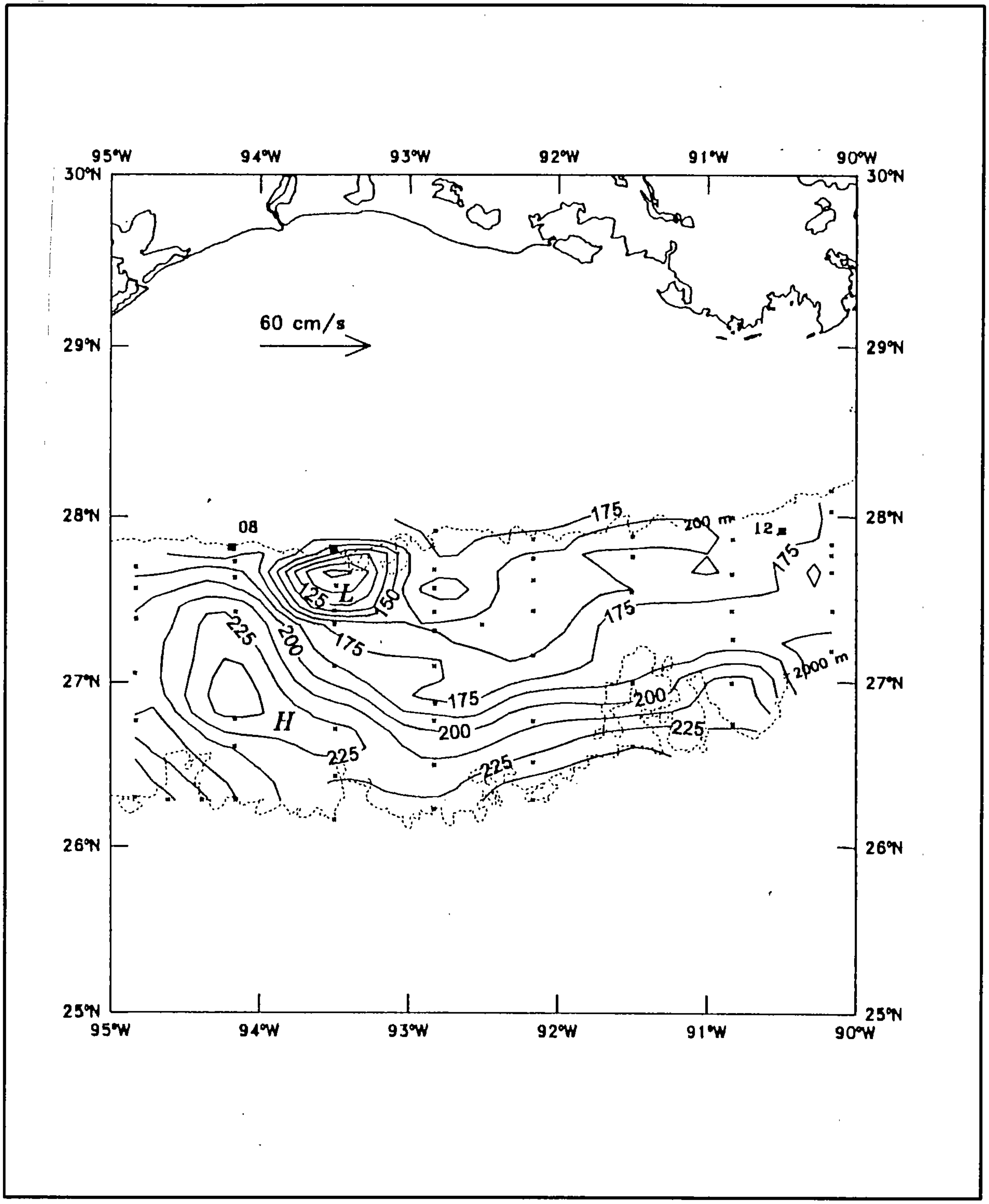

Figure 16. Topography of the 15 °C isotherm from GulfCet data on September 2, 1993. Notice the cold rimg (L) near the 200-m isobath cernered around 93.5° W. Notice the warm ring (H) centered around 27° N and 94° W. From Berger et al. (1996).

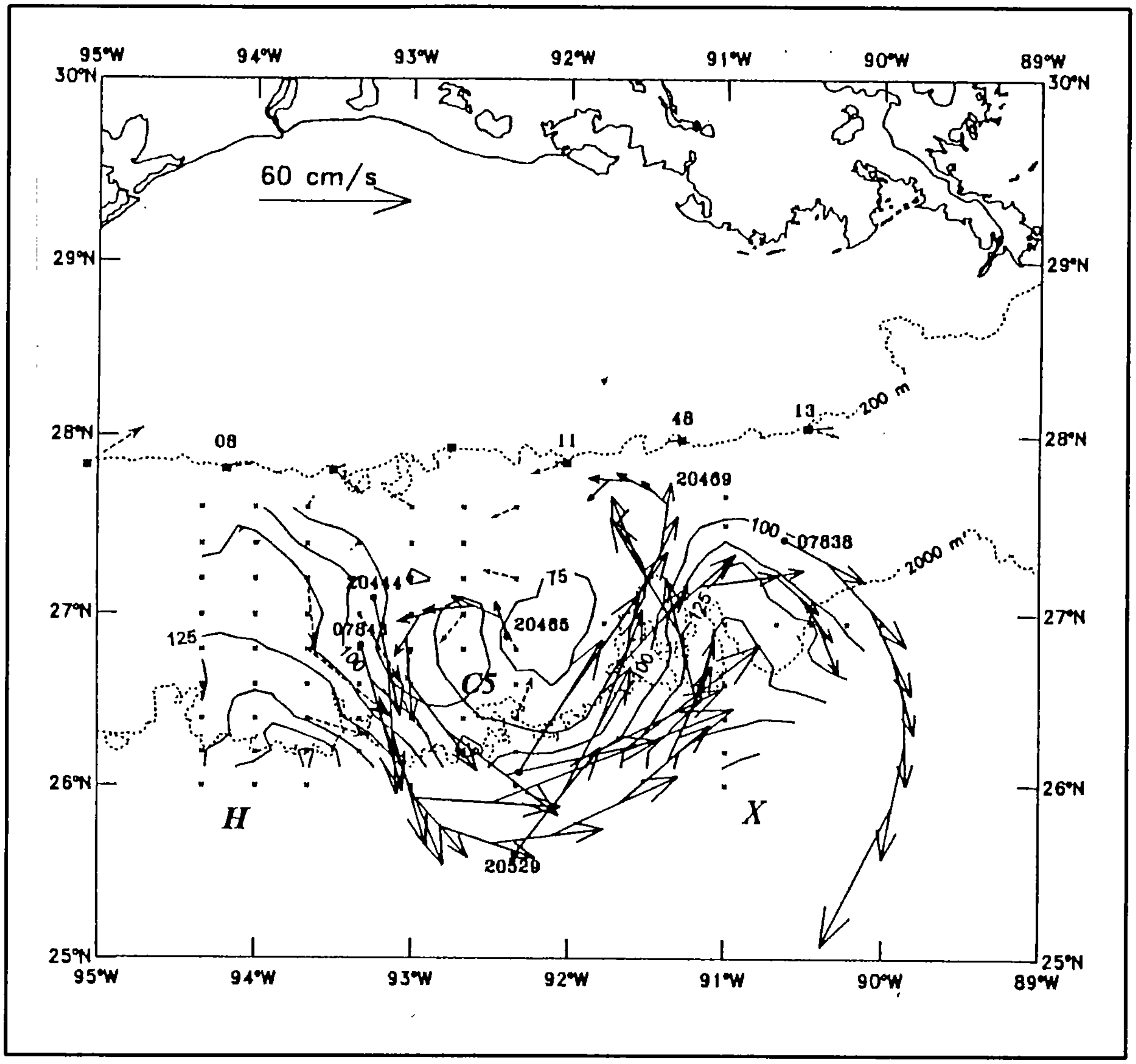

Figure 17. Topography of the 20 °C isotherm based on LATEX C data of December 1993 showing strong currents between cyclone C5 and eddy X are very strong. Arrows are daily mean current from Sculp Drifters 20444, 20465, 20469, and 20529 from December 15, 1993; and from LATEX Drifters 07838 and 07843 starting on December 20, 1993. Solid and dashed arrows from the squares represent daily low-passed current averages at 12 and 100 crosses represent 25-100 smoothed AXCP current progiles. (from Berger et al., 1996).

clockwise. In the semidiurnal band, M2 dominated the currents. Near the banks, the amplitude of this component is again 1-2 cm/s and vertically sheared. The tidal currents at the semidiurnal period rotate clockwise. The main difference compared with the diurnal components is that current phases change across the shelf, the western sites lagging those on the eastern. This lag is expected because the semidiurnal wave moves counterclockwise in the Gulf of Mexico. Estimates of tidal currents through the year at the banks range from 1 to 5 cm/s for the M2 component. Currents of K1 are from 2 to 5 cm/s with a high of 9 cm/s (McGrail, 1983).

Aside from the tidal currents on the LATEX shelf, inertial motions with periods close to the diurnal components were observed (Chen et al., 1996; Nowlin et al., 1998). These inertial motions had periods in the band of 22-28 hours, rotated clockwise, persisted for 3-5 days, and had amplitudes of 20-30 cm/s (Chen et al., 1996). The amplitudes of inertial oscillations decayed with depth and their vertical phase differences depended on the column stratification (McGrail, 1983). These motions achieved their maximum amplitudes at the shelf edge and decayed both onshore and offshore. Chen et al. (1996) interpreted these motions as caused by diurnal variations of the wind stress, but this result was based on only eight months of data. Using the 30-month current data from LATEX, Nowlin et al. (1998) found that in summer these motions were clockwise and had a period approaching 24 hours, and ascribed them to diurnal heating and cooling cycles. They also concluded that, in the non-summer period, the mechanism suggested by Chen et al. (1996) was still valid. Summarizing, the inertial motions in the LATEX shelf are caused by wind stress variations in non-summer periods and by diurnal heating in summer.

In July 1979, Hurricane Bob and Tropical Storms Claudette and Elena affected the Flower Garden Banks (McGrail, 1983). Hurricane Bob, which passed about 200 km southeast of the banks, induced a reversal of the easterly surface flow to a westerly flow at the banks. It also induced strong, inertial oscillations plus strong (> 20 cm/s) near-bottom currents. Tropical Storm Claudette passed over the banks, but before it reached them it created currents to the southeast at a depth of approximately 60 m, rotating in a counterclockwise fashion, and increasing in speed. As it passed, the current rotated, strengthened to the northwest, and accelerated to over 60 cm/s. Currents at lower levels rotated initially, then during the storm crossover pulsed northeast at > 20 cm/s, reversed afterwards, and decayed. Inertial oscillations of 10 cm/s amplitude were observed (McGrail, 1983; Bright et al., 1985). More recently, Hurricane Andrew crossed the LATEX shelf between 90° and 92°W (Nowlin et al., 1998). These cyclones reversed the surface flow to downcoast with speeds of near 30 cm/s at the shelf break. The SST was observed to decrease 1-2 °C at various points on the shelf (Breaker et al., 1994). Wave orbital velocities (motions of water parcels beneath waves) from storm-induced surface waves can induce significant motions near the banks (McGrail, 1983).

The vertical and horizontal dimensions of the Flower Garden Banks are such that orographic effects on the currents need to be considered. Present understanding and theory of orography show that flow around the banks diverges laterally with small vertical displacements (~ 10 m) at the point of divergence. These effects are caused by rotation, friction, and water column stratification. At the lee side, the data suggest the presence of waves and vertical displacement of the isotherms. The upper column isotherms are depressed, while the near-bottom isopleths rise when compared with upstream conditions. These effects have biological implications for the reef community. With deep water not rising over the banks, reef organisms are mostly immersed in clear, warm water year-round and are subjected to patterns that resemble near-surface conditions (McGrail, 1983). Episodes of discolored waters at the Flower Gardens are mostly limited to the summer period (frequently in July) when short-lived algal blooms (e.g., *Trichodesmium*) occur over and around the banks (Capt. Gary Rinn, Rinn Boats, Inc., pers. comm., 1997). Green discolorations at the Flower Gardens have on occasion been associated with sudden brief spells of cooler waters (e.g., temperature drops from 29 to 24 °C). *Trichodesmium* blooms usually occur when seawater temperature is at 28-29 °C and precede the August-September temperature peak.

3. METEOROLOGY

Terry L. Scholten and Kenneth J.P. Deslarzes

The Gulf of Mexico is influenced by a maritime subtropical climate controlled mainly by the clockwise circulation around the semipermanent area of high barometric pressure commonly known as the Bermuda High. The Gulf of Mexico is located to the southwest of this center of circulation. This proximity to the high-pressure system results in a predominantly southeasterly flow in the western Gulf of Mexico region. Two important classes of cyclonic storms are occasionally superimposed on this circulation pattern. During the winter months, December through March, the northern Gulf Coast area can experience low temperatures following the passage of cold fronts associated with cold and dry continental air masses, also locally known as "northers."

From 1957 to the mid-1980's, a decrease in average and minimum winter temperature in the northern Gulf area corresponded to a shift in the position of the Jet Stream over North America (e.g., Slowey and Crowley, 1995). A north-south displacement as opposed to a west-east displacement of the Jet Stream over North America during winter months consistently allowed for dry Arctic air to flow over the northern Gulf area, causing unusual coastal winter conditions (more frequent atmospheric fronts, record air temperature minima, and stronger surface winds) (e.g., Slowey and Crowley, 1995). Coincident with this post-1957 shift of the Pacific/North America pattern, there was a 20 percent decrease in the rate of upward growth of the coral *Montastraea faveolata* at the Flower Gardens (Hudson and Robbin, 1980). It is likely that massive corals at the Flower Gardens, such as *M. faveolata*, exhibit growth patterns and contain chemical signatures useful to elucidate past and future long-term regional climate trends. The interaction between the El Niño Southern Oscillation and the shift of the atmospheric circulation described above (also known as the Pacific/North American atmospheric circulation pattern) has yet to be fully investigated.

Tropical cyclones may develop or migrate into the Gulf of Mexico during the warmer months. These storms may affect any area of the Gulf of Mexico and substantially alter the local wind circulation. In their absence, the sea breeze effect becomes the primary coastal circulation feature during the summer months of May through October.

a. Pressure, Temperature, and Relative Humidity

The western extension of the Bermuda High dominates the circulation throughout the year, weakening in the winter and strengthening in the summer. The average monthly pressure shows a west-east gradient along the northern Gulf during the summer. In the winter, the monthly pressure is more uniform along the northern Gulf. The minimum average monthly pressure occurs during the summer. The maximum pressure occurs during the winter as a result of the presence and influence of denser transitional continental cold air.

Average air temperatures at coastal locations vary with latitude and exposure. Average coastal temperatures ranged from 24.7 to 28.0 °C in the summer and from 2.1 to 21.7 °C in the winter. Winter temperatures depend on the frequency and intensity of penetration by polar air masses from the north. Air temperatures over the open Gulf exhibit narrower limits of variations on a daily and seasonal basis due to the moderating effect of the large body of water. The average temperature over the center of the Gulf is about 29 °C in the summer and between 17 and 23 °C in the winter.

The relative humidity over the Gulf is high throughout the year. Humidity minima occur during the late fall and winter when cold continental air masses bring dry air into the northern Gulf. Humidity maxima occur during the spring and summer when prevailing southerly winds bring in warm, moist air.

b. Visibility and Cloudiness

Fog occurrence decreases seaward, but sea or frontal fog can reduce visibility at the Flower Gardens to less than 800 m (2,625 ft). Particularly dense sea fogs may persist for several days. The poorest visibility conditions occur during winter and early spring. The period from November to April has the lowest visibility. Industrial pollution and agricultural burning also impact visibility. On the South Texas coast, fog reduces visibility to less than 1 km on an average of 28 days/yr; dense fog in Galveston reduces visibility to 600 m about 16 days/yr; and Port Arthur has an average of 42 days/yr with visibility less than 600 m (USDOI, MMS, 1988). The duration and frequency of fog at the Flower Gardens are unknown.

On a yearly average, four- to six-tenths of the sky in the northern Gulf is obscured by cloud cover. October is usually the most cloud-free month and December through March the cloudiest. The clouds in the winter season are mostly widespread stratus-type clouds, while summer clouds are cumulus type (USDOI, MMS, 1988).

Insolation (Photosynthetically Active Radiation; μmol m^{-2} day^{-1}) on Flower Gardens coral reefs, as measured from 1995 to 1997, was highest from August to September (40-50 μmol m^{-2} day^{-1}). The rest of the time, irradiance levels varied from 2 to 50 μmol m^{-2} day^{-1} (Continental Shelf Associates, Inc., 1997; Dokken et al., in prep). December through February and mid-June to mid-July were the periods with lowest light levels. The summer low light levels were associated with algal blooms and turbid waters (Capt. Gary Rinn, Rinn Boats, Inc., pers. comm., 1997; Hagman et al., submitted). Photographic transects taken at the Flower Gardens by Gittings et al. (1992a, 1992b) using identical film and camera settings revealed significant differences in the color intensity displayed by coral colonies when winter and summer photographic datasets were compared. This may be indicative of an adaptation by the coral endosymbionts to seasonal light levels. Coincidentally, the growth of corals at the Flower Gardens is at its peak during the winter (Deslarzes, 1992), which may reflect enhanced calcium carbonate accretion induced by an increase in the density of endosymbionts in the coral animal tissue.

c. Wind

Winds are more variable near the coast than over open waters because coastal winds are more directly influenced by the moving cyclonic storms that are characteristic of the continent and because of differential heating by sea and land. The Azores-Bermuda atmospheric high pressure cell dominates circulation over the Gulf, particularly during the spring and summer. In late summer there is a general northward shift of the circulation, and the Gulf becomes more directly influenced by the equatorial low-pressure cell. During the relatively constant summer conditions, the southerly locations of the Azores-Bermuda cell generate predominantly southeasterly winds, which become more southerly in the northern Gulf. Winter winds usually blow from easterly directions with fewer southerlies and more northerlies. Winds from the west and southwest are rare at anytime during the year. During the spring and summer months the predominantly southeasterly offshore average wind speed ranges from 7 to 12 kn (1990-1993; National Data Buoy Center/NOAA). Average winter wind speed ranges from 13 to 14 kn (1990-1993; National Data Buoy Center/NOAA). Maximum winter wind speed can reach 42 kn (e.g., March 1993; National Data Buoy Center/NOAA). Winds may be calm during any time of the year, but they can also reach as high as 305 km/hr (190 mph) during hurricanes (e.g., Hurricane Camille in 1969).

d. Precipitation

Oceanic precipitation over the Texas-Louisiana shelf is relatively frequent and abundant throughout the year but does show distinct seasonal variation. The highest precipitation (as much as 42 cm/season; typically 15-35 cm/mo) over the LATEX shelf occurs during spring and summer (Etter, 1996). The fall and winter months usually have 2-10 cm/mo of oceanic precipitation (~ 22 cm/season). These precipitation data were acquired by satellite methods (Etter, 1996). The warmer months usually have convective cloud systems that produce showers and thunderstorms; however, these thunderstorms rarely cause any damage or have attendant hail. The month of maximum rainfall for most locations is July. Winter rains are usually associated with the frequent passage of frontal systems through the area. Rainfalls are generally slow, steady, and continuous, often lasting several days. Incidence of frozen precipitation decreases with distance offshore and rapidly reaches zero.

e. Severe Weather

The Gulf of Mexico is part of the Atlantic tropical cyclone basin. Tropical cyclones generally occur in summer and fall seasons; however, the Gulf also experiences winter storms or extratropical storms. These winter storms generally originate in middle and high latitudes. The Gulf is an area of cyclone development during cooler months due to the contrast of the warm air over the Gulf and the cold continental air over North America. Cyclogenesis, or the formation of extratropical cyclones, in the Gulf of Mexico is associated with frontal overrunning (Hsu, 1992). The most severe extratropical storms in the Gulf originate when a cold front encounters the subtropical jetstream over the warm waters of the Gulf. An analysis of 100-year data of extratropical cyclones revealed that most activity occurs above 25°N in the western Gulf of Mexico. The mean number of these storms ranges from 0.9 per year near the southern tip of Florida to 4.2 per year over central Louisiana (USDOI, MMS, 1988). Extratropical cyclones, which may vary greatly in intensity, occur primarily during the winter months.

The frequency of cold fronts in the coastal Gulf exhibits similar patterns during the 4-month period of December through March. During this time, the area of frontal influence reaches 10 °N. Frontal frequency is about nine fronts per month in February (1 front every 3 days on the average) and about seven fronts per month in March (1 front every 4-5 days on the average). By May, the frequency decreases to about four fronts per month (1 front every 7-8 days) and the region of frontal influence retreats to about 15 °N. During June-August, frontal activity decreases to almost zero and fronts seldom reach below 25 °N (USDOI, MMS, 1988).

The largest and most destructive storms affecting the Gulf of Mexico and adjacent coastal zones are tropical cyclones that have their origin over the warm tropical waters of the central Atlantic Ocean, Caribbean Sea, or southeastern Gulf of Mexico. Tropical cyclones occur most frequently between June and late October, and there is a high probability that they will cause damage in the Gulf each year.

Forty-two years of data indicate that there are about 9.9 storms per year with about 5.5 of those becoming major hurricanes (Category 4 and Category 5) in the Atlantic Ocean. Data from 1886 to 1986 show that 44.5 percent of all these storms, or 3.7 storms per year, have affected the Gulf of Mexico (USDOI, MMS, 1988). From 1899 to 1996, 99 hurricanes and 96 tropical storms occurred within the northern Gulf of Mexico, Central and Western Planning Areas (area north of 25°N and west of 85°W). Approximately 50 percent of the hurricanes were of Category 1 intensity (Saffir-Simpson scale), 6 percent were Category 5 hurricanes, and the remainder were Category 2 (13.1%), 3 (17.2%), and 4 (15.2%) hurricanes. Sustained winds for major hurricanes (Saffir-Simpson Category 3 and above) are higher than 49 m/sec (109.6 mph). Hurricane wind intensity ranged from 70 to 165 kn (128-306 km/h), and the associated surge ranged from 1 to over 6 m (3 to >19 ft). Tropical storm winds ranged from 35 to 60 kn (64-111 km/h) (Vietor, 1997). Category 4 and 5 hurricanes that probably caused the most severe weather at the Flower Gardens since 1899, in terms of wind speed and surge, occurred in 1900, 1909, 1915, 1957, 1961, 1964, 1974, 1979, and 1980. All were Category 4 storms, except those of 1961 and 1980, which were Category 5.

There is a high probability that tropical storms will cause damage to physical, economic, biological, and social systems in the Gulf. Tropical storms also affect OCS operations and activities; platform design needs to consider the storm surge, waves, and currents generated by tropical storms. Most of the damage is caused by storm surge, waves, and high winds. Storm surge depends on local factors, such as bottom topography and coastline configuration, and storm intensity. Water depth and storm intensity control wave height during hurricane conditions. The passage of a hurricane in the vicinity of the Flower Gardens may cause reef damage due to severe surge as witnessed in 1980 following Hurricane Allen. Hurricane track records show that on August 8 and 9, Hurricane Allen was closest to the Flower Gardens (~ 250 km away) and was at one of its Category 5 peaks (155 mph winds, >18 ft surge). At least one boulder-sized coral head (estimated weight 2 tons) at the East Flower Garden Bank was displaced several tens of meters away from its original location by the hurricane-generated surge (Mr. Christopher L. Combs, pers. comm., 1989).

4. BIOLOGICAL RESOURCES

Kenneth J.P. Deslarzes and Dagmar C. Fertl

a. Pelagic Environment

The pelagic offshore water column biota contains primary producers (phytoplankton and bacteria), secondary producers (zooplankton), and consumers (larger marine species including fish, sea turtles, cephalopods, crustaceans, and cetaceans). Planktonic primary producers drift with currents. Zooplankters drift with currents as well but are also motile. The species diversity, standing crop, and primary productivity of offshore phytoplankton are known to fluctuate much less than their coastal counterparts, as the offshore phytoplankton are less subject to changes of salinity, nutrient availability, vertical mixing, and zooplankton predation. Yet, significant water column discolorations (algal blooms) are known to occur annually at the Flower Gardens, mostly in July (Capt. Gary Rinn, Rinn Boats Inc., pers. comm., 1997). A permanent record of the recurrence of changes in primary productivity rates at the Flower Gardens may be found in coral colonies. Recurrent, highly fluorescing bands incorporated in coral skeleton attest to the repeated availability of unusually elevated levels of dissolved organic matter in the water column (Deslarzes, 1992). Aside from green discolorations, blooms of the cyanobacterium *Trichodesmium* have regularly been observed in July giving the sea surface a brownish appearance. During this same time period, the water column has also contained aggregates of organic/particulate matter known to Flower Gardens divers as "seasnot" (Capt. Gary Rinn, Rinn Boats Inc., pers. comm., 1997). These seawater conditions usually coincide with calm seas, low winds, and elevated seawater temperature (≥29 °C). Light measurements at the Flower Gardens collected during the NOAA/MMS-funded monitoring of the high-diversity reefs since August 1995 indicate lowered levels on incident light from late June to mid-July both in 1996 and 1997 (Continental Shelf Associates, Inc., 1997; Dokken et al., in prep.). Potential influences on nutrient fluxes on the outer shelf are the freshwater river runoff (discharges of the Atchafalaya-Mississippi Rivers and of 13 rivers west of the Atchafalaya River; Nowlin et al., 1998) (Atchafalaya-Mississippi Rivers mean discharge: 9,000-32,000 m^3/s^{-1}) January to August; peak in April >30,000 $m^3\ s^{-1}$), deep Gulf upwelled waters, cold ring waters, and shelf water squirted offshore (convergence of warm and cold rings creating a jet that forces water offshore) (Fargion et al., 1996; Murray and Donley [eds.], 1996; Nowlin et al., 1998). Although these interpretations are useful for this general description, they have yet to be corroborated by rigorous studies that better characterize the mechanisms by which primary production is enhanced, as well as the seasonality and abundance of primary and secondary producers at the banks.

Zooplankton at the Flower Gardens is typically more abundant during the winter months. The zooplankton consists of holoplankton (organisms for which all life stages are spent in the water column, including protozoans, gelatinous zooplankton, copepods, chaetognaths, polychaetes, and euphausids) and meroplankton (mostly invertebrate and vertebrate organisms for which larval stages are spent in the water column, including corals, polychaetes, echinoderms, gastropods, bivalves, and fish larvae and eggs). Shelf phyto- and zooplankton are more abundant, more productive, and seasonally more variable than the deep Gulf plankton. These are related to salinity changes, greater nutrient availability, increased vertical mixing, and different zooplankton predation in the shelf environment. In general, the diversity of pelagic planktonic species increases with increased salinity, and biomass decreases with distance from shore. The geographical and vertical ranges of plankters and consumers are limited by temperature, salinity, and nutrient availability.

There are over 175 tropical reef fish species that reside within the high-diversity zone at the Flower Gardens (Dennis and Bright, 1988; Pattengill, in prep.). A recent study of fish populations at the Flower Garden Banks and at the HIES Block A-389 platform found mid-water pelagics (carangids and scombrids) to be most abundant around the artificial substrate (>50%), and reef-dependent species to dominate on the banks (99%).

Abundant organisms of the neuston (organisms living at the air-seawater interface) are copepods, windrows of floating *Sargassum*, and the many organisms associated with the *Sargassum* (up to 100 animal species including hydroids, copepods, fish, crabs, gastropods, polychaetes, bryozoans, barnacles, anemones, and sea-spiders). *Sargassum* windrows are also temporary refuges and sources of food for hatchling sea turtles in the Gulf as they drift with these floating ecosystems, spending their "lost years" (Carr, 1987). Two 10-12 cm loggerhead (*Caretta caretta*) hatchlings were seen in 1996 in a *Sargassum* windrow at the Flower Gardens (Ms. Emma Hickerson, TAMU-Biology, pers. comm., 1997).

b. The Benthos

The benthos of the Flower Gardens has both floral and faunal components; floral representatives include bacteria and algae (80 species). In the frequently clear waters at the Flower Gardens, benthic algae, especially coralline red algae, are known to grow in water depths to at least 100 m (Rezak et al., 1983). Benthic fauna (21 reef coral species; 250+ invertebrate species) include infauna (animals that live in the substrate, including mostly burrowing sponges, worms, crustaceans, and mollusks) and epifauna (animals that live on or are attached to the substrate, including crustaceans, echinoderms, mollusks, hydroids, sponges, bryozoans, soft and hard corals) (Bright and Pequegnat [eds.], 1974; Bright et al., 1983 and 1984; Rezak et al., 1985).

Bright and Pequegnat (eds.) (1974) and Rezak et al. (1983 and 1985) identified seven biotic zones at the Flower Gardens. Both banks exhibit nearly identical depth-related biotic zonation. The biotic zonation of the two banks is shown in Figures 18 and 19. Figure 20 depicts the general biotic zonation of the banks in relationship to depth. The benthic organisms on these topographic features are mainly limited by temperature and light, as well as a turbid nepheloid layer surrounding the banks. Extreme water temperature and light intensity are known to stress corals. Temperatures lower than 16 °C reduce coral growth, while temperatures in excess of 30 °C will impede coral growth and induce coral bleaching (loss of symbiotic zooxanthellae). Though intertidal corals are adapted to high light intensity, most corals become stressed when exposed to unusually high light levels. Furthermore, although corals will grow or survive under low light level conditions, they do

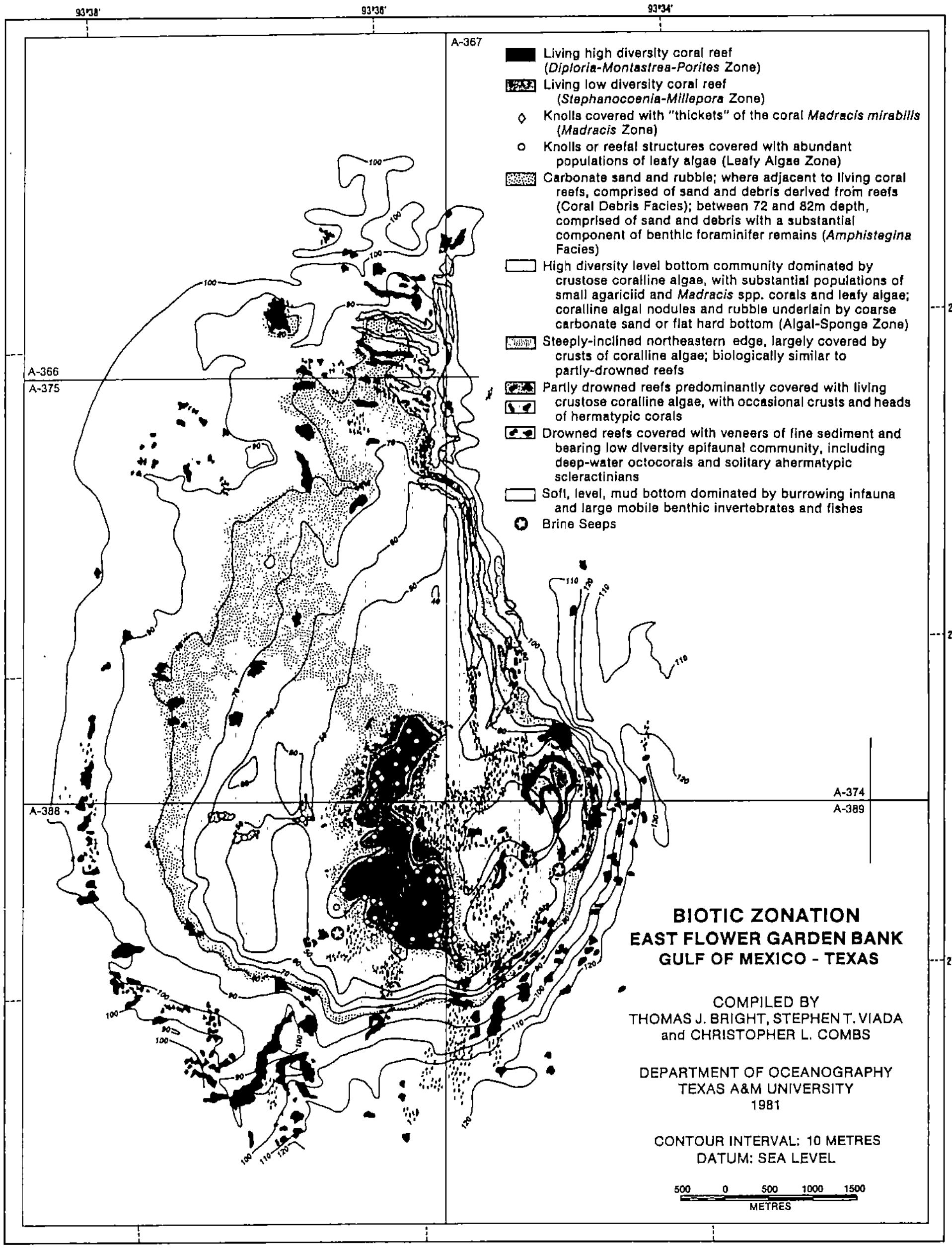

Figure 18. Biotic zonation of the East Flower Garden Bank (after Bright et al., 1983).

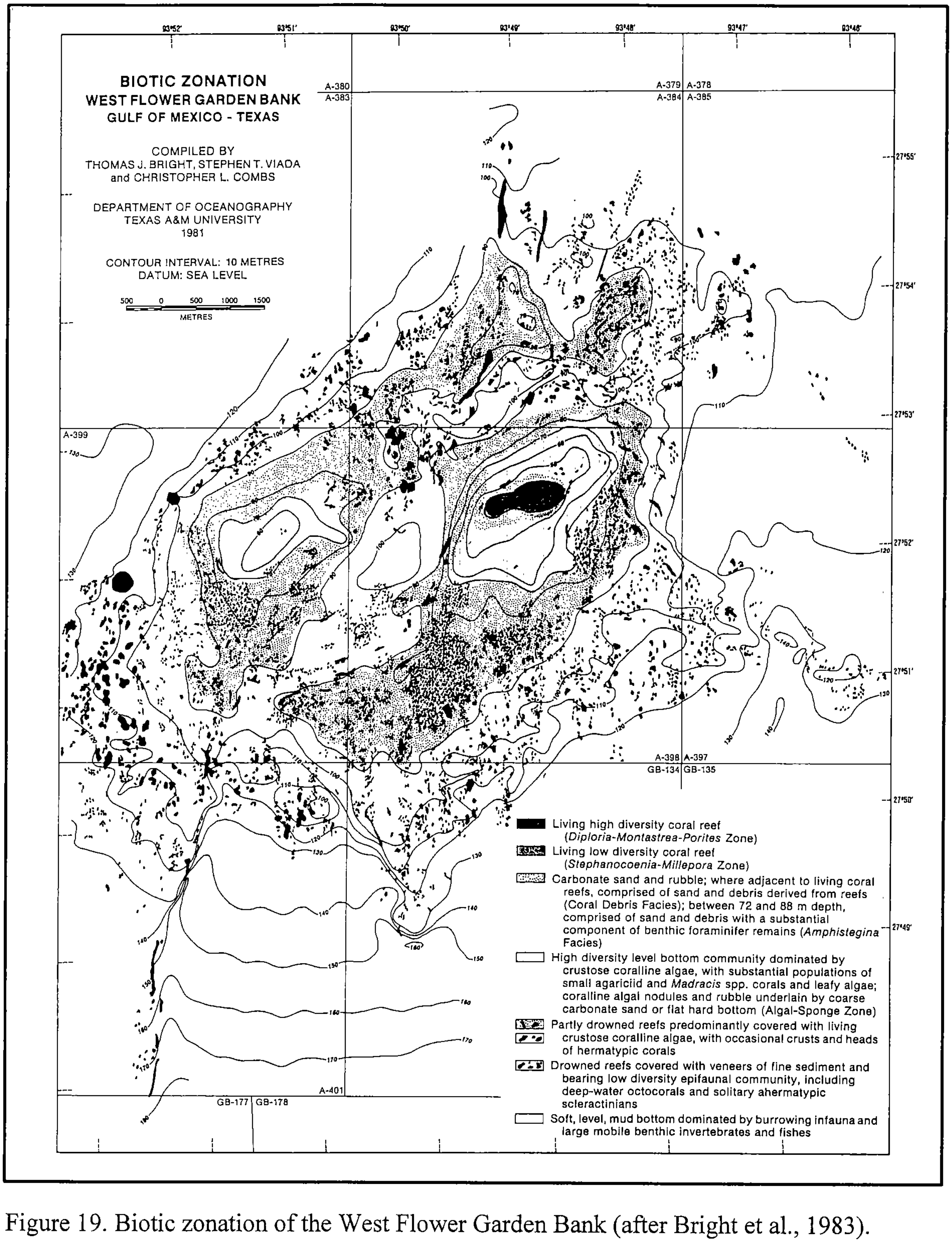

Figure 19. Biotic zonation of the West Flower Garden Bank (after Bright et al., 1983).

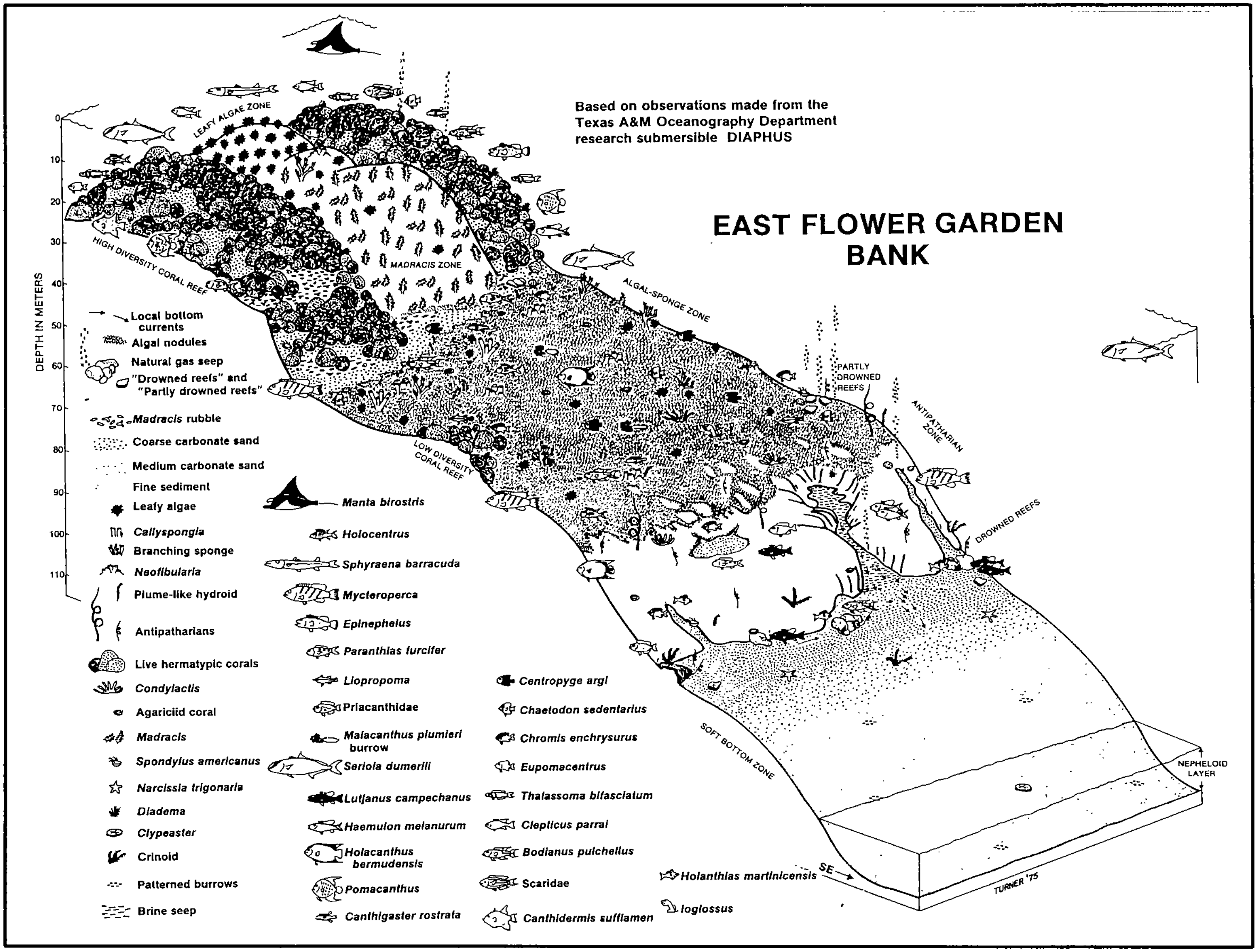

Figure 20. Depiction of biotic zonation of the Flower Garden Banks (after Bright et al. (1983).

best while submerged in clear, nutrient-poor waters. Horizontal Secchi disk water transparency over the coral reef at the Flower Gardens has been estimated at 46 m during the summer, and water temperature at 18-23 m was found to range from 19 to 30 °C, from 1990 to 1997 (Hagman et al., submitted).

c. Seven Biotic Zones at the Flower Gardens

Zones of Major Reef Building and Primary Production

Diploria-Montastraea-Porites Zone (water depth: < 36 m)

This zone is characterized by 18 hermatypic coral species. The dominant species of the zone in order of dominance are *Montastraea franksi*, *Diploria strigosa*, *Montastraea cavernosa*, *Colpophyllia* spp., and *Porites asteroides*. Coralline algae are abundant, adding substantial amounts of calcium carbonate to the substrate. Leafy algae are usually sparse, probably due to grazing. Typical sport and commercial fish include grouper, hind, amberjack, barracuda, cottonwick, porgy, and creole-fish. Coral cover in this zone is estimated at 46 percent (Gittings et al., 1992a and 1992b).

Madracis Zone *and Leafy Algae Zone* (water depth: 28-46 m)

The *Madracis* Zone occurs intermittently along the periphery of the main reefal structure and is dominated by the small branching coral *Madracis mirabilis*, which produces large amounts of carbonate rubble and sediment. In places, large (possibly ephemeral) populations of leafy algae dominate the *Madracis* gravel substratum (Leafy Algae Zone). The *Madracis* Zone may have a successional relationship with the *Diploria-Montastraea-Porites* Zone. *Madracis* colony remains build up the substrate and allow the successional species to grow.

Stephanocoenia-Millepora Zone (water depth: 36-52 m)

The *Stephanocoenia-Millepora* Zone is inhabited by a low-diversity coral assemblage of 12 hermatypic corals. The eight most conspicuous species in order of dominance are *Stephanocoenia michelini*, *Millepora alcicornis*, *Montastraea cavernosa*, *Colpophyllia* spp., *Diploria strigosa*, *Agaricia agaricites*, *Mussa angulosa*, and *Scolymia* sp. The assemblages associated with this zone are not well known. Coralline algae are most conspicuous in this zone. Reef fish populations are less diverse. The spiny oyster (*Spondylus americanus*) is frequently observed.

Algal-Sponge Zone (water depth: 46-88 m)

The Algal-Sponge Zone covers the largest area among the reef-building zones. The dominant organisms of the zone are the coralline algae, which are the most important carbonate producers, forming both pavements on the substrate and algal nodules. The algae nodules range from 1 to 25 cm in size, cover 50-80 percent of the bottom in places, and generally occur between a depth of 55 and 85 m. The habitat created by the algae nodules supports communities that are probably as diverse as the coral-reef communities. Leafy algae also occur in this zone and contribute large amounts of food to the surrounding communities. Calcareous green algae (*Halimeda* and *Udotea)* and several species of hermatypic corals are major contributors to the substrate. Deepwater alcyonarians are abundant in the lower Algal-Sponge Zone. Sponges, especially *Neofibularia nolitangere,* are conspicuous. Echinoderms are abundant and also add to the carbonate substrate. Small gastropods and pelecypods are also abundant. Gastropod shells are known to form the center of some of the algal nodules. Characteristic fish of the zone are yellowtail reef fish, sand tilefish, cherubfish, and orangeback bass.

Partly drowned reefs are a major biotope of the Algal-Sponge Zone. They are defined as those reefal structures covered with living crusts of coralline algae with occasional heads of hermatypic corals. In addition to the organisms typical of the Algal-Sponge Zone, the partly drowned reefs are also inhabited by large anemones, large comatulid crinoids, basket stars, limited crusts of *Millepora*, and infrequent small colonies of other hermatypic species. The relief and habitat provided by the carbonate structures also attract a variety of fish species, especially yellow tail reef fish and blue and queen angelfish.

Transitional Zone of Minor to Negligible Reef Building

Antipatharian Zone (water depth: 52-90 m)

This transitional zone is not distinct but blends in with the lower Algal-Sponge Zone. It is characterized by an abundance of antipatharian whips growing with the Algal-Sponge assemblage. With increased water depth, the assemblages of the zone become less diverse, characterized by antipatharians, comatulid crinoids, few leafy or coralline algae, and limited fish (yellowtail reef fish, queen angelfish, blue angelfish, and spotfin hogfish). Again, the depth of this zone varies at the various banks but extends generally to 90 m.

Zone of No Reef Building

Nepheloid Zone (water depth: 90-130 m)

High turbidity, sedimentation, and resuspension occur in this zone. Rocks or drowned reefs are often thinly covered by sediment. Epifauna are scarce. The most noticeable are comatulid crinoids, octocoral whips and fans, antipatharians, encrusting sponges, and solitary ahermatypic corals. The fish fauna is different and less diverse than that of the coral reefs or partly drowned reefs. Fish species include red snapper, Spanish flag, snowy grouper, bank butterflyfish, scorpionfishes, tuttler and roughtongue bass.

d. Threatened Species

Federally designated threatened species that have been observed within the 4-Mile Zone at the Flower Gardens include the loggerhead (*C. caretta*), the hawksbill (*Eretmochelys imbricata*), and the leatherback sea turtles (*Dermochelys coriacea*) (Dr. Stephen Gittings, NOAA/NOS/SRD, pers. comm., 1997). Sea turtles spend nearly all of their lives in the water. The females must emerge periodically from the ocean to nest on beaches. Sea turtles are long-lived, slow reproducing organisms. It is generally believed that all sea turtle species spend the first few years of their lives in pelagic waters, and can occur in windrow aggregates of floating particles and *Sargassum* algae where they find refuge and food (Carr, 1986, 1987). Adult turtles in the Gulf are apparently less abundant in the deeper waters of the Gulf of Mexico than in waters less than 27-50 m (89-164 ft) deep (NRC, 1990).

The leatherback is the largest of the sea turtles, with an average curved carapace length for adult turtles of 155 cm (5 ft) and weight ranging from 200 to 700 kg (441-1,543 lb) (USDOC, NMFS, 1992). This species is also the most pelagic and most wide-ranging of sea turtles, undertaking extensive migrations following depth contours for hundreds, even thousands, of kilometers (Morreale et al., 1996). Leatherback nesting is concentrated on coarse-grain beaches in tropical latitudes (Pritchard, 1971), though there are rare occurrences on the Panhandle and Flagler County coasts in Florida (Ogren et al., 1989). Leatherbacks have unique, deep diving abilities (Eckert et al., 1986), a specialized jellyfish diet (Brongersma, 1972), and unique physiological properties that distinguish them from other sea turtles (Lutcavage et al., 1990; Paladino et al., 1990). Leatherbacks were the most abundant turtle sighted during the GulfCet study (Davis and Fargion [eds.], 1996); though sighted throughout the study area, concentrations were found from Mississippi Canyon east to DeSoto Canyon.

The hawksbill is a small to medium-sized sea turtle. Nesting females average about 87 cm in curved carapace length and can weigh up to 80 kg (176 lb) in the Caribbean (USDOC, NMFS, 1993a). This turtle is a solitary nester. The six-month nesting season of the hawksbill is longer than that of other sea turtles; nesting occurs between July and October (USDOC, NMFS, 1993a). Nesting within the southeastern United States occurs principally in Puerto Rico and the U.S. Virgin Islands. Within the continental U.S., nesting is restricted to the southeast coast of Florida and the Florida Keys. Post-hatchlings occupy the pelagic environment, taking shelter in weedlines. Hawksbill turtles are generally associated with coral reefs or other hard substrate areas, where they forage primarily on sponges (Carr and Stancyk, 1975; Meylan, 1988). This species feeds in the photic zone and prefers warm water. The hawksbill occurs in tropical and subtropical seas of the Atlantic, Pacific, and Indian Oceans. The species is widely distributed in the Caribbean Sea and western Atlantic Ocean, with representatives of at least some life history stages occurring along southern Florida and the northern Gulf of Mexico (especially Texas), along the Greater and Lesser Antilles, and along the Central American mainland south to Brazil. In the continental U.S., the species is recorded from all the Gulf States and from along the eastern seaboard as far north as Massachusetts, with the exception of Connecticut; however, sightings north of Florida are rare (USDOC, NMFS, 1993a). The hawksbill is the least commonly reported sea turtle in the Gulf (Hildebrand, 1982). Stranded hawksbills have been reported in Texas (Hildebrand, 1982; Ogren et al., 1989) and recently in Louisiana (Mr. J.B. Choromanski, Aquarium of the Americas-New Orleans, pers. comm., 1992); these tend to be either hatchlings or yearlings. Northerly currents may carry them away from their natal beaches in Mexico northward into Texas (Amos, 1989; Collard and Ogren, 1989). Texas and Florida are the only States where hawksbills are sighted with any regularity (USDOI, FWS, 1995). Commercial exploitation is the major cause of the continued decline of the hawksbill sea turtle (USDOC, NMFS, 1993a).

The loggerhead sea turtle occurs worldwide in habitats ranging from estuaries to the continental shelf (Dodd, 1988). The mean straight carapace length of adult southeastern U.S. loggerheads is approximately 92 cm (3 ft); the corresponding mean body mass is approximately 113 kg (249 lb) (USDOC, NMFS, 1990). In the Gulf of Mexico, recent surveys indicate that the Florida Panhandle accounts for approximately one-third of the nesting on the Florida Gulf Coast. In the Central Gulf, loggerhead nesting has been reported on Gulf Shores and Dauphin Island, Alabama; Ship Island, Mississippi; and the Chandeleur Islands, Louisiana (Fuller et al., 1987). Nesting in Texas occurs primarily on North and South Padre Islands, although occurrences are recorded throughout coastal Texas (Hildebrand, 1982). Aerial survey results indicate that western North Atlantic loggerheads are distributed about 54 percent in the southeast U.S. Atlantic, 29 percent in the northeast U.S. Atlantic, 12 percent in the eastern Gulf of Mexico, and 5 percent in the western Gulf of Mexico (Byles et al., 1996). Aerial surveys indicate that loggerheads are common in areas of less than 50-m (164-ft) depth, but they are also found in deep water (Shoop et al., 1981; Fritts et al., 1983). Juvenile and subadult loggerheads are omnivorous, foraging on pelagic crabs, molluscs, jellyfish, and vegetation captured at or near the surface. Adult loggerheads are generalist carnivores that forage on nearshore benthic invertebrates (Dodd, 1988). The banks off the central Louisiana coast and near the Mississippi Delta are also important marine turtle feeding areas (Hildebrand, 1982).

Twenty-eight species of whales and dolphins have been reported in the northern Gulf (Davis and Fargion [eds.], 1996), but only two have been seen with regularity at the Flower Gardens: the Atlantic spotted dolphin (*Stenella frontalis*) and the bottlenose dolphin (*Tursiops truncatus*). Whales are rarely sighted at the Flower Gardens, with one large unidentified whale being the only known observation (Mr. Hector Guttierez, formerly on Mobil's HIES Block A-389 platform, pers. comm., 1994). All marine mammals are considered threatened and are protected by the Marine Mammal Protection Act. Six species are currently on the Federal Endangered Species List.

e. Special Ecological Functions

Recent observations have shown the importance of the Flower Gardens as habitats supporting the feeding, reproduction, and nursing of biota, and their significance as schooling grounds and as migratory stopovers. The summer months (June-October) are a time of active reproduction by fish and benthic invertebrates at the Flower Gardens. One major reproduction event at the Flower Gardens is the late August and early September annual mass spawning by corals, a synchronous release of gametes by virtually all star and brain coral colonies including *M. franksi*, *M. annularis*, *M. faveolata*, *S. michelini*, *Colpophyllia natans*, *M. cavernosa*, and *D. strigosa* (Gittings et al., 1992a and 1994). The spawning of the dominant corals at the Flower Gardens happens in two events, one of them being a "major" event during which most of the corals on the reefs burst into a synchronous mass spawning. Each event is spread out over two to three evenings and lasts less than six hours. The major spawning event usually takes place eight evenings following a late August full moon or an early September full moon. This mass reproduction at the Flower Gardens has coincided with spawning events in several locations of the western Atlantic (Florida Keys, Bahamas, Honduras, Netherlands Antilles) (Gittings et al., 1994). Spawning observations were also made for four other invertebrate species and four fish species (Gittings et al., 1994). Fish species such as the ocean triggerfish (*Canthidermis sufflamen*) have been seen to reproduce before the mass spawning of corals.

Recent investigations suggest that sharks and rays use the areas of major reef-building at the Flower Gardens as feeding and nursery habitats, and in one case as perhaps a migratory stopover (Childs et al., 1996). During winter months, the Atlantic manta ray (*Manta birostris*), the Caribbean reef shark (*Carcharhinus perezi*), and the silky shark (*Carcharhinus falciformis*) have been seen using the Flower Gardens as nursery habitats. The scalloped hammerhead shark (*Sphyrna lewini*), the spotted eagle ray (*Aetobatus narinari*), the tiger shark (*Galeocerdo cuvieri*), and the sandbar shark (*Carcharhinus plumbeus*) appear to use the Flower Gardens as a winter feeding habitat. The scalloped hammerheads will form large schools at the Flower Gardens during winter months. The reasons for this behavior are unknown. The whale shark (*Rhincodon typus*) seems to use the Flower Gardens as summer feeding grounds (July-October). The lesser devil ray (*Mobula hypostoma*) is thought to use the Flower Gardens as a springtime migratory stopover.

The Flower Gardens evidently support the special ecological functions involving numerous tropical reef organisms. Studies have focused on elements of reproduction and habitat usage. Further work will probably reveal further functions that confirm the essential nature of habitat provided by the Flower Gardens.

5. WATER QUALITY

Kenneth J.P. Deslarzes and Gail B. Rainey

a. Hydrology

The Gulf of Mexico is a semi-enclosed tropical and subtropical sea. It covers a 1.54 million km^2 (595,000 mi^2) area and holds 2.33 million km^3 (8.23×10^{16} ft^3) of water (assuming a mean depth of 1.51 km [0.94 mi]) (Rand McNally, 1975; John Bartholomew and Son, Ltd., 1985). The Loop Current supplies the Gulf with an estimated 30 million m^3/s (1.06 billion ft^3/s) of seawater through the Yucatan Channel (e.g., Nowlin and Hubertz, 1972). The average outflow of the Gulf through the Straits of Florida amounts to 30 million m^3/s (Science Applications International Corporation, 1992). Recent estimates of average oceanic precipitation using satellite data in the northwestern Gulf show maximum rainfall (15-35 cm/mo [6-14 in]) in April/May and September/October, and minimum rainfall (2-10 cm/mo [0.8-3.9 in]) in July and December (Etter, 1996). In the northern Gulf, the Atchafalaya-Mississippi Rivers produce most of the river discharge (18,400 m^3/s [650,000 ft^3/s]; Milliman and Meade, 1983). The total river discharge in the southwestern Gulf (> 10,000 m^3/s [>353,100 ft /s^3]) is generated mainly by the Usumacinta, Grijalva, Coatzacoalcos, Papaloapan, and Pánuco Rivers (UNEP-GEMS/WATER, 1995). Starting in November and continuing into May, the northern Gulf shelf receives increased amounts of river discharge with a maximum in April/May of 75-85 cm/mo (30-33 in/mo) (total monthly river discharge rates of the northern Gulf divided by the area of the shelf). River discharge declines from June on and attains a minimum rate of 20 cm/mo (8 in/mo) from September to November (based on 1992-1994 satellite data; Etter, 1996). Evaporation rates in the northern Gulf are highest from September to December (20-30 cm/mo [8-12 in/mo]) and lowest in May/June (~ 10 cm/mo [~ 4 in/mo]) (Etter, 1996). The hydrologic balance (evaporation-precipitation) of the northern Gulf is positive except for during the spring, when the precipitation rate is at its peak (data collected from 1992-1994; Etter, 1996). Finally, June and September estimates of the rate of freshwater storage (offshore freshwater storage = precipitation + discharge - evaporation) (1992-1994) at the Flower Gardens were typically 0 cm/mo (Etter, 1996). This rate contrasted with results from the water column 150 km (93 mi) to the east of the Flower Gardens, which had a decreased salinity in June (50-100 cm/mo [20-39 in/mo]) and an increased salinity in September (-50 to -100 cm/mo [-20 to -39 in/mo]) (Etter, 1996).

The freshwater budget in the northern Gulf, however, shows a net deficit due to the high rate of evaporation (Etter, 1996). This is particularly true at the Flower Gardens, considering the negligible contribution of direct river discharge to the Flower Gardens, the lack of freshwater storage, and evaporation being greater than precipitation most of the time (Etter, 1996). Yet, chronic discolorations of the otherwise clear and nutrient-poor waters at the Flower Gardens attest to natural variations of water quality. Furthermore, charter boat captains frequently visiting the Flower Gardens during the summer have consistently observed low salinity and turbid superficial water lenses (1989-1997). These unusual superficial conditions are suspected to originate from Mississippi-Atchafalaya Rivers coastal waters or bay waters that move out onto the outer shelf. Squirts (high velocity offshore flows) and cyclonic circulation could be prevalent causes of these water quality changes, considering that under maximum high river discharge conditions the western edge of the Mississippi plume remains more than 250 km away from the Flower Garden Banks (Walker, 1996).

During the summer of 1993, extreme flooding of the Mississippi and Atchafalaya Rivers resulted in lowered salinities and increased nutrient loadings within a 7,000-km^2 (2,702-mi^2) area extending 270 km (168 mi) eastward from the mouth of the Mississippi to the Florida Keys and along the U.S. East Coast. The buoyant flood plume did not reach the Flower Gardens despite the usual westerly flow. Instead, the flow of the runoff was deflected by dominant westerly and southwesterly winds and the anticyclonic flow of the Loop Current (Walker et al., 1994; Murray and Donley [eds.], 1996).

b. Potential Sources of Degradation

Primary sources of the potential degradation of offshore water quality in the Central and Western Gulf include coastal runoff, river discharges (210 million tons of sediments/yr [463 billion pounds of sediments/yr] for the Mississippi River [Milliman and Meade, 1983]), and effluent discharges from offshore activities such as OCS oil and gas development and marine transportation. Oxygen-depleted or "hypoxic" near-bottom waters have been identified in a large area of the northern Gulf. Often called the "dead zone," the areal extent of the oxygen-depleted waters has included up to 16,500 km^2 (6,370 mi^2) of bottom waters on the inner continental shelf from the Mississippi River Delta to the Texas coast, as far south as Freeport (Murray and Donley [eds.], 1996). Although primarily a summer phenomenon, the hypoxic zone off the Mississippi River has been identified as early as February and as late as October and may affect more than the bottom waters. Researchers have expressed concern that this phenomenon may be increasing in frequency and intensity. Although the causes of this hypoxic zone have yet to be conclusively determined, high summer temperatures combined with freshwater runoff contributing to stratification and carrying large amounts of excess nutrients (nitrogen) from the Mississippi River have been implicated. The hypoxic conditions vary spatially and seasonally depending on the flow of the Mississippi River discharge and are affected by physical features such as water circulation patterns, saltwater and freshwater stratification, wind mixing, tropical storms, and thermal fronts (Meier, 1997). Efforts are underway, facilitated by the Gulf of Mexico Program, to reduce the runoff and discharge of nutrients coming not only from the lower Mississippi River watershed, but also the upper Mississippi River and Ohio River watersheds (Meier, 1997). Impacts on phytoplankton and benthic ecosystems are being documented.

Red tides are a natural phenomenon, primarily occurring off southwestern Florida and Mexico. However, in 1996 there was a particularly widespread outbreak causing beaches to be closed and oyster beds to be shut down. The Texas Brown Tide, which appeared during the winter of 1989-1990 in Laguna Madre (south Texas), caused a significant decrease in light penetration, loss of seagrasses, and decline of zooplankton community and larval fish populations (DeYoe, 1995).

The northern Gulf coastal area has more point sources of contaminants than any other region in the country--more than 3,700 sites according to one assessment (Weber et al., 1992). Point sources contribute contaminants through discharges and accidental releases. More than half of the 3,700 sites identified were industrial facilities. About 460 of the 3,700 point sources are discharging directly into the waters of the Gulf or its estuaries. Of these 460 sites, 113 are municipalities discharging more than a billion gallons (more than 3.8 billion liters) a day of sewage effluent into Gulf coastal waters (Weber et al., 1992). Of the remaining point-sources discharging directly into Gulf coastal waters, 192 are in Texas, 79 in Louisiana, 30 in Mississippi, 29 in Alabama, and 17 in Florida. Most are petroleum refineries and petrochemical plants. The Houston Ship Channel is heavily impacted by point sources from both municipal and industrial facilities, especially oil, steel, and petrochemical industries, receiving waste waters from approximately 400 point-source discharges (Crocker and Koska, 1996).

Activities associated with offshore production and shipping activities are potential sources of discharge of treated waste waters and accidental spills of oil and other chemicals. By the end of 1995, approximately 5,000 production platforms had been installed in the northern Gulf (fewer than 1,000 of these platforms were subsequently removed), 32,000 wells had been drilled, and 208,350 km (129,469 mi) of pipeline installed. In addition, there has been a significant use of northern Gulf waters by the maritime industry to ship crude oil and petroleum products. Indeed, the northern Gulf has 4 of 10 busiest ports in the United States. Approximately 1.5 billion barrels of crude oil were imported through Gulf waters by tanker in 1993, about five times the volume piped from domestic production. In addition, about 236 million barrels of petroleum products were imported and 175 million barrels were exported via Gulf waters.

c. Chemical Contamination

Heavy metal and hydrocarbon contamination in the area of the Flower Gardens has been extensively examined at the site surrounding the gas production platform in HIES Block A-389 (near the East Flower Bank) (Fig. 2). Chemical contamination from this platform was characterized using both biological and geochemical parameters (Continental Shelf Associates, Inc., 1983 and 1985; Montagna and Harper, 1996; Kennicutt et al., 1996; Ellis et al., 1996; Carr et al., 1996; Peterson et al., 1996). Studies show that chemical contamination resulting from oil and gas operations within the 4-Mile Zone is geographically limited to areas immediately surrounding the platform. This is partly a consequence of the mandatory shunting of drilling fluids in the 4-Mile Zone to within 10 m of the seafloor. Relatively high concentrations of contaminants were found within a 500-m radius of the platform (mainly heavy metals originating from drilling discharges including barium, cadmium, silver, arsenic, mercury, lead, zinc; hydrocarbons were consistently found in low concentrations) (Kennicutt et al., 1996). Sediments and pore water sampled farther than 500 m away from the platform contained comparatively low to background trace metal levels. As expected, the most abundant contaminant was barium, since barite is a major component of drilling muds (as much as 90% dry weight). Drilling discharges generated large amounts of sand, the concentration of which decreased with an increased distance from the source. This sand concentration gradient correlated with gradients of the discharged barium, cadmium, and mercury. Lead and zinc were also found in relatively high concentrations, but probably originated from discharges other than drilling muds, such as produced water. Ten years after the initial discharge of drilling muds, trace metals other than lead still had the same distribution and concentration in bottom sediments ("stability of the contamination field"). This was thought to reflect the deep (130 m [427 ft]) and low energy seafloor environment surrounding the platform. Concentrations of lead continued to increase in sediments beyond the cessation of drilling (Kennicutt et al., 1996). Concentrations of silver, cadmium, mercury, lead, and zinc in sediments near HIES Block A-389 exceeded the Long and Morgan (1990) 50 percent bioeffects criterion (biological effects could be observed 50% of the time) (Kennicutt et al., 1996). Yet, these levels only constituted a highly localized and an overall minimal impact on macroinfauna (metazoans > 500 μm; polychaetes, mollusks, amphipods), meiofauna (metazoans 63-500 μm; nematods and harpactoid copepods), and macroepifauna (shrimp, crabs, echinoderms, molluscs, stomatopods). USEPA-determined toxic levels of sediment contaminants were concentrated within a 150-m (492-ft) radius of the platform. There was no significant evidence of impacts by toxicants on fish and large mobile invertebrates mostly because of their mobility and the lack of exposure to contaminants generated by HIES Block A-389. The bioavailability of the trace metals in sediments around the platform and their speciation have yet to be determined (Kennicutt et al., 1996). Furthermore, the long-term studies of coral populations at the banks conducted for more than 20 years (e.g., Bright and Pequegnat [eds.], 1974; Bright et al., 1983 and 1984; Gittings et al., 1992a and 1992b; Continental Shelf Associates, 1997) show no evidence of human-induced change other than mechanical disturbances.

d. Current Water Quality Status

Water quality within the 4-Mile Zone has supported thriving benthic and pelagic resources at the Flower Gardens despite localized and regional sources of chemical contamination. Dispersion and dilution of contaminants are thought to contribute significantly to the favorable water quality conditions within the 4-Mile Zone. This is probably the case considering the dynamic nature of the shelf edge location of the Flower Gardens, the large volume of water contained within the LATEX shelf (6,250 km^3 = 2,500 $km^3 \times 2.5$ annual turnovers [$2.28 \times 10^{14} ft^3$] [Dinnel and Wiseman, 1986]) including the 175 km^3 (6.2×10^{12} ft^3) of water within the 4-Mile Zone (70 $km^3 \times 2.5$ annual turnovers), the stringent directives of the Topographic Features Stipulation implemented in 1973 (USDOI, MMS, 1997a), and the provisions imposed by the designation of the banks as a National Marine Sanctuary in 1992. With additional provisions made to the USDOI Topographic Features Stipulation specifically for the Flower Garden Banks, an elevated level of natural resource protection was attained. The added provisions require that (1) the No Activity Zone be based on the 100-m (328-ft) isobath instead of the 85-m (279-ft) isobath and be defined by the "1/4 1/4 1/4" system (a method of defining a specific portion of a block) rather than the actual isobath and (2) there be a 4-Mile Zone instead of a 1-Mile Zone within which all drill cuttings and drilling fluids are shunted to within 10 m (33 ft) of the bottom (USDOI, MMS, 1997a). The stipulation applied to the Flower Gardens prevents activity within the 100-m isobath by forbidding structures, drilling rigs, pipelines, or anchoring. Further and continued studies of water quality and living resources at the Flower Gardens would allow for the long-term and objective assessment of human-induced impacts. This would also allow for a continued evaluation of the effectiveness of protective measures.

6. COMMERCIAL FISHING

Ann Scarborough-Bull

a. Status of Commercial Fishing at the Flower Gardens

Fishermen have longlined at the East and West Flower Garden Banks and other prominences along the shelf break off Texas since the late 1800's. Indeed, fishermen of the turn of the century gave the Flower Gardens their names based on the colors they could see from the surface, as well as the colorful plants and animals they often hooked and brought to the surface. Although there are a number of economically important demersal and pelagic species associated with the Flower Garden Banks, the commercial fish harvest from the area has generally consisted of snappers and groupers. Commercial fishing with bottom longlines, traps, nets, bottom trawls or any other gear other than conventional hook and line is no longer allowed within the Sanctuary boundaries (slightly larger than the area encompassed by the MMS No Activity Zone). Commercial fishing has always been most active on deeper portions of the banks in 50-100 m (164-328 ft) water depths, where snappers are encountered in some abundance. This fishing on the fringes may have been due in part to those species being over-harvested from the small reefal cap areas. Anecdotal evidence of increasing populations of snappers and groupers on the reefs caps within the Sanctuary boundaries supports this conclusion.

The fishing fleets that frequent the area consist of vessels from as far away as the panhandle of Florida and Brownsville-Port Isabel, Texas (USDOC, NOAA, 1991; USDOC, NMFS, 1993b). It is not known what amounts of reef fishes are landed from the Flower Garden Banks and vicinity. Landings into Texas ports of snappers and groupers from 3 to 200 mi (5 to 322 km) offshore are listed in Table 2. It is likely that a significant portion of these landings comes from prominences along the shelf break, including the Flower Garden Banks. Anecdotal information indicates that continuous low to moderate levels of longlining occur around the Flower Garden Banks, with an occasional spike in activity during the late winter, early summer, and after the opening of the commercial snapper season in September, at which time no fewer than five longlining vessels with Spanish- and English-speaking crews have been seen illegally fishing in the Flower Garden Banks Sanctuary.

Table 2. Texas 1996 Landings from 3 to 200 Miles (5 to 322 km) Offshore, Selected Species in Pounds (thousands) and U.S. Dollars (thousands). (Source: USDOC, NMFS Fisheries Statistics and Economics Division, 1996)

Species	Weight (lb)	Value (U.S. $)
Red snapper	1,105	2,072
Other snapper	146	275
Grouper	39	79
Total	1,290	2,426

b. Effects of Hydrocarbon Development on Commercial Fishing

Effects on commercial fisheries from activities associated with oil and gas exploration and production in the vicinity of the Flower Garden Banks could come from emplacement of production platforms, underwater OCS obstructions, production platform removals, seismic surveys, oil spills, and discharges of drilling muds and produced waters.

The emplacement of a production platform, with a surrounding 100-m (328-ft) navigation safety zone, in water depths less than 152 m (500 ft) results in the loss of approximately 6 ha of bottom trawling area to commercial fishermen and causes space-use conflicts. Underwater OCS obstructions, such as pipelines, cause gear conflicts that result in losses of trawls and shrimp catch, business downtime, and vessel damage. However, all pipelines in water depths less than 61 m (200 ft) must be buried, at least 1 m (3 ft) below the bottom, and their locations made public knowledge (Alpert, 1990). Nearly 97 percent of trawl fishing in the CPA occurs in water depths less than 61 m and certainly not in the vicinity of such hard-bottom areas as the Flower Garden Banks, but does occur near Stetson Bank (Louisiana Dept. of Wildlife and Fisheries, 1992). Although Gulf fishermen are experiencing some economic loss from gear conflicts, the economic loss for a fiscal year has historically been less than 0.1 percent of the value of that same fiscal year's commercial fisheries landings. In addition, most financial losses from gear conflicts are covered by the Fishermen's Contingency Fund.

Lessees are required to remove all structures and underwater obstructions from their leases in the Federal OCS within one year of the lease relinquishment or termination of production. However, doing so by means of explosive charges, the traditional means of removal, would produce concussive forces that are lethal to fish with internal air chambers (swim bladders). The explosive removal would be particularly lethal to the demersal fish or those in close association with the platform being removed (Young, 1991; Scarborough-Bull and Kendall, 1992).

Within the past decade, stocks of reef fish have declined in the Gulf. There is some concern over a possible connection between this decline and the explosive removal of platforms. To examine this issue, MMS entered into a formal Interagency Agreement with NOAA/NMFS and is investigating fish death associated with structure removal. This study attempts to relate the relationship of fish deaths from platform removals to the status of reef fish stocks in the Gulf of Mexico. Preliminary information suggests that less than 1 percent of the annual harvest of red snapper from the Gulf of Mexico can be attributed to explosive platform removals.

The airgun-generated acoustic pulses used in seismic surveys have little effect on even the most sensitive fish eggs set 5 m (16 ft) from the source (Chamberlain, 1991; Falk and Lawrence, 1973). Closer than 5 m, fish with swim bladders may be impacted. Within one meter, injuries may be fatal. In general, the acoustic pulses from airguns have relatively little effect on marine invertebrates, presumably due to their lack of air spaces such as a swim bladder. Available scientific information concerning the effects of acoustic airgun sources on fish eggs and larvae indicates that commercial fishery resources are little disturbed by seismic surveys (Wingert, 1988).

Adult fish are likely to actively avoid an oil spill, thereby limiting the effects and lessening the extent of damage (Baker et al., 1991; Malins et al., 1982). Direct effects of spilled oil on fish may occur, however, through the ingestion of oil or oiled prey, through the uptake of dissolved petroleum products through the gills and epithelium by adults and juveniles, and through the death of eggs and the decreased survival of larvae (NRC, 1985). Upon exposure to spilled oil, liver enzymes of fish oxidize soluble hydrocarbons into compounds that are easily excreted in the urine (Spies et al., 1982). Due to their limited mobility and metabolism, floating eggs and larvae and most juvenile fish are killed when contacted by spilled oil (Linden et al., 1979; Longwell, 1977). Ordinary environmental stresses may increase the sensitivity of fish to oil toxicity. These stresses may include changes in salinity, temperature, and food abundance (Evans and Rice, 1974; NRC, 1985).

For OCS-related oil spills to have an effect on commercial fishery resources in the vicinity of the Flower Garden Banks, eggs and larvae would have to be abnormally concentrated in the immediate spill area. Oil components also would have to be present in highly toxic concentrations when both eggs and larvae are in the pelagic stage (Longwell, 1977). There is no evidence at this time that commercial fisheries in the Gulf have been adversely affected on a regional level by spills or chronic oiling.

Drilling muds contain materials toxic to commercial fishery resources; however, the plume disperses rapidly and is usually undetectable at distances greater than 3,000 m (9,483 ft) (e.g., Kennicutt et al., 1996). In addition to toxic trace elements and hydrocarbons in produced waters, there are additional components and properties, such as hypersalinity and organic acids, that have a potential to affect commercial fishery resources adversely. Produced waters that are discharged offshore are diluted, dispersed, and undetectable at a distance of 3,000 m (9,843 ft) from the discharge point, and no detectable effects on water column organisms are encountered (Harper, 1986; Rabalais et al., 1991).

7. RECREATION

Kenneth J.P. Deslarzes and Villere C. Reggio

Fishermen discovered the Flower Gardens and named the banks after the colorful tropical fauna they saw and caught. By 1950, navigational charts clearly located the banks. Thereafter, the Flower Gardens gained in popularity as fishermen, scientists, journalists, boaters, and industry increasingly visited the banks. Recreational fishing and SCUBA diving probably started to grow in the late 1950's to reach current levels estimated at 3,000 divers per year and more than 150 boats per year (USDOC, NOAA, 1991; Dr. Stephen Gittings, NOAA/NOS/SRD, pers. comm., 1997). Recreational divers and hook-and-line sports fishermen are the primary "users" of the banks today. The divers use the portion of the banks that is shallower than 36 m (118 ft) (high-diversity reef), and the fishermen probably focus on areas where desirable game fish are most abundant (i.e., the reef drop-off area and deeper). Furthermore, the number of recreational and commercial fishing boats per year within the 4-Mile Zone could well increase as they use fishing opportunities created by an increasing number of structures (platforms) emplaced nearby. The unique and varied biota of the banks should continue to attract SCUBA divers from all the Gulf States, especially Texas and Louisiana, as well as other parts of the Nation and foreign countries. Since its designation as a National Marine Sanctuary, broader national interest in the banks is attracting many more divers from throughout the nation. Charter dive services are available from Texas and Louisiana ports with peak visitation in July, August, and September.

Both private boats, generally greater than 9 m (30 ft) in length, and charter boats (up to 30 m [100 ft]) visit the site regularly and often stay overnight because of the distance and time involved in reaching either the East or West Flower Garden Bank.

Permanent mooring buoys have been strategically installed in recent years to encourage the nondestructive use and appreciation of the reef resources. Anchoring directly on the reef would otherwise cause substantial scarring and breakage of coralline substrate (e.g., living coral heads) by anchors, and anchor lines or chains. An example of such damage was documented by Bright (1983) and Gittings and Bright (1986). In fact, recreational divers spearheaded the funding and logistics required to install the permanent mooring buoys at the Flower Gardens, which probably constituted a major push toward the designation of the Flower Gardens as a National Marine Sanctuary. Volunteers from the local diving community (Texas), Gulf Reef Environmental Action Team (GREAT), and Rinn Boats, Inc. joined forces with NOAA (Florida Keys NMS) personnel, TAMU researchers, and members of the MMS dive program to install these buoys. Their installation was a key conservation effort toward protecting the Flower Gardens, and served as one of the strongest statements made by recreational divers as they sought sanctuary status for the Flower Gardens.

The contribution of recreational divers to the protection and documentation of the banks was already significant in the early 1960's as members of the Houston Underwater Club took part in the "discovery" of the Flower Gardens coral reefs. Thirty years later, recognizing the value of this natural heritage, recreational divers continue to successfully push for conservation efforts that protect the banks. It was they who requested that specimen collecting, trash disposal, anchoring, and spearfishing should be prohibited at the banks. Thanks to their observations and records, recreational divers were able to alert scientists with information about coral mass spawning, the schooling of hammerheads, whale sharks, sharks, mantas, and sea turtles. Successful and recent collaborations between researchers and recreational divers at the banks include the monitoring of fish populations, elasmobranchs, turtles, and spawning of corals (Flower Garden Banks National Marine Sanctuary, 1997). Furthermore, the recreational diving community has significantly contributed to the funding of research at the Flower Gardens by sponsoring graduate students through organizations including Seaspace (Houston), the Houston Underwater Club, the Texas Gulf Coast Council of Dive Clubs, and GREAT.

The MMS-funded studies at the banks through the 1970's and mid-1980's to formulate an optimal and objective Topographic Features Stipulation that applies to the Flower Gardens. The stipulation was introduced in 1973 and responded to the scientific data, the concerns expressed by the public, and the needs of the industry. The protection of the banks has been a success, considering the unchanged and healthy condition of the coral populations in terms of coral cover, diversity, and growth documented by numerous studies since the 1970's. The recreational community certainly contributed to the continued well-being of the Flower Gardens resources and so did restrictive regulations on oil and gas development by MMS, NOAA's National Marine Sanctuary Program, the U.S. Coast Guard, the National Marine Fisheries Service, and the U.S. Environmental Protection Agency.

With 56 square miles under special protective management by NOAA, along with Government-sponsored shoreside educational programs and activities aimed at focusing public attention, interest, and appreciation of this special marine area (e.g., Flower Gardens educational airport display, conferences, a *National Geographic* article [Chadwick, 1998], workshops, world wide web, Sanctuary designation anniversary events), recreational interest and visitation are likely to grow with time and economic prosperity.

8. MILITARY WARNING AREA W-147A

Kenneth J.P. Deslarzes

A portion of Military Warning Area W-147AB (sea surface to 15,240 m [50,000 ft] altitude) contains the eastern half of the 4-Mile Zone (Figs. 2 and 3; USDOI, MMS, 1997c). This warning area airspace is controlled by the Federal Aviation Administration (FAA). The U.S. Navy and Air Force conduct intercepts and air-to-air combat maneuvers (electronic) within the W-147A area.

The nature of military operations dictates that some oil and gas activity may have to be delayed on some occasions. To promote a compatible joint usage of an area, negotiations between the Department of the Interior and the Department of Defense have resulted in established procedures to resolve all conflicts prior to any offshore activity. As part of the mitigating measures required for oil and gas activities, a stipulation is attached to leases within the warning area. The stipulation contains a liability disclaimer and requires operators to control their electromagnetic emissions so as not to interfere with Defense activities. The stipulation also requires that the operator enter into an agreement with an established Department of Defense contact concerning the coordination of boat and air traffic into the warning area. The address for contact is Federal Aviation Administration, Houston Air Route Traffic Control (ARTC) Center, 16600 John F. Kennedy Boulevard, Houston, TX 77032, Telephone: (281) 230-5536 or 5630. The coordination requirement of this stipulation would be made a condition of the plan approval for operations on any leases that are located within the W-147A area but that may have been leased without the stipulation. The imposition of the terms of the stipulation should effectively mitigate any impacts that could result from military activities in the area.

9. HYDROCARBON DEVELOPMENT

Kenneth J.P. Deslarzes and Joseph R. Hennessy

a. Onshore Bases, Platforms, and Pipelines

The 4-Mile Zone surrounding the Flower Gardens currently contains 10 production platforms and approximately 161 km (100 mi) of pipeline (half of which are dedicated oil lines). There are 20 pipelines that either originate within, terminate within, or transit the 4-Mile Zone of the East and West Flower Garden Banks (Table 3). From 1984 to 1997 thirteen pipelines were added to the 4-Mile Zone. The number of pipelines will probably change considering, for example, the recent increase in exploratory activity near the West Flower Garden Bank. High Island, South Addition (HIS) Blocks A-573 and A-596 are located in the western portion of the 4-Mile Zone and have been a significant source of the hydrocarbon production for this general area. From 1973 to June 1997 oil production totaled 84.4 MMbbl of oil and 445 Bcf of gas. HIES Block A-382 was the source of relatively large amounts of hydrocarbon production: 28.2 percent of the oil and 15.9 percent of the gas production in this area. In the 1990's, HIES Blocks A-379, A-384, and A-385, three blocks located within the 4-Mile Zone and close to the West Flower Garden Bank 1-Mile Zone, yielded 8.8 percent of the oil and 13.1 percent of the gas produced within the 4-Mile Zone area (including HIS Blocks A-573 and A-596).

Table 3. Pipelines within the 4-Mile Zone of the East and West Flower Garden Banks.

Seg./ROW #	Size (in)	Service	Origin	Destination	Length (ft)	Operator
6669/-G05238	10	Gas	HIES A-376 "A"	HIES A-356 SSTI	37,718	Trunkline Gas Co.
8256	10	Bulk Oil	HIES A-382 "F"	HIS A-595 "CF"	25,875	Mobil Producing
9109/-G12318	10	Gas/Condensate	HIES A-384 "A"	HIS A-573	49,408	Transco
10252/-G14299	8	Oil	HIES A-379 "A"	HIS A-521 SSTI	71,946	Sun Operating
6870/-G05150	6	Oil	HIES A-376 "A"	HIS A-546 SSTI	106,807	Amoco Pipeline
10308	6	Bulk Gas	HIES A-385 "A"	HIES A-379 "A"	18,454	Oryx Energy
10309	8	Bulk Gas	HIES A-384 "A"	HIES A-379 "A"	4,629	Oryx Energy
10310	8	Gas	HIES A-379 "A"	HIES A-384 "A"	4,533	Oryx Energy
9328/-G12690	4	Bulk Gas	GB 224 Well 5	HIES A-384 "A"	75,439	Oryx Energy
9412/-G13219	8	Oil	GB 189 "A"	HIES A-377 SSTI	180,632	Texaco Pipeline
10196	8	Gas	HIES A-376 "B"	HIES A-376 "A"	10,212	Anadarko
10197	4	Gas/Oil	HIES A-376 "B"	HIES A-376 "A"	10,217	Anadarko
8299/-G09359	10	Gas/Condensate	HIES A-389 "A"	HIES A-332 SSTI	74,250	Koch Industries
9489/-G13244	4	Bulk Gas	HIES A-373 Well 1	HIES A-368 "A"	18,400	Enron O&G
6757/-G05266	12	Gas	HIES A-368 "A"	HIES A-370 SSTI	27,557	ANR Pipeline
11089	8	Bulk Gas	HIES A-385 "D"	HIES A-384 "A"	16,705	Oryx Energy
11090	8	Bulk Gas	HIES A-385 "D"	HIES A-384 "A"	16,705	Oryx Energy
11114	6	Bulk Oil	HIES A-379 "E"	HIES A-379 "B"	13,738	Oryx Energy
11115	6	Bulk Oil	HIES A-379 "E"	HIES A-379 "B"	13,738	Oryx Energy
11116	2	Gas Lift	HIES A-379 "B"	HIES A-379 "E"	13,738	Oryx Energy

10. SHIP TRAFFIC

Kenneth J.P. Deslarzes

No fairways or shipping anchorage areas are located in the Flower Gardens 4-Mile Zone area (USDOI, MMS, 1997b). The nearest fairway is located immediately to the south (Figs. 2 and 3; USDOI, MMS, 1997b). This fairway is traveled by a large proportion of the vessels using Texas coastal ports. The amount of ship traffic within the Flower Gardens' 4-Mile Zone and the adjacent fairway is best observed from platforms, such as Mobil's HIES Block A-389 gas production platform, located southeast of the EFGB (Fig. 2). Ship traffic observations made from Mobil's HIES Block A-389 platform during the 1990 to 1996 time period indicate 1-2 service vessels (supply, crew, and utility vessels) every other day, 3-5 ships/week (mostly supertankers, some cargo), 1 barge/month, and 10 fishing vessels/week (vessel lengths: 21-30 m [70-100 ft]) mostly from April to June and October to December (Mr. Hector Guttierez, formerly on Mobil's HIES Block A-389 platform, pers. comm., 1997). Seismic ships as well as fishing vessels were frequently seen navigating directly over the EFGB. Tankers usually navigated on the fringes of the bank and stayed east of the bank when traveling north-south, and south of the ba-nk when traveling east-west. Incidences of anchoring at the EFGB were reported mostly for commercial fishing vessels. Anchoring incidences by other types of vessels (including tankers) probably took place more frequently on the WFGB, considering its more southerly location and proximity to the fairway.

With increased hydrocarbon development within the 4-Mile Zone, service vessel traffic will probably increase between onshore support bases and offshore facilities. This increase could result in congestion in certain areas, and possibly collisions, which could result in personal injury or potential spills. At night or during rough weather, fog, or heavy seas, ships not using established fairways could collide with an uncharted or unmanned exploratory drilling rig or platform. However, significant impacts to shipping are not expected since no structures are permitted in fairways and offshore structures are required to be marked with navigational lights, and unmanned platforms are required to be equipped with foghorns through U.S. Coast Guard regulations (33 CFR 67). The temporary nature of the drilling rigs and platform removal requirements also mitigate potential long-term impacts to shipping. As positive impacts, offshore structures serve as navigational aids by radar contact and marking requirements in 30 CFR 250.115 (Identification) and as areas of safety for small boat operators during storms (Gramling et al., 1995). Offshore operators also often provide assistance during emergencies.

11. POTENTIAL ENVIRONMENTAL IMPACTS

Kenneth J.P. Deslarzes and Dagmar C. Fertl

a. Impacts on the Biological Environment

The potential impact-producing factors on the northern Gulf topographic features in general are anchoring (refer to Section IV.A.3.b.(1) in USDOI, MMS [1997a]), seismic surveys (refer to Section IV.A.2.a.(1) in USDOI, MMS [1997a]), effluent discharges (refer to Section IV.A.3.d. in USDOI, MMS [1997a]), oil spills (refer to Section IV.A.3.h.(2) in USDOI, MMS [1997a]), blowouts (refer to Section IV.A.3.h.(1) in USDOI, MMS [1997a]), structure removal (refer to Section IV.A.3.c. in USDOI, MMS [1997a]), and structure emplacement (refer to Section IV.A.3.a. in USDOI, MMS [1997a]). These disturbances have the potential to disrupt and alter the environmental, commercial, recreational, scientific, and aesthetic values of the Flower Garden Banks.

Anchoring

The anchoring of pipeline lay barges, drilling rigs, or service vessels, as well as the emplacement of structures (e.g., pipelines, drilling rigs, or production platforms), would potentially result in mechanical disturbances of the benthic environment at the Flower Gardens. Anchor damage has been shown to be a significant threat to the biota of the offshore banks in the Gulf (Bright and Rezak, 1978; Rezak et al., 1985). Such anchoring damage, however, would be prevented within any given No Activity Zone by compliance with the Topographic Features Stipulation and Sanctuary regulations. Over the past 20 years there have been several incidences at the Flower Gardens of significant impacts caused by the anchoring of large industry vessels and fishing vessels, particularly in shallow parts of the banks (Gittings et al., 1996). Foreign cargo vessels and oceangoing tugs have, on occasion, anchored at the Flower Gardens without knowing of the anchoring restrictions. This continues to be a problem as U.S. National Marine Sanctuary and MMS regulations have yet to be routinely placed on foreign navigational charts. Enforcement by the U.S. Coast Guard and the Sanctuary has prevented extensive anchor damage caused by illegally anchored vessels. Furthermore, hailing of vessels preparing to illegally anchor by dive charter boats and platform operators has also significantly contributed to damage prevention. Permanent mooring buoys installed on the banks have also aided in preventing reef breakage that would have been otherwise caused by vessels anchoring directly on the reef (30 m [100 ft] or less). Since 1994, there have been at least three large vessel anchoring incidents at the Flower Gardens (a 150-m [500-ft] freighter at the WFGB, an oceangoing tugboat at the WFGB, and a snapper fishing boat at the EFGB) (Dr. Stephen Gittings, NOAA/NOS/SRD, pers. comm., 1997). A closely related type of damage occurred in June 1997 when cables between a tow and barge scarred, cracked, cut, and toppled coral heads over a 200-300 m (656-984 ft) distance at the WFGB between permanent Buoys #5 and #3. There is also a known site of extensive anchor damage on the WFGB near Buoy #5. The circumstances of this damage are unknown. The impacts of future anchoring incidents at the Flower Gardens would be best documented by comparing the damaged reef area to a baseline record.

Seismic Surveys

Prior to 1989, explosives (dynamite) were used to generate seismic pulses. Explosives have been replaced by piston-type acoustic sources that generate superior acoustic signals and that do not cause the damaging environmental impacts associated with explosives. Acoustical energy from explosives is characterized by rapid rise time (high velocity), high peak pressure, and rapid energy decrease. Seismic airguns are considered nonexplosive and have long rise times to peak pressure (low velocity). In contrast with explosives, piston-type acoustic sources used for seismic surveys have been shown not to affect most marine organisms (Linton et al., 1986). Seismic surveys at the Flower Gardens are not prohibited by Sanctuary regulations and will be allowed as long as they do not harm Sanctuary resources (Gittings et al., 1997). The number of recent prelease geophysical permits in the vicinity of the Flower Gardens has remained small. Four 2-dimensional and six 3-dimensional surveys have been completed since 1992. A survey of the effects of a 3-dimensional seismic survey on reef resources at the Flower Gardens showed that fish and manta rays were not driven away from the high-diversity zone of the reef or disturbed in any apparent manner during a pass of a seismic survey vessel within one mile of the reef. Activity of benthic organisms also appeared unchanged during the passage of the seismic array (Dr. Stephen Gittings, NOAA/NOS/SRD, pers. comm., 1997). The graphic presentation of underwater power curves of this type of survey showed that impacts would be restricted to within a few meters from the acoustic source.

State-of-the-art, 3-dimensional seismic data have enabled industry to identify, with greater precision, where the most promising hydrocarbon prospects are located. This 3-dimensional technology is also being used in developed areas to identify bypassed hydrocarbon-bearing zones in currently producing formations and new productive horizons near or below currently producing formations. It is also being used in developed areas for reservoir monitoring and field management. Prelease surveys will probably decline in number as data coverage becomes complete, although some previously surveyed areas may be resurveyed to gather better data as technology advances.

Postlease seismic surveying may include high-resolution, 3- or 4-dimensional surveying. High-resolution surveying is done on a site-specific or lease sale basis or along a proposed pipeline route. These surveys are used to identify potential shallow geologic hazards for engineering considerations and site planning for bottom-founded structures. They are also used to identify environmental resources such as hard-bottom areas, topographic features, potential chemosynthetic community habitat, or historical archaeological resources. Postlease high-resolution seismic surveying is assumed to be done once for each lease that is drilled.

Deep seismic surveying (3-dimensional as described above, or 4-dimensional, which is a series of 3-dimensional surveys collected over time) may also be done postlease. The 3-

dimensional seismic technology allows more accurate identification of potential reservoirs, increasing success rates for exploratory drilling and aiding in the identification of additional reservoirs in “known” fields. The 4-dimensional seismic surveying is used for reservoir monitoring and management, as well as to identify bypassed “pay zones.” Through time-lapsed surveys, the movement of oil, gas, and water in reservoirs can be observed. Postlease deep seismic surveying may occur periodically throughout the productive life of a lease.

Effluent Discharges

The discharge of drilling muds and cuttings (10,542 bbl/exploratory well and 7,436 bbl/development well [USEPA, 1993]) could impact biological resources of the Flower Gardens particularly at drill sites located in blocks directly adjacent to the No Activity Zones. Potential impacts include increased water column turbidity and local accumulations of contaminants, causing the smothering of sessile benthic invertebrates, the short-term and local mortality of planktonic organisms, reduced primary productivity, and the clogging of the filter-feeding mechanisms or the respiratory surfaces of zooplankton. Yet, the degree of such impacts would be restrained by discharge limitations set by the Topographic Features Stipulation (namely the shunting requirement within the 4-Mile Zone) and the special restrictions imposed by the USEPA general NPDES.

Produced waters could also represent a significant potential source of impact on the biota of topographic features, considering that they constitute the largest single discharge during routine oil and gas operations (typically 68 bbl water/day gas well and 450 bbl water/day oil well). The MMS records of produced water discharges for the eight leases within the 4-Mile Zone indicate that from 1980 to 1997 a total of 42,675,158 bbl were discharged (average = 520,429 bbl water/yr; stdev = 656,542 bbl water/yr; n = 82) (1980 is the earliest record of produced water in the 4-Mile Zone). Sixty percent of the total produced water discharge occurred in the last four years. The USEPA general NPDES permit’s restrictions on the discharge of produced water limit the impacts on biological resources of topographic features. The recent evaluation of offshore produced-water discharges, conducted by Neff (1997) during a bioaccumulation study approved by USEPA, assessed that metals discharged in produced water would at worst affect living organisms found in the immediate vicinity of the discharge, particularly those attached to the submerged portion of platforms. Arsenic, in particular, was found to bioaccumulate in 25 percent of the fish analyzed (Neff, 1997). Naturally occurring radioactive material in produced water was not found to bioaccumulate in marine animals (2 species of molluscs, 5 species of fish). Polycyclic aromatic hydrocarbons (PAH’s) in produced water can be toxic to organisms near the discharge point and in underlying sediments, but because high molecular PAH’s are usually in such low concentrations in produced water, they were found to pose little threat to marine organisms and their consumers, and were anticipated not to biomagnify in marine food webs. Monocyclic hydrocarbons and other miscellaneous organic chemicals are known to be moderately toxic but do not bioaccumulate in marine organisms, and are not known to pose a risk to their consumers. A detailed description of the impacts of produced waters on water quality and seafloor sediments is presented in Section IV.D.1.a.(3) in USDOI, MMS (1997a).

Oil Spills

Dodge et al. (1995) observed that a 2-m (7-ft) deep reef environment off the Caribbean coast of Panama was negatively impacted by dispersed oil (probably at a concentration greater than 10 ppm) compared to a control site and to a site exposed to oil alone. The oil exposure reduced the cover of all reef organisms as much as 40 percent, particularly that of live, substrate binding sponges. Ten years later, the same impacted sites regained or even exceeded their respective pre-impact live cover. Guzman et al. (1991), however, found that a prolonged exposure to oil alone, as well as a chronic exposure to oil, greatly depressed both the coverage and growth rates of reef corals within a 6-m deep reef area along the Caribbean coast of Panama. Also, Bak (1987) showed that reef corals on the shallow (4-6 m [13-20 ft]) southwestern shore of Aruba (Netherlands Antilles) had incurred mortality, decreases in live coral cover (by as much as 70%), reductions of species diversity (as many as 10 out of 24 species missing), and reef structural changes over a 10- to 15-km (6- to 9-mi) downstream shore length as a result of the exposure to long-term (1929-1985) and chronic oil spills, dispersed oil, and refinery discharges. *Diploria strigosa* appeared to be more resilient to the effects of oil pollution than other reef coral species, since its cover did not seem to be affected by the pollutants. Therefore, it has been shown that oil as well as dispersed oil has the potential to impact directly oiled reef coral communities substantially, particularly when the exposure is chronic and long term. The time needed for the recovery of such impacted reefs could exceed 10 years and would depend on the frequency and impact of future human-made and natural disturbances.

Oil spills potentially affecting the Flower Gardens and their biological communities could result from surface and seafloor spills. Surface oil spills may occur as a result of tanker spillages or platform spills. Spills on the seafloor could be caused by a pipeline rupture or a well blowout. Both surface and subsurface spills could result in a steady discharge of oil over a long period of time. Oil from a surface spill can be driven into the water column; measurable amounts have been documented down to a 10-m (33 ft) depth, although modeling exercises have indicated such oil may reach a depth of 20 m. At this depth, the oil is found at concentrations several orders of magnitude lower than the amount shown to have an effect on corals (Lange, 1985; McAuliffe et al., 1975 and 1981; Knap et al., 1985). Because the crests of the Flower Gardens are found below 15 m (49 ft), no concentrated oil from a surface spill could reach their sessile biota. Yet, a spill would probably cause impacts on planktonic organisms in the upper 10 m of the water column, including a temporarily reduced primary productivity, and the clogging of the filter-feeding mechanisms or the respiratory surfaces of zooplankton, thereby causing their mortality. Furthermore, turtles, cetaceans, elasmobranchs, and fish that surface or occupy the uppermost portion of the water column could also be affected by spilled oil.

An Oil Spill Risk Analysis (OSRA) run by MMS for the northwestern Gulf (500 locations) produced 3-, 10-, and 30-day spill contact probability contours (expressed in percentages) encircling the Flower Gardens Sanctuary. These were run for each season and for all seasons combined. Findings of the analysis led MMS to require that oil and gas operations occurring within the 10 percent or higher, 3-day spill contact probability contour inform the Sanctuary of spills needing countermeasure responses. This would enable initiation of the monitoring of the effects of the spilled oil on Sanctuary resources (Fig. 21). The Sanctuary is not informed of spills not requiring countermeasures, as they probably do not jeopardize Sanctuary resources.

A subsurface oil spill (pipeline spill) could reach one or both of the Flower Garden Banks and could impact biota contacted by the oil. Such impacts could be severe and long-lasting, including loss of habitat, loss of biodiversity, loss of live coral coverage, destruction of hard substrate, change in sediment characteristics, and reduction or loss of one or more commercial and recreational fishery habitats. Because of these potential impacts, MMS requires heightened pipeline safety measures, obligating operators in the 4-Mile Zone to shut-in pipelines when the pressures drop 10 percent below the normal low range ("10% Pressure Safety Low"). Subsurface spills from pipelines or blowouts, however, could result in the formation and settling of oil-saturated material, and oil-sediment particles could come into contact with living animal or plant tissue. Yet, most of a subsurface spill should rise to the surface, and any oil remaining at depth would probably be swept clear of the banks by currents moving around the banks (Rezak et al., 1983). Should any of the spilled oil come in contact with adult sessile biota, effects would be primarily sublethal, with few incidences of actual mortality. The sublethal effects could, however, be long-lasting and affect the resilience of coral colonies to natural disturbances (e.g., elevated water temperature, diseases) (Jackson et al., 1989). Continental Shelf Associates, Inc. (1992) modeled the potential impacts of a pipeline rupture using worst case scenario and assumptions (10,000 bbl spilled over 2-7 days) to maximize the estimates of dispersed oil concentrations reaching four topographic features (East Flower Garden Bank, West Flower Garden Bank, MacNeil Bank, and Rankin Bank). In their model, Continental Shelf Associates, Inc. estimated that the worst case concentrations of crude oil reaching the four banks would be sublethal to the corals and much of the other biota present. Continental Shelf Associates, Inc. (1994) also investigated the potential effects of oil spilled from a platform-pipeline complex proposed for installation near the Flower Garden Banks using a worst case scenario of high oil concentrations. Twenty-four different spill scenarios from two platforms and three pipelines were modeled (the maximum concentration of oil reaching the East Flower Garden Bank). The most damaging scenarios resulting from this modeling effort included a 2,617-bbl/day and a 1,000-bbl/day spill, both lasting 30 days and both occurring at the same platform location. Although the model predicted no acute toxicity to reef coral colonies, the values were within the range of acute toxicity to embryos and larvae of fish, corals, and other invertebrates.

In 1996, the Regional Response Team for Region VI (including the coastal States of Texas and Louisiana), in consultation with the Flower Gardens Sanctuary and MMS approved, the use of chemical dispersants on surface oil spills in what had been named "exclusion zones" of the northern Gulf such as the Flower Garden Banks National Marine Sanctuary (revised *Federal On-Scene Coordinator Preapproved Dispersant Use Manual--Region VI Oil and Hazardous Substances Pollution Contingency Plan*). Depending on the toxicity of the dispersant used, tradeoffs to responding to surface oil spills using dispersants include impacts on pelagic organisms and on the adult as well as the larval stages of benthic

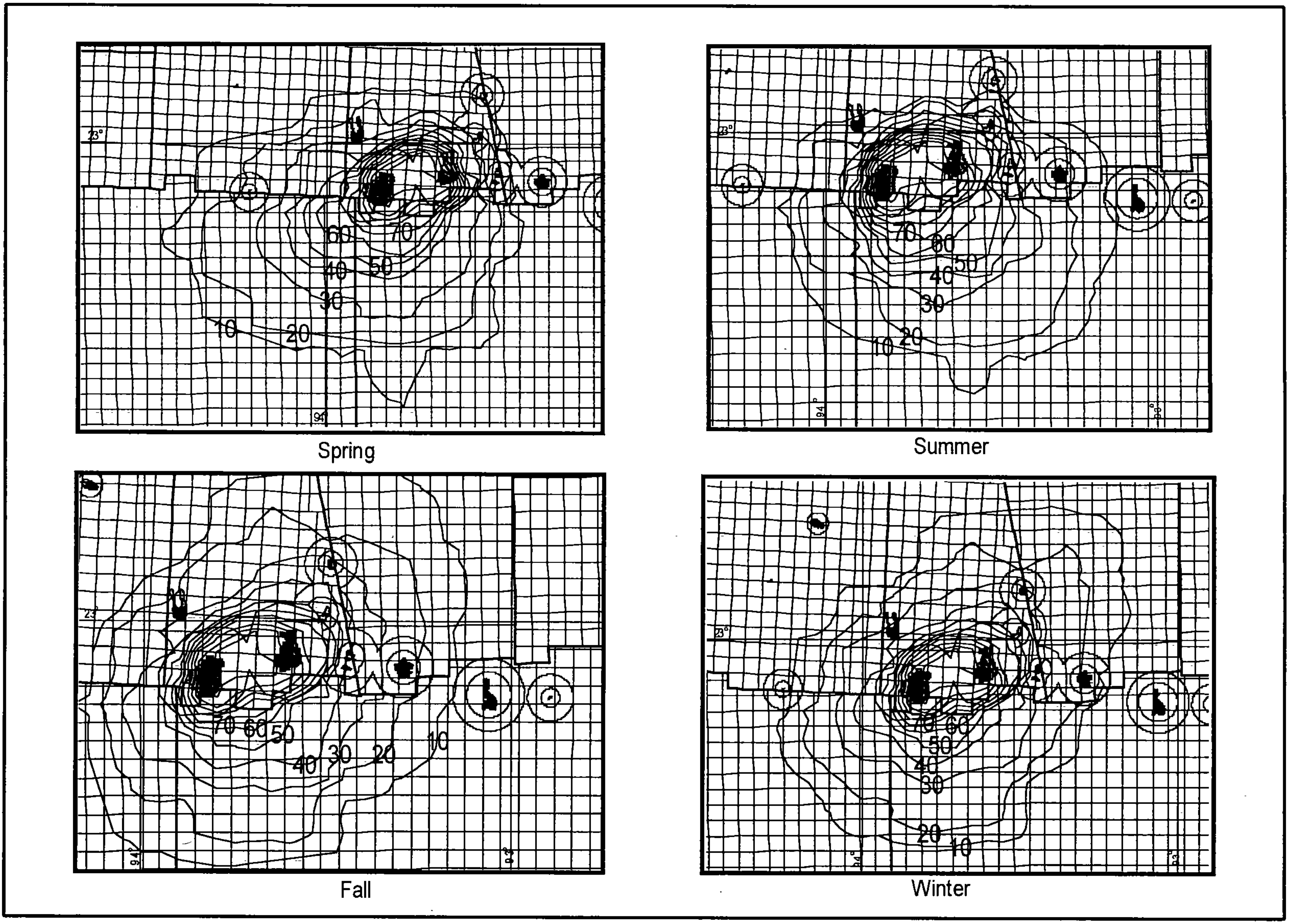

Figure 21. MMS Oil Spill Risk Assessment (OSRA) 3-day spill contact probability contour lines by season for the 4-Mile Zone surrounding the Flower Garden Banks.

organisms on topographic features. Gulf of Mexico oil is usually dispersed with Corexit 9527 and would reach benthic communities at very low concentrations (less than 1 ppm), taking into account the depth of the crests of topographic features (greater than 15 m [49 ft]), the dilution by seawater, and the added dispersion by currents. Such low oil concentrations would not be life threatening to larval or adult stages at depth (Fucik et al., 1994). Dispersant use would probably not be approved during predicted coral spawning time periods (e.g., August-September for major reef-building species) (Gittings et al., 1992b and 1994) in order to limit the impacts of oil pollution on the near-surface portion of the water column. Otherwise, the use of dispersants would be encouraged to prevent direct oiling of some members of the pelagics and seabirds, and to avoid the inhalation, consumption or ingestion of toxic hydrocarbons (Gittings et al., 1997) by surfacing or surface-dwelling animals. The dispersants would preferably be applied to spilled oil in deep waters so as to augment dilution and limit the effects of the spill on shallow water resources.

Blowouts

Oil or gas well blowouts are possible occurrences in the OCS. The benthic community exposed to the large amounts of resuspended sediments following a subsurface blowout could be subject to sediment smothering, exposure to resuspended toxic contaminants, and light attenuation. Should oil or condensate be present in the producing reservoir, liquid hydrocarbons could be an added source of negative impact on the benthic community (low-molecular-weight gases would dissolve in the water column until saturation is reached). The amounts of oil or sediments that settle vary as a function of their specific gravity, dilution, dispersion, and response to currents (Brooks and Bernard, 1977). In most cases, currents should sweep the impact-producing materials around a topographic feature rather than deposit them on top of it (Rezak et al., 1983). The bulk of the blowout materials would be redeposited within a few thousand meters of their source (sand would be redeposited within 400 m [1,312 ft] of the blowout site). The extent of the damage incurred by the benthic community would depend on the amount and duration of exposure to sediments or oil. The consequences of a blowout directly on or near a topographic feature could last more than 10 years. Since the Topographic Features Stipulation precludes drilling in the No Activity Zone, however, most adverse effects on topographic features from blowouts would likely be prevented.

Structure Removal

The impacts of structure removal on the Flower Gardens could include water turbidity, sediment resuspension and deposition, and explosive shock wave impacts. Both explosive and nonexplosive removal operations would disturb the seafloor by creating turbidity. Explosive methodologies generate considerably more turbidity. The deposition of resuspended sediments would occur much in the same manner as discussed for discharges of muds and cuttings and could smother and kill sessile benthic organisms. Turbidity could both reduce light levels and obstruct filter-feeding mechanisms, leading to reduced productivity, susceptibility to infection, and mortality. The shock waves produced by explosive structure removals could also harm neighboring biota. Corals and other sessile invertebrates are apparently resistant to shock. O'Keeffe and Young (1984) described the impacts of underwater explosions on various forms of sea life using, for the most part, open-water explosions much larger than those used in typical structure removal operations. They found that sessile benthic organisms such as barnacles and oysters, and many motile forms of life such as shrimp and crabs that do not possess swim bladders, were remarkably resistant to shock waves generated by underwater explosions. Oysters located 8 m (26 ft) away from a detonation of 135-kg (298-lb) charges in open water incurred a 5 percent mortality. Crabs distanced 8 m from the explosion of 14-kg (31-lb) charges in open water had a 90 percent mortality rate. Few crabs died when the charges were detonated 46 m away. O'Keeffe and Young (1984) also noted ". . . no damage to other invertebrates such as sea anemones, polychaete worms, isopods, and amphipods." Benthic organisms appear to be further protected from the impacts of subbottom explosive detonations by the very rapid attenuations of the underwater shock wave traversing the seabed away from the structure being removed. Theoretical predictions suggest that the shock waves of explosives set 5 m below the seabed as required by MMS regulations would further attenuate blast effects. Charges used in OCS structure removals are typically much smaller than some of those cited by O'Keeffe and Young. The *Programmatic Environmental Assessment for Structural Removal Activities* (USDOI, MMS, 1987) predicts low impacts on the sensitive offshore habitats from platform removal precisely because of the effectiveness of the Topographic Features Stipulation in preventing platform emplacement in sensitive areas. Impacts on the biotic communities, other than those on or directly associated with the platform, would be conceivably limited by the relatively small size of individual charges (normally 22.7 kg [50 lb] or less per well piling and per conductor jacket) and by the fact that charges are detonated 5 m (16 ft) below the mudline and at least 0.9 seconds apart (timing needed to prevent shock waves from becoming additive). The Topographic Features Stipulation precludes platform installation in the No Activity Zone, thus preventing adverse effects from nearby removals. In the case of the gas production platform located within the Sanctuary boundary (500 m [1,640 ft] away from the bank), removal options include nonexplosive removal by cutting below the mudline, and leaving a large portion of the platform in place to serve as an artificial reef. Nonexplosive methods would favor the survival of fish populations associated with the platform, as well as those from the bank that benefit from the presence of the platform (Gittings et al., 1996).

Structure Emplacement

Structure emplacement and pipeline emplacement are other oil- and gas-related activities that could resuspend sediments. The stipulation also prevents these activities from occurring in the No Activity Zone, thus preventing most of these resuspended sediments from reaching the biota of the banks.

b. Impacts on Endangered or Threatened Species

Marine Mammals

Cetaceans that frequent the Flower Gardens' 4-Mile Zone could be impacted by the degradation of water quality resulting from operational discharges, helicopter and vessel traffic and noise, platform noise, explosive platform removals, seismic surveys, oil spills, oil-spill response activities, accidental loss of debris from service vessels and OCS structures, commercial fishing, capture and removal, and pathogens. The long-term result of these exposures could be a number of chronic and sporadic sublethal effects (behavioral effects and nonfatal exposure to or intake of OCS-related contaminants or discarded debris) that may serve to stress and/or weaken individuals of a local group or population and make them more susceptible to infection from natural or anthropogenic sources.

Few deaths of cetaceans would probably result from oil- and gas-related activities within the 4-Mile Zone. Lethal effects, if any, could result from oil spills greater than 1,000 bbl, chance collisions with OCS service vessels, ingestion of plastic material, commercial fishing, and pathogens. Oil spills of any size would be irregular events that might be expected to contact cetaceans. Deaths as a result of structure removals are not expected to occur because of mitigation measures (namely the NMFS observer program). Disturbance (noise from ship traffic and drilling operations, etc.) and/or exposure to sublethal levels of biotoxins and anthropogenic contaminants may stress animals, weaken their immune systems, and make them more vulnerable to parasites and diseases that normally would not be fatal. The net result of any disturbance would be dependent upon the size and percentage of the population likely to be affected, and environmental and biological parameters that influence an animal's sensitivity to disturbance and stress (Geraci and St. Aubin, 1980). Collisions between cetaceans and ships, though expected to be rare events, could cause serious injury or even be fatal.

Sea Turtles

Impacts on sea turtles from oil and gas operations at the Flower Gardens could result from effluent discharges, offshore traffic-generated noise, lights on structures, vessel collisions, structure removals, seismic operations, marine trash and debris, and oil spills. In addition to the impacts from oiling itself, oil-spill response activities could adversely affect sea turtles. Impacting factors might include artificial lighting from night operations, booms, and machine and human activity. Some of the resulting impacts from cleanup could include entanglement in booms (Newell, 1995; Lutcavage et al., 1997).

The gas production platform in HIES Block A-389 is the only platform that could be considered for removal in the immediate vicinity of the Flower Gardens. Recent plans for drilling at this platform (1998) may postpone the removal until the end of the 30-year life expectancy of the platform (i.e., year 2015). Since this platform is located within the Sanctuary boundary, it is expected that special protective measures will be used for its removal to minimize impacts on protected resources, including turtles (Gittings et al., 1997).

At worst, it is assumed that such a structure removal would cause only sublethal effects on turtles as a result of the implementation of the MMS and NMFS guidelines for explosive removals.

Sea turtles may be the animals most seriously affected by marine debris. In addition to the incremental amount of trash and debris generated by the OCS oil and gas activities and other users of the Gulf (e.g., commercial fishing) (Miller et al., 1995), marine debris is carried into the Gulf and Atlantic via oceanic currents from other parts of the world (Plotkin and Amos, 1988; Hutchinson and Simmonds, 1992). Turtles that consume or become entangled in debris may die or become debilitated (O'Hara, 1989; USDOC, NMFS, 1989; Heneman and the Center for Environmental Education, 1988). Monofilament line is the most common type of debris that entangles turtles (NRC, 1990). Fishing related-debris is involved in about 68 percent of all cases of sea turtle entanglement (e.g., netting, rope, traps) (O'Hara and Iudicello, 1987). Floating plastics and petroleum residues drifting on the sea surface accumulate in *Sargassum* windrows commonly inhabited by hatchling sea turtles during their pelagic stage; these materials could interfere with food passage, respiration, and buoyancy, and could reduce the fitness of a turtle and/or kill it. Hatchling and juvenile sea turtles would be most particularly imperiled by floating trash and debris as they are known to be indiscriminate feeders, and are especially vulnerable to plastic bags (Lutz, 1990).

In a review of sea turtle debris ingestion and entanglement worldwide, Balazs (1985) found that tar was the most common item ingested. The suspected cause of death of a leatherback (female, 250 lb) found stranded in the northern Gulf was the ingestion of a tarball (3 by 5 cm [1 by 2 in]) imbedded with particulate matter that had caused the necrosis of its intestinal lining (Dr. David Owens, TAMU-Biology, pers. comm., 1997). High rates of oiling of hatchlings netted from *Sargassum* rafts suggest that bioaccumulation may occur over their potentially long lifespan.

Oil spills can adversely affect sea turtles by toxic ingestion or blockage of the digestive tract, inflammatory dermatitis, ventilatory disturbance, disruption or failure of salt gland function, red blood cell disturbances, immune responses, and displacement from preferred habitats (Witham, 1978; Vargo et al., 1986; Lutz and Lutcavage, 1989; Lutcavage et al., 1995).

Sea turtles may become entrapped by tar and oil slicks and rendered immobile (Witham, 1978; Plotkin and Amos, 1988). In the past, tanker washings have been the main source of this oil (Van Vleet and Pauly, 1987). Although disturbances may be temporary, long-term effects remain unknown, and chronically ingested oil may accumulate in organs. Exposure to oil may be fatal, particularly to juvenile and hatchling sea turtles. Hatchling and small juvenile turtles are particularly vulnerable to contacting or ingesting oil because the currents that concentrate oil spills also form the debris mats in which these turtles are sometimes found (Collard and Ogren, 1989; Witherington, 1994). Skin damage in turtles is in marked contrast to that observed in dolphins, where all structural and biochemical changes in the epidermis are minor and reversible. Changes in the skin are consistent with an acute, primary contact or irritant dermatitis. The eye epithelium is most vulnerable to toxic hydrocarbon substances (Dr. David Owens, TAMU-Biology, pers. comm., 1997). A break in the skin barrier could act as a portal of entry for pathogenic organisms, leading to infection, neoplastic conditions, and debilitation (Vargo et al., 1986).

c. Potential Impacts on Special Ecological Functions of the Flower Gardens

Operators of permitted oil and gas activities within the Flower Gardens area should take into consideration the documented importance of the Flower Gardens as habitats supporting the feeding, reproduction, and nursing of biota, and their significance as schooling grounds and as migratory stopovers. The timing of industrial activities that would impact the surrounding environment may be critical in achieving an optimal coexistence between conservation and development. The summer reproduction of biota at the Flower Gardens seems to stand out as one of the more impact-sensitive time periods (June-October). In addition to the care with which industrial operations are run throughout the year, particular caution should be applied during operations in the June to October period so as to ensure the successful replenishment and continuity of species at the Flower Gardens. Further information is needed to uncover what elasmobranchs do as they congregate at the Flower Gardens during winter months, and what mechanisms and cues draw them to the Banks. In the meantime, special precautions should be applied so as not to disturb sharks and rays from schooling at the Flower Gardens. Disturbances most likely to affect these animals include water quality alteration and noise production.

12. LITERATURE CITED

Alpert, B. 1990. Pipeline inspection set in bill. The Times-Picayune, National News, New Orleans, Wednesday, October 17, 1990. P. A-4.

Amos, A.F. 1989. The occurrence of hawksbills (*Eretmochelys imbricata*) along the Texas coast. In: Proceedings of the Ninth Annual Workshop on Sea Turtle Conservation and Biology, February 7-11, 1989, Jekyll Island, Georgia. NOAA-TM-NMFS-SEFC-232. Miami, Florida.

Bak, R.P.M. 1987. Effects of chronic oil pollution on a Caribbean coral reef. Mar. Poll. Bull. 18(10):534-539.

Baker, J.M., R.B. Clark, and P.F. Kingston. 1991. Two years after the spill: environmental recovery in Prince William Sound and the Gulf of Alaska. Institute of Offshore Engineering, Heriot-Watt University, Edinburgh, EH14 4AS, Scotland. 31 pp.

Balazs, G.H. 1985. Impact of ocean debris on marine turtles: entanglement and ingestion. In: Shomura, R.S. and H.O. Yoshida (eds.). Proceedings, Workshop on the Fate and Impact of Marine Debris, 26-29 November 1984, Honolulu, Hawaii. U.S. Dept. of Commerce. NOAA Tech. Memo. NOAA-TM-NMFS-SWFC-54. Pp. 387-429.

Barry A. Vittor & Associates. 1985. Tuscaloosa trend regional data search and synthesis study, final report. Volume I: synthesis report. Contract No. 14-12-0001-30048. U.S. Dept. of the Interior, Minerals Management Service, Gulf of Mexico OCS Region, New Orleans, Louisiana. 477 pp.

Bender III, L.C. and R.O. Reid. Submitted. Volume fluxes on the Texas-Louisiana continental shelf from a structure-function box model. Journal of Geophysical Research.

Berger, T.J., P. Hamilton, J.J. Singer, R.R. Leben, G.H. Born, and C.A. Fox. 1996. Louisiana/Texas shelf physical oceanography program: eddy circulation study, final synthesis report. Volume I: technical report. OCS Study MMS 96-0051. U.S. Dept. of the Interior, Minerals Management Service, Gulf of Mexico OCS Region, New Orleans, Louisiana. 324 pp.

Bottomley, M., C.K. Folland, J. Hsiung, R.E. Newell, and D.E. Parker. 1990. Global ocean surface temperature atlas ("GOSTA"). Meteorological Office and Massachusetts Institute of Technology. 20 pp. and 313 plates.

Breaker, L.C., L.D. Burroughs, J.F. Culp, N.L. Guinasso, Jr., R.L. Teboulle, and C.R. Wong. 1994. The impact of Hurricane Andrew and the near-surface marine environment in the Bahamas and the Gulf of Mexico. Weather and Forecasting 9(4):542-556.

Bright, T.J. 1983. Flower Garden reefs fragile beauty. Texas Parks & Wildlife. 41(4):8-11.

Bright, T.J. and L.H. Pequegnat (eds.). 1974. Biota of the West Flower Garden Banks. Houston, Texas: Gulf Publishing Company, Book Division. 435 pp.

Bright, T.J. and E.N. Powell. 1983. The East Flower Garden brine seep, a unique ecosystem. In: Rezak, R., T.J. Bright, and D.W. McGrail (eds.). Reefs and banks of the northwestern Gulf of Mexico: their geological, biological, and physical dynamics. Final Report. Tech. Rept. No. 83-1-T. U.S. Dept. of the Interior, Minerals Management Service, Gulf of Mexico OCS Region, New Orleans, Louisiana. Pp. 277-310.

Bright, T.J. and R. Rezak. 1978. Northwestern Gulf of Mexico topographic features study. Final report to the BLM, Contract No. AA550-CT7-15. College Station, Texas: Texas A&M Research Foundation and Texas A&M University, Department of Oceanography. 667 pp. Available from NTIS, Springfield, Virginia: PB-294-769/AS.

Bright, T.J., G.P. Kraemer, G.A. Minnery, and S.T. Viada. 1983. Zonation, abundance, and growth of reef-builders at the Flower Garden Banks. In: Rezak, R., T.J. Bright, and D.W. McGrail (eds.). Reefs and banks of the northwestern Gulf of Mexico: their geological, biological, and physical dynamics. Final Report. Tech. Rept. No. 83-1-T. U.S. Dept. of the Interior, Minerals Management Service, Gulf of Mexico OCS Region, New Orleans, Louisiana. Pp. 231-276.

Bright, T.J., G.P. Kraemer, G.A. Minnery, and S.T. Viada. 1984. Hermatypes of the Flower Garden Banks, northwestern Gulf of Mexico: a comparison to other western Atlantic reefs. Bull. Mar. Sci. 34(3):461-476.

Bright, T.J., D.W. McGrail, R. Rezak, G.S. Boland, and A.R. Trippett. 1985. The Flower Gardens: a compendium of information. OCS Study MMS 85-0024. U.S. Dept. of the Interior, Minerals Management Service, Gulf of Mexico OCS Region, New Orleans, Louisiana. 103 pp.

Brongersma, L. 1972. European Atlantic turtles. Zool. Verh. Mus., Leiden. 121:1-3.

Brooks, J.M. and B.B. Bernard. 1977. Report to Pennzoil Oil Company through Decca Survey Systems, Inc. on geochemical study around a platform blowout in High Island, South Addition, Block 563. Houston, Texas: Pennzoil Co.

Byles, R., C. Caillouet, D. Crouse, L. Crowder, S. Epperly, W. Gabriel, B. Gallaway, M. Harris, T. Henwood, S. Heppell, R. Marquez-M., S. Murphy, W. Teas, N. Thompson, and B. Witherington. 1996. A report of the turtle expert working group: results of a series of deliberations held in Miami, Florida, June 1995-June 1996.

Carr, A. 1986. Rips, FADS, and little loggerheads. Bioscience 36:92-100.

Carr, A. 1987. Impact of nondegradable marine debris on the ecology and survival outlook of sea turtles. Mar. Poll. Bull. 18:352-356.

Carr, A. and S. Stancyk. 1975. Observations on the ecology and survival outlook of the hawksbill turtle. Biol. Conserv. 8:161-172.

Carr, R.S., D.C. Chapman, B.J. Presley, J.M. Biedenbach, L. Robertson, P.N. Boothe, R. Kilada, T. Wade, and P. Montagna. 1996. Sediment porewater toxicity assessment studies in the vicinity of offshore oil and gas production platforms in the Gulf of Mexico. Can. J. Fish. Aquat. Sci. 53:2618-2628.

Chadwick, D.H. 1998. Blue refuges: U.S. National Marine Sanctuaries. National Geographic. 193(3):2-31.

Chamberlain, D.W. 1991. Effects of nonexplosive seismic energy releases on fish. American Fisheries Society Symposium 11:22-25.

Chen, C., R.O. Reid, and W.D. Nowlin. 1996. Near-inertial oscillations over the Texas-Louisiana shelf. J. Geoph. Res. 101(C2):3509-3524.

Childs, J.N., E.L. Hickerson, and K.J.P. Deslarzes. 1996. Spatial and temporal resource use of the Flower Garden Banks by charismatic megafauna. Proceedings: Fifteenth Information Transfer Meeting, December 1995. OCS Study MMS 96-0056. U.S. Dept.

of the Interior, Minerals Management Service, Gulf of Mexico OCS Region, New Orleans, Louisiana. Pp. 74-79.

Cochrane, J.D. and F.J. Kelly. 1986. Low-frequency circulation on the Texas-Louisiana continental shelf. J. Geoph. Res. 91(C9):10,645-10,659.

Collard, S.B. and L.H. Ogren. 1989. Dispersal scenarios for pelagic post-hatchling sea turtles. Bull. Mar. Sci. 47:233-243.

Continental Shelf Associates, Inc. 1983. Environmental monitoring program for exploratory well No. 3, Lease OCS-G 3316, Block A-384, High Island Area, South Extension near the West Flower Garden Bank. Final report to Union Oil Company, Tequesta, Florida. 2 volumes.

Continental Shelf Associates, Inc. 1985. Environmental monitoring program for platform "A," Lease OCS-G 2759, High Island Area, South Extension, East Addition, Block A-389 near the East Flower Garden Bank. Final report to Mobil Producing, Texas and New Mexico, Inc., Houston, Texas. 3 volumes.

Continental Shelf Associates, Inc. 1992. Preliminary report of potential effects of oil spilled from Texaco's proposed pipeline from Platform A in Garden Banks Block 189 to the subsea tie-in with High Island Pipeline System's (HIPS) existing pipeline in High Island Area Block A-377 (modified route). Prepared for Texaco Pipeline, Inc. Jupiter, Florida.

Continental Shelf Associates, Inc. 1994. Analysis of potential effects of oil spilled from proposed structures associated with Oryx's High Island Block 384 unit on the biota of the East Flower Garden Bank and on the biota of Coffee Lump Bank. Prepared for Oryx Energy Company. Jupiter, Florida.

Continental Shelf Associates, Inc. 1997. Long-term monitoring at the East and West Flower Garden Banks. OCS Study MMS 96-0046. U.S. Dept. of the Interior, Minerals Management Service, Gulf of Mexico OCS Region, New Orleans, Louisiana. 77 pp.

Crocker, P.A. and P.C. Koska. 1996. Trends in water and sediment quality for the Houston Ship Channel. Texas Journal of Science 48(4):267-282.

Davis, R.W. and G.S. Fargion, eds. 1996. Distribution and abundance of cetaceans in the north-central and western Gulf of Mexico: final report. Volume II: technical report. U.S. Dept. of the Interior, Minerals Management Service, Gulf of Mexico OCS Region, New Orleans, Louisiana. OCS Study MMS 96-0027. 357 pp.

Dennis, G.D. and T.J. Bright. 1988. Reef fish assemblages on hard banks in the northwestern Gulf of Mexico. Bull. Mar. Sci. 43(2):280-307.

Deslarzes, K.J.P. 1992. Long-term monitoring of reef corals at the Flower Garden Banks (northwest Gulf of Mexico): reef coral population changes and historical incorporation of barium in *Montastrea annularis*. Ph.D. dissertation. Dept. of Oceanography, Texas A&M University, College Station, Texas.

DeYoe, H.R. 1995. The possible role of a natural nitrogen source in the initiation of the Texas brown tide. Corpus Christi Bay National Estuary Program. Presentation Summary in the 3rd Gulf of Mexico Symposium, March 29-April 1, 1995, Corpus Christi, Texas. Publication No. EPA-55-R-97-002.

Dinnel, S.P. and W.J. Wiseman, Jr. 1986. Fresh water on the Louisiana and Texas shelf. Cont. Shelf Res. 6(6):765-784.

Dodd, C.K., Jr. 1988. Synopsis of the biological data on the loggerhead sea turtle *Caretta caretta* (Linnaeus 1758). U.S. Fish and Wildlife Service. Biological Report 88(14). Gainesville, Florida: National Ecology Research Center. 119 pp. Available from NTIS, Springfield, Virginia: PB89-109565.

Dodge, R.E., B.J. Baca, A.H. Knap, S.C. Snedaker, and T.D. Sleeter. 1995. The effects of oil and chemically dispersed oil in tropical ecosystems: 10 years of monitoring experimental sites. Marine Spill Response Corporation, Washington, D.C. MSRC Technical Report Series 95-014. 82 pp.

Dokken, Q.R., C.R. Beaver, D.C. Hagman, I.R. MacDonald, and J.W. Tunnell. In prep. Long-term monitoring at the East and West Flower Garden Banks: 1996-1997. U.S. Dept. of the Interior, Minerals Management Service, Gulf of Mexico OCS Region, New Orleans, Louisiana.

Eckert, S.A., D.W. Nellis, K.L. Eckert, and G.L. Kooyman. 1986. Diving patterns of two leatherback sea turtles (*Dermochelys coriacea*) during internesting intervals at Sandy Point, St. Croix, U.S. Virgin Islands. Herpetologica 42:381-388.

Ellis, M.S., E.A. Wilson-Ormond, and E.N. Powell. 1996. Effects of gas-producing platforms on continental shelf macroepifauna in the northwestern Gulf of Mexico: abundance and size structure. Can. J. Fish. Aquat. Sci. 53:2589-2605.

Etter, P.C. 1996. LATEX shelf data report: heat and freshwater budgets on the Texas-Louisiana shelf April 1992 through November 1994. TAMU Oceanography Technical Report No. 96-1-T, LATEX Program Office, College Station, Texas. 96 pp.

Evans, D.R. and S.D. Rice. 1974. Effects of oil on marine ecosystems: a review for administrators and policy makers. Fishery Bull. 72(3):625-637.

Falk, M.R. and M.J. Lawrence. 1973. Seismic exploration: its nature and effects on fish. Winnipeg, Manitoba, Canada: Dept. of the Environment, Fisheries and Marine Service, Fisheries Operations Directorate, Central Region. Technical Report Series, No. CENT-73-9. 51 pp.

Fargion, G.S., N. May, T.D. Leming, and C. Schroeder. 1996. Oceanographic surveys. In: Davis, R.W. and G.S. Fargion (eds.). Distribution and abundance of cetaceans in the north-central and western Gulf of Mexico: final report. Volume II: technical report. OCS Study MMS 96-0027. U.S. Dept. of the Interior, Minerals Management Service, Gulf of Mexico OCS Region, New Orleans, Louisiana. 357 pp.

Flower Garden Banks National Marine Sanctuary. 1997. Hammerhead Chronicles Summer/Fall 1997: News from the Flower Garden Banks National Marine Sanctuary. 6 pp.

Fritts, T.H., A.B. Irvine, R.D. Jennings, L.A. Collum, W. Hoffman, and M.A. McGehee. 1983. Turtles, birds, and mammals in the northern Gulf of Mexico and nearby Atlantic waters. FWS/OBS-82/65. U.S. Fish and Wildlife Service, Division of Biological Services, Washington, D.C. 455 pp.

Fucik, K.W., K.A. Carr, and B.J. Balcom. 1994. Dispersed oil toxicity tests with biological species indigenous to the Gulf of Mexico. Prepared by Continental Shelf Associates, Inc. OCS Study MMS 94-0021. U.S. Dept. of the Interior, Minerals Management Service, Gulf of Mexico OCS Region, New Orleans, Louisiana. 97 pp. + appendices.

Fuller, D.A., A.M. Tappan, and M.C. Hester. 1987. Sea turtles in Louisiana's coastal waters. Louisiana Sea Grant College, August 1987.

Geraci, J.R. and D.J. St. Aubin. 1980. Offshore petroleum resource development and marine mammals: a review and research recommendations. Marine Fisheries Review 42:1-12.

Gittings, S.R., T.J. Bright, and E.N. Powell. 1984. Hard-bottom macrofauna of the East Flower Garden brine seep: impact of a long-term, sulfurous brine discharge. Contributions in Marine Science 27:105-125.

Gittings, S.R. and T.J. Bright. 1986. Assessment of coral recovery following an incident of anchoring damage at the East Flower Garden Bank, northwest Gulf of Mexico. Final Report to USDOC, NOAA, National Marine Sanctuaries Division, Silver Spring, Maryland. Contract No. NA85AA-H-CZ015. 45 pp.

Gittings, S.R., G.S. Boland, K.J.P. Deslarzes, D.K. Hagman, and B.S. Holland. 1992a. Long-term monitoring at the East and West Flower Garden Banks. OCS Study MMS 92-0006. U.S. Dept. of the Interior, Minerals Management Service, Gulf of Mexico OCS Region, New Orleans, Louisiana. 206 pp.

Gittings, S.R., K.J.P. Deslarzes, D.K. Hagman, and G.S. Boland. 1992b. Reef coral population and growth on the Flower Garden Banks, northwest Gulf of Mexico. Proceedings: 7th International Coral Reef Symposium, Guam. 1:90-96.

Gittings, S.R., G.S. Boland, C.R.B. Merritt, J.J. Kendall, K.J.P. Deslarzes, and J. Hart. 1994. Mass spawning by reef corals in the Gulf of Mexico and Caribbean Sea: a report on Project Reef Spawn '94. Flower Gardens Fund Technical Series Report Number 94-03. The Flower Gardens Fund of the Gulf of Mexico Foundation, Bryan, Texas. 24 pp.

Gittings, S.R., C.L. Ostrom, and K.J.P. Deslarzes. 1997. Regulation by reason: Science and management in the Flower Gardens Sanctuary, northwest Gulf of Mexico. Proceedings: 8th International Coral Reef Symposium, Panama. 2:1967-1972.

Gramling, R., S. Brabant, C.J. Forsyth, and C.E. Palmer. 1995. Outer continental shelf issues: Central Gulf of Mexico. OCS Study MMS 95-0032. U.S. Dept. of the Interior, Minerals Management Service, Gulf of Mexico OCS Region, New Orleans, Louisiana. 72 pp.

Guzman, H.M., J.B.C. Jackson, and E. Weil. 1991. Short-term ecological consequences of a major oil spill on Panamanian subtidal reef corals. Coral Reefs 10:1-12.

Hagman, D.K., S.R. Gittings, and K.J.P. Deslarzes. Submitted. Observations on the timing, species participation and environmental factors influencing annual mass spawning at the Flower Garden Banks (northwest Gulf of Mexico). Gulf of Mexico Science.

Harper, D.E. 1986. A review and synthesis of unpublished and obscure published literature concerning produced water fate and effects. Prepared for the Offshore Operators Committee, Environmental Science Task Force (Chairman, R.C. Ayers, Exxon Production Research Co., Houston, Texas).

Heneman, B. and the Center for Environmental Education. 1988. Persistent marine debris in the North Sea, northwest Atlantic Ocean, wider Caribbean area, and the west coast of Baja California. Final report for MMC. Contract MM3309598-5. Washington, D.C. Available from NTIS, Springfield, Virginia: PB89-109938. 161 pp.

Hicks S.D., H.A. Debaugh, Jr., and L.E. Hickman, Jr. 1983. Sea level variations for the United States 1855-1980. USDOC/NOAA/NOS Tides and Water Levels Branch, Rockville, Maryland. 170 pp.

Hildebrand, H.H. 1982. A historical review of the status of sea turtle populations in the western Gulf of Mexico. In: Bjorndal, K.A. (ed.). Biology and conservation of sea turtles. Washington, DC: Smithsonian Institution Press. Pp. 447-453.

Hsu, S.A. 1992. A study of extratropical cyclogenesis events along the mid- to outer Texas-Louisiana shelf. In: Proceedings: Twelfth Annual Gulf of Mexico Information Transfer Meeting, November 5-7, 1991. OCS Study MMS 92-0027. U.S. Dept. of the Interior, Minerals Management Service, Gulf of Mexico OCS Region, New Orleans, Louisiana. Pp. 341-347.

Hutchinson, J. and M. Simmonds. 1992. Escalation of threats to marine turtles. Oryx 26:95-102.

Jackson, J.B.C., J.D. Cubit, B.D. Keller, V. Batista, K. Burns, H.M. Caffey, R.L. Caldwell, S.D. Garrity, C.D. Getter, C. Gonzalez, H.M. Guzman, K.W. Kaufmann, A.H. Knap, S.C. Levings, M.J. Marshall, R. Steger, R.C. Thompson, and E. Weil. 1989. Ecological effects of a major oil spill on Panamanian coastal marine communities. Science 243:37-44.

John Bartholomew and Son, Ltd. 1985. The Times atlas of the world. Times Books, a division of Random House, New York. 912 pp.

Kennicutt II, M.C., P.N. Boothe, T.L. Wade, S.T. Sweet, R. Rezak, F.J. Kelly, J.M. Brooks, B.J. Presley, and D.A. Wiesenburg. 1996. Geochemical patterns in sediments near offshore production platforms. Can. J. Fish. Aquat. Sci. 53:2554-2566.

Knap, A.H., S.C. Wyers, R.E. Dodge, T.D. Sleeter, H.R. Frith, S.R. Smith, and C.B. Cook. 1985. The effects of chemically and physically dispersed oil on the brain coral *Diploria strigosa* (Dana) - a summary review. In: Proceedings, 1985 Oil Spill Conference, February 25-28, 1985, Los Angeles, California. Washington, D.C.: American Petroleum Institute. Pp. 547-551.

Lange, R. 1985. A 100 ton experimental oil spill at Halten Bank, off Norway. In: Proceedings, 1985 Oil Spill Conference. February 25-28, 1985, Los Angeles, California. Washington, D.C.: American Petroleum Institute. Pp. 503-505.

Linden, O., J.R. Sharp, R. Laughlin, Jr., and J.M. Neff. 1979. Interactive effects of salinity, temperature, and chronic exposure to oil on the survival and development rate of embryos of the estuarine killfish *Fundulus heteroclitus*. Mar. Biol. 51:101-109.

Linton, T.L., N. Hall, D. LaBomascus, and A.M. Landry. 1986. Effects of seismic sounds on marine organisms: an annotated bibliography and literature review. Texas A&M Sea Grant College Program, College Station, Texas. TAMU-SG-86-604.

Long, E.R. and L.G. Morgan. 1990. The potential for biological effects of sediment-sorbed contaminants tested in the National Status and Trends Program. NOAA Tech. Memo. NOS OMA 52. U.S. Dept. of Commerce, National Oceanic and Atmospheric Administration, Seattle, Washington.

Longwell, A.C. 1977. A genetic look at fish eggs and oil. Oceanus 20(4):46-58.

Louisiana Dept. of Wildlife and Fisheries. 1992. A fisheries management plan for Louisiana penaeid shrimp fishery: summary and action items. November 1992, Baton Rouge, Louisiana. 16 pp.

Lugo-Fernandez, A. In review. Ecological implications of hydrography and circulation to the Flower Garden Banks, northwest Gulf of Mexico. Gulf of Mexico Science.

Lutcavage, M.E., P.G. Bushnell, and D.R. Jones. 1990. Oxygen transport in the leatherback sea turtle, *Dermochelys coriacea*. Physiol. Zool. 63:1012-1024.

Lutcavage, M.E., P.L. Lutz, G.D. Bossart, and D.M. Hudson. 1995. Physiologic and clinicopathologic effects of crude oil on loggerhead sea turtles. Arch. Environ. Contam. Toxicol. 28:417-422.

Lutcavage, M.E., P. Plotkin, B. Witherington, and P.L. Lutz. 1997. Human impacts on sea turtle survival. In: Lutz, P.L. and J.A. Musick (eds.). The biology of sea turtles. Boca Raton, Florida: CRC Press. Pp. 387-409.

Lutz, P.L. 1990. Studies on the ingestion of plastic and latex by sea turtles. In: Shomura, R.S. and M.L. Godfrey (eds). Proceedings, Workshop on the Fate and Impact of Marine Debris, 26-29 November 1984, Honolulu, Hawaii. U.S. Dept. of Commerce. NOAA Tech. Memo. NOAA-TM-NMFS-SWFC-154. Pp. 719-735.

Lutz, P.L. and M. Lutcavage. 1989. The effects of petroleum on sea turtles: applicability to Kemp's ridley. In: Caillouet, C.W., Jr. and A.M. Landry, Jr. (compilers). Proceedings of the First International Symposium on Kemp's Ridley Sea Turtle Biology, Conservation, and Management, Galveston, Texas. TAMU-SG-89-105.

Malins, D.C., S. Chan, H.O. Hodgins, U. Varanasi, D.D. Weber, and D.W. Brown. 1982. The nature and biological effects of weathered petroleum. Environmental Conservation Division, Northwest and Alaska Fisheries Center, National Marine Fisheries Service, Seattle, Washington. 43 pp.

McAuliffe, C.D., A.E. Smalley, R.D. Groover, W.M. Welsh, W.S. Pickle, and G.E. Jones. 1975. Chevron Main Pass Block 41 oil spill: chemical and biological investigation. In: Proceedings, 1975 Conference on Prevention and Control of Oil Pollution, March 25-27, 1975, San Francisco, California. Washington, D.C.: American Petroleum Institute.

McAuliffe, C.D., B.L. Steelman, W.R. Leek, D.F. Fitzgerald, J.P. Ray, and C.D. Barker. 1981. The 1979 southern California dispersant treated research oil spills. In: Proceedings, 1981 Oil Spill Conference, March 2-5, 1981, Atlanta, Georgia. Washington, D.C.: American Petroleum Institute. Pp. 269-282.

McGrail, D.W. 1983. Flow, boundary layers, and suspended sediment at the Flower Garden Banks. In: Rezak, R., T.J. Bright, and D.W. McGrail (eds.). Reefs and banks of the northwestern Gulf of Mexico: their geological, biological, and physical dynamics. Final Report. Tech. Rept. No. 83-1-T. U.S. Dept. of the Interior, Minerals Management Service, Gulf of Mexico OCS Region, New Orleans, Louisiana. Pp. 141-230.

Meier, G. 1997. The hypoxia issue along the Louisiana Coast of the Gulf of Mexico: progress report. Presentation at the Sixteenth Gulf of Mexico Information Transfer Meeting, December 10-12, 1996, New Orleans, Louisiana. Sponsored by the U.S. Dept. of the Interior, Minerals Management Service, Gulf of Mexico OCS Region, New Orleans, Louisiana. OCS Study MMS 97-0038. Pp. 33-34.

Meylan, A. 1988. Spongivory in hawksbill turtles: a diet of glass. Science 239:393-395.

Miller, J.E., S.W. Baker, and D.L. Echols. 1996. Marine debris point source investigation: Padre Island National Seashore, March 1994-September 1995. OCS Study MMS 96-0023. U.S. Dept. of the Interior, Minerals Management Service, Gulf of Mexico OCS Region, New Orleans, Louisiana. 35 pp.

Milliman, J.D. and R.H. Meade. 1983. World-wide delivery of river sediment to the ocean. J. Geol. 91:1-21.

Montagna, P.A. and D.E. Harper, Jr. 1996. Benthic infaunal long-term response to offshore production platforms in the Gulf of Mexico. Can. J. Fish. Aquat. Sci. 53:2567-2588.

Morreale, S.J., E.A. Standora, J.R. Spotila, and F.V. Paladino. 1996. Migration corridor for sea turtles. Nature 384:319-320.

Murray, S.P. and J. Donley, eds. 1996. Mississippi River plume hydrography: second annual report. OCS Study MMS 96-0022. U.S. Dept. of the Interior, Minerals Management Service, Gulf of Mexico OCS Region, New Orleans, Louisiana. 175 pp.

National Data Buoy Center, NOAA, National Weather Service. Historical NDBC Data, buoy 42019. http://seaboard.ndbc.noaa.gov/historical_data.shtml#stdmet

National Research Council (NRC). 1985. Oil in the sea: inputs, fates, and effects. Washington, D.C.: National Academy Press. 601 pp.

National Research Council (NRC). 1990. The decline of sea turtles: causes and prevention. Committee on Sea Turtle Conservation. Washington, D.C.: National Academy Press. 183 pp.

Neff, J.M. 1997. Metals and organic chemicals associated with oil and gas well produced water: bioaccumulation, fates, and effects in the marine environment (Gulf of Mexico produced water bioaccumulation study). Prepared for Continental Shelf Associates, Inc., Jupiter, Florida. 357 pp.

Newell, M.J. 1995. Sea turtles and natural resource damage assessment. In: Rineer-Garber, C. (ed.) Proceedings: The effects of oil on wildlife, Fourth International Conference, Seattle, Washington. Pp. 137-142.

Nowlin, W.D. and J.M. Hubertz. 1972. Contrasting summer circulation patterns for the eastern gulf. In: Capurro, L.R.A. and J.L. Reid (eds.) Contributions on the physical oceanography of the Gulf of Mexico, Texas A&M Univ. Oceanogr. Stud. Gulf, Houston. 2:119-137.

Nowlin, W.D., Jr., A.E. Jochens, R.O. Reid, and S.F. DiMarco. 1998. Texas-Louisiana shelf circulation and transport processes study: synthesis report. Volume I: technical report and Volume II: appendices. OCS Study MMS 98-0035 and 98-0036. U.S. Dept. of the Interior, Minerals Management Service, Gulf of Mexico OCS Region, New Orleans, Louisiana. 492 and 288 pp.

O'Hara, K. 1989. Plastic debris and its effects on marine wildlife. In: Conservation Challenges.

O'Hara, K.J. and S. Iudicello. 1987. Plastics in the ocean: more than a litter problem. Center for Environmental Education, Washington, D.C.

O'Keeffe, D.J. and G.A. Young. 1984. Handbook on the environmental effects of underwater explosives. NSWC TR 83-240. Naval Surface Weapons Center. Dahlgren, Virginia, and Silver Spring, Maryland.

Oey L.-Y. 1995. Eddy- and wind-forced shelf circulation. J. Geoph. Res. 100(C5):8621-8637.

Ogren, L., F. Berry, K. Bjorndal, H. Kumpf, R. Mast, G. Medina, H. Reichart, and R. Witham. (compilers). 1989. Proceedings of the Second Western Atlantic Turtle Symposium, October 12-16, 1987, Mayaguez, Puerto Rico. Panama City, Florida: U.S. Dept. of Commerce, National Oceanic and Atmospheric Administration. NOAA Technical Memorandum NMFS SEFC-226.

Paladino, F.V., M.P. O'Connor, and J.R. Spotila. 1990. Metabolism of leatherback turtles, gigantothermy, and thermoregulation of dinosaurs. Nature (London) 344:859-860.

Pattengill, C.V. In prep. Fish census data generated by non-experts in the Flower Garden Banks National Marine Sanctuary: how powerful is it? Gulf of Mexico Science.

Peterson, C.H., M.C. Kennicutt II, R.H. Green, P. Montagna, D.E. Harper, Jr., E.N. Powell, and P.F. Roscigno. 1996. Ecological consequences of environmental perturbations associated with offshore hydrocarbon production: a perspective on long-term exposures in the Gulf of Mexico. Can. J. Fish. Aquat. Sci. 53:2637-2654.

Plotkin, P. and A.F. Amos. 1988. Entanglement in and ingestion of marine debris by sea turtles stranded along the South Texas coast. In: Proceedings of the Eighth Annual Workshop on Sea Turtle Conservation and Biology. U.S. Dept. of Commerce. NOAA Technical Memo. NMFS-SEFC-214.

Pritchard, P.C.H. 1971. The leatherback or leathery turtle *Dermochelys coriacea*. IUCN Mono. No. 1, Morges, Switzerland. 39 pp.

Rabalais, N.N., B.A. McKee, D.J. Reed, and J.C. Means. 1991. Fate and effects of nearshore discharges of OCS produced waters. OCS Study MMS 91-0004 through 91-0006. U.S. Dept. of the Interior, Minerals Management Service, Gulf of Mexico OCS Region, New Orleans, Louisiana. 3 volumes.

Rand McNally. 1975. Rand McNally family world atlas. Rand McNally & Company, New York. 201 pp.

Reid, R.O. 1988. Tide/storm surge modeling. In: Mitchell T. (ed.). Physical oceanography of the Louisiana-Texas continental shelf. Proc. of a symposium held in Galveston, Texas. MMS Contract No. 14-12-0001-30305. U.S. Dept. of the Interior, Minerals Management Service, Gulf of Mexico OCS Region, New Orleans, Louisiana. Pp. 94-111.

Rezak, R. 1983. Geology of the Flower Garden Banks. In: Rezak, R., T.J. Bright, and D.W. McGrail (eds.). Reefs and banks of the northwestern Gulf of Mexico: their geological, biological, and physical dynamics. Final Report. Tech. Rept. No. 83-1-T. U.S. Dept. of the Interior, Minerals Management Service, Gulf of Mexico OCS Region, New Orleans, Louisiana. Pp. 111-140.

Rezak, R. and T. J. Bright. 1981. Northern Gulf of Mexico Topographic Features Study. Final report to the U.S. Dept. of the Interior, Bureau of Land Management, Contract No. AA551-CT8-35. College Station, Texas: Texas A&M University, Department of Oceanography, Technical Report No. 81-2-T.

Rezak, R., T.J. Bright, and D.W. McGrail. 1983. Reefs and banks of the northwestern Gulf of Mexico: their geological, biological, and physical dynamics. Northern Gulf of Mexico topographic features synthesis. Contract No. AA851-CT1-55. College Station, Texas: Texas A&M University, Department of Oceanography, Technical Report No. 83-1-T.

Rezak, R., T.J. Bright, and D.W. McGrail. 1985. Reefs and banks of the northwestern Gulf of Mexico: their geological, biological, and physical dynamics. New York: John Wiley and Sons.

Robinson, M.K. 1973. Atlas of monthly mean sea surface and subsurface temperature and depth of the top of the thermocline Gulf of Mexico and Caribbean Sea. Scripps Institution of Oceanography Reference 73-8.

Sahl, L.E., W.J. Merrell, and D.C. Biggs. 1993. The influence of advection on the spatial variability of nutrient concentrations on the Texas-Louisiana continental shelf. Continental Shelf Research 13(2/3):233-251.

Sahl, L.E., D.A. Wiesenburg, and W.J. Merrell. 1997. Interactions of mesoscale features with Texas shelf and slope waters. Continental Shelf Research. 17(2):117-136.

Scarborough-Bull, A. and J.J. Kendall, Jr. 1992. Preliminary investigation: platform removal and associated biota. In: Cahoon, L.B. (ed.). Diving for science, 1992, American Academy of Underwater Sciences, Costa Mesa, California. Pp. 31-38.

Science Applications International Corporation. 1989. Gulf of Mexico physical oceanography program, final report: Year 5. Volume II: Technical report. OCS Study MMS 89-0068. U.S. Dept. of the Interior, Minerals Management Service, Gulf of Mexico OCS Region, New Orleans, Louisiana. 333 pp.

Science Applications International Corporation. 1992. Straits of Florida physical oceanography field study. OCS Study MMS 92-0024. U.S. Dept. of the Interior, Minerals Management Service, Gulf of Mexico OCS Region, New Orleans, Louisiana. 85 pp.

Shoop, C., T. Doty, and N. Bray. 1981. Sea turtles in the region between Cape Hatteras and Nova Scotia in 1979. In: Shoop, C., T. Doty, and N. Bray. 1981. A characterization of marine mammals and turtles in the mid- and north-Atlantic areas of the U.S. outer continental shelf: annual report for 1979, Chapter IX. Kingston: University of Rhode Island. Pp. 1-85.

Slowey, N.C. and T.J. Crowley. 1995. Interdecadal variability of Northern Hemisphere circulation recorded by Gulf of Mexico corals. Geophysical Research Letters 22(17):2345-2348.

Spies, R.B., J.S. Felton, and L. Dillard. 1982. Hepatic mixed-function oxidases in California flatfishes are increased in contaminated environments and by oil and PCB ingestion. Mar. Biol. 70:117-127.

The Conrad Blucher Institute for Surveying and Science Division of Coastal Observations, Texas A&M University-Corpus Christi, Texas 78412. http://tcoon.cbi.tamucc.edu/data.

United Nations Environment Programme Global Environment Monitoring System Freshwater Quality Programme (UNEP-GEMS/WATER). 1995. WWW address: http://cs715.cciw.ca/gems/.

U.S. Dept. of Commerce, National Marine Fisheries Service. 1989. Fisheries of the United States, 1988. Current fisheries statistics no. 8800. Washington, D.C.

U.S. Dept. of Commerce, National Marine Fisheries Service. 1990. Recovery plan for U.S. population of loggerhead turtle (*Caretta caretta*). U.S. Dept. of Commerce, National Marine Fisheries Service, St. Petersburg, Florida.

U.S. Dept. of Commerce, National Marine Fisheries Service. 1992. Recovery plan for leatherback turtles in the U.S. Caribbean, Atlantic and Gulf of Mexico. U.S. Dept. of Commerce, National Marine Fisheries Service, Washington, D.C.

U.S. Dept. of Commerce, National Marine Fisheries Service. 1993a. Recovery plan for hawksbill turtles in the U.S. Caribbean Sea, Atlantic Ocean, and Gulf of Mexico. U.S. Dept. of Commerce, National Marine Fisheries Service, St. Petersburg, Florida.

U.S. Dept. of Commerce, National Marine Fisheries Service. 1993b. Fishing trends and conditions in the Southeast Region. 99 pp.

U.S. Dept. of Commerce, National Oceanic and Atmospheric Administration, National Ocean Service, Sanctuaries and Reserves Division. 1991. Final environmental impact statement and management plan for the proposed Flower Garden Banks National Marine Sanctuary. 141 pp.

U.S. Dept. of Commerce, National Oceanic and Atmospheric Administration, National Ocean Service, Coast and Geodetic Survey. 1992. Flower Garden Banks National Marine Sanctuary, Bathymetric Map MS-1. UTM Projection, WGS-84, 1:25,000.

U.S. Dept. of the Interior, Fish and Wildlife Service. 1995. Florida manatee recovery plan (second revision). U.S. Dept. of the Interior, Fish and Wildlife Service, Southeast Region, Atlanta, Georgia. 160 pp.

U.S. Dept. of the Interior, Minerals Management Service. 1984. Area-wide environmental assessment exploration and production activities four mile zone of the East and West Flower Garden Banks. OCS EIS/EA MMS 84-0053. U.S. Dept. of the Interior, Minerals Management Service, Gulf of Mexico OCS Region, New Orleans, Louisiana. 156 pp.

U.S. Dept. of the Interior, Minerals Management Service. 1987. Programmatic environmental assessment: structure removal activities, Central and Western Gulf of Mexico Planning Areas. OCS EIS/EA MMS 87-0002. U.S. Dept. of the Interior, Minerals Management Service, Gulf of Mexico OCS Region, New Orleans, Louisiana. 84 pp.

U.S. Dept. of the Interior, Minerals Management Service. 1988. Meteorological database and synthesis for the Gulf of Mexico. Prepared by Florida A&M University. OCS Study MMS 88-0064. U.S. Dept. of the Interior, Minerals Management Service, Gulf of Mexico OCS Region, New Orleans, Louisiana. 486 pp.

U.S. Dept. of the Interior, Minerals Management Service. 1996a. Regulatory compliance for OCS oil and gas operations. OCS Report MMS 96-0039. U.S. Dept. of the Interior, Minerals Management Service, Gulf of Mexico OCS Region, New Orleans, Louisiana. 22 pp.

U.S. Dept. of the Interior, Minerals Management Service. 1996b. Estimated proved and unproved oil and gas reserves, Gulf of Mexico, December 31, 1995. OCS Report MMS

96-0061. U.S. Dept. of the Interior, Minerals Management Service, Gulf of Mexico OCS Region, New Orleans, Louisiana. 25 pp.

U.S. Dept. of the Interior, Minerals Management Service. 1997a. Gulf of Mexico OCS oil and gas lease sales 171, 174, 177, and 180. Western Planning Area. Draft environmental impact statement. OCS EIS/EA MMS 97-0032. U.S. Dept. of the Interior, Minerals Management Service, Gulf of Mexico OCS Region, New Orleans, Louisiana. 446 pp.

U.S. Dept. of the Interior, Minerals Management Service. 1997b. Visual 2. Gulf of Mexico outer continental shelf offshore multiple use map. U.S. Dept. of the Interior, Minerals Management Service, Gulf of Mexico OCS Region, New Orleans, Louisiana.

U.S. Dept. of the Interior, Minerals Management Service. 1997c. Visual 3. Gulf of Mexico outer continental shelf offshore regulatory features map. U.S. Dept. of the Interior, Minerals Management Service, Gulf of Mexico OCS Region, New Orleans, Louisiana.

U.S. Environmental Protection Agency, Office of Water. 1993. Supplemental information for effluent limitation guidelines and new source performance standards for the offshore subcategory of the oil and gas extraction point source category (40 CFR 435). Also supportive documents produced by the Office of Water Regulations and Standards, Washington, D.C. Economic impact analysis of proposed effluent limitation guidelines and standards for the offshore oil and gas industry. Prepared by Eastern Research Group, Inc. EPA 440/2-91-001. Regulation published in the *Federal Register*, Vol. 58, No. 41, pp. 12453-12512 (March 4, 1993).

Van Vleet, E.S. and G. Pauly. 1987. Characterization of oil residues scraped from stranded sea turtles from the Gulf of Mexico. Carib. J. Sci. 23:77-83.

Vargo, S., P. Lutz, D. Odell, E. Van Vleet, and G. Bossart. 1986. Effects of oil on marine turtles. Prepared by the Florida Institute of Oceanography. OCS Study MMS 86-0070. U.S. Dept. of the Interior, Minerals Management Service, Gulf of Mexico OCS Region, New Orleans, Louisiana. 3 volumes. 360 pp.

Vietor, D.E. 1997. WXP, the weather processor. Hurricane/Tropical Data. WWW address: http://wxp.atms.purdue.edu/hurricane/index.html

Vukovich, F.M. 1995. An updated evaluation of the Loop Current's eddy-shedding frequency. J. Geoph. Res. 100(C5):8655-8659.

Walker, N.D. 1996. Satellite assessment of Mississippi River plume variability: causes and predictability. Remote Sens. Environ. 58:21-35.

Walker, N.D., G. Fargion, L.J. Rouse, Jr., and D. Biggs. 1994. Circulation of Mississippi River water discharged into the northern Gulf of Mexico by the great flood of summer 1993. EOS Trans. Am. Geophys. Union 75(36):409, 414-415.

Weber, M., R.T. Townsend, and R. Bierce. 1992. Environmental quality in the Gulf of Mexico: a citizen's guide. Center for Marine Conservation. 2nd Edition, June 1992. 130 pp.

Wingert, R.C. 1988. Geophysical survey and commercial fishing conflicts, environmental studies, and conflict mitigation in the Minerals Management Service, Pacific OCS Region. In: Oceans '88: a partnership of marine interests. New York: Institute of Electrical and Electronics Engineers. 1:150-155.

Witham, R. 1978. Does a problem exist relative to small sea turtles and oil spills? In: Proceedings, Conference on Assessment of Ecological Impacts of Oil Spills, 14-17 June, Keystone, Colorado. American Institute of Biological Sciences, Washington, D.C. Pp. 630-632.

Witherington, B.E. 1994. Flotsam, jetsam, post-hatchling loggerheads, and the advecting surface smorgasbord. In: Proceedings of the Fourteenth Annual Symposium on Sea Turtle Biology and Conservation. NOAA Technical Memorandum NMFS-SEFSC-351.

Young, G.A. 1991. Concise methods for predicting the effects of underwater explosions on marine life. Naval Surface Warfare Center, Silver Spring, Maryland. NAVSWC-TR-91-220. 13 pp.

Zettler, B.D. and D.V. Hansen. 1972. Tides in the Gulf of Mexico. In: Capurro, L.R.A. and J.L. Reid (eds.). Contributions on the physical oceanography of the Gulf of Mexico. Vol. 2. Texas A&M University Oceanographic Studies, College Station, Texas. Pp. 265-275.

APPENDIX 1. The Flower Garden Banks: A Chronology of Research

The following bibliographies were compiled by Dr. Stephen Gittings (Manager, Flower Garden Banks NMS) and are the most comprehensive list of scientific publications on research conducted at the Flower Garden Banks. They also contain significant articles published outside of the scientific literature. An updated list can be obtained from the Flower Garden Banks National Marine Sanctuary, 216 W. 26th St., Suite 104, Bryan, Texas 77803, USA.

Biology

Parker, R.H. and J.R. Curray. 1956. Fauna and bathymetry of banks on continental shelf, northwestern Gulf of Mexico. Bull. Am. Assoc. Petrol. Geol. 40:2428-2439.

Pulley, T.E. 1963. Texas to the tropics. Houston Geol. Soc. Bull. 6:13-19.

Pierce, W.E. 1967. Flower Garden Reef. Tex. Parks and Wildlife Mag., Dec., Pp. 28-31.

Cashman, C.W. 1973. Contributions to the ichthyofaunas of the West Flower Garden Reef and other reef sites in the Gulf of Mexico and western Caribbean. Ph.D. Dissertation, Texas A&M University, Dept. of Oceanography, College Station, Texas. 247 pp.

Cropper, D.A. 1973. Living Cheilostome Bryozoa of West Flower Garden Bank, northwest Gulf of Mexico. M.S. Thesis, Texas A&M University, Dept. of Oceanography, College Station, Texas.

Bright, T.J. and L.H. Pequegnat, eds. 1974. Biota of the West Flower Garden Bank. Gulf Publishing Company, Book Division, Houston, Texas. 435 pp.

Burke, T.E. 1974. Echinoderms of the West Flower Garden Bank. M.S. Thesis, Texas A&M University, Dept. of Oceanography, College Station, Texas.

Ray, J.P. 1974. A study of the coral reef crustaceans (Decapoda and Stomatopoda) of two Gulf of Mexico reef systems: West Flower Garden, Texas, and Isla de Lobos, Veracruz, Mexico. Ph.D. Dissertation, Texas A&M University, Dept. of Oceanography, College Station, Texas.

Tresslar, R.C. 1974. The living benthonic foraminiferal fauna of the West Flower Garden Bank coral reef and biostrome. M.S. Thesis, Texas A&M University, Dept. of Oceanography, College Station, Texas. 239 pp.

Abbott, R.E. 1975. The faunal composition of the algal-sponge zone of the Flower Garden Banks, northwest Gulf of Mexico. M.S. Thesis, Texas A&M University, Dept. of Oceanography, College Station, Texas. 205 pp.

Dubois, R. 1975. A comparison of the distribution of the Echinodermata of a coral community with that of a nearby rock outcrop on the Texas continental shelf. M.S. Thesis, Texas A&M University, Dept. of Oceanography, College Station, Texas.

Hogg, D.M. 1975. Formation, growth, structure, and distribution of calcareous algal nodules on the Flower Garden banks. M.S. Thesis, Dept. of Oceanography, Texas A&M Univ., College Station, Texas. 59 pp.

Teerling, J. 1975. A survey of sponges from the northwestern Gulf of Mexico. Ph.D. Dissertation, University of Southwestern Louisiana, Dept. of Biology, Lafayette, Louisiana. 186 pp.

Bright, T.J. and R. Rezak. 1976. A biological and geological reconnaissance of selected topographical features on the Texas continental shelf. Final Rept. to U.S. Dept. of the Interior, Bureau of Land Management. Contract No. 08550-CT5-4. 377 pp.

Defenbaugh, R.E. 1976. A study of the benthic macroinvertebrates of the continental shelf of the northern Gulf of Mexico. Ph.D. Dissertation, Texas A&M University, Dept. of Oceanography, College Station, Texas. 410 pp.

Sonnier, F., J. Teerling and H.D. Hoese. 1976. Observations on the offshore reef and platform fish fauna of Louisiana. Copeia 1:105-111.

Wills, J.B. 1976. Benthonic Polychaeta of the West Flower Garden Bank. M.S. Thesis, University of Houston, Dept. of Biology, Houston, Texas. 181 pp.

Bright, T.J. 1977. Coral reefs, nepheloid layers, gas seeps and brine flows on hard-banks in the northwestern Gulf of Mexico. Proc. Third Int. Coral Reef Symp. 1:39-46.

Bright, T.J. and R. Rezak. 1977. Reconnaissance of reefs and fishing banks of the Texas continental shelf. In: R.A. Geyer (ed.). Submersibles and Their Use in Oceanography. Elsevier, New York. Pp. 113-150.

Bright, T.J. and R. Rezak. 1978. Northwestern Gulf of Mexico topographic features study. Final Rept. to U.S. Dept. of the Interior, Bureau of Land Management. Contract No. AA550-CT7-15.

Giammona, C.P. 1978. Octocorals in the Gulf of Mexico their taxonomy and distribution with remarks on their paleontology. Ph.D. Dissertation, Texas A&M University, Dept. of Oceanography, College Station, Texas. 260 pp.

Abbott, R.E. 1979. Ecological processes affecting the reef coral population at the East Flower Garden Bank, northwest Gulf of Mexico. Ph.D. Dissertation, Texas A&M Univ., Dept. of Oceanography, College Station, Texas. 154 pp.

Leuterman, A. 1979. The taxonomy and systematics of the Gymnolaemate and Stenolaemate Bryozoa of the northwest Gulf of Mexico. Ph.D. Dissertation, Texas A&M University, Dept. of Oceanography, College Station, Texas.

Bright, T.J., P.A. LaRock, R.D. Lauer, and J.M. Brooks. 1980a. A brine seep at the East Flower Garden Bank, northwestern Gulf of Mexico. Int. Rev. Ges. Hydrobiol. 65(4):535-549.

Bright, T.J., E.N. Powell, and R. Rezak. 1980b. Environmental effects of a natural brine seep at the East Flower Garden Bank, northwestern Gulf of Mexico. In: R.A. Geyer (ed.). Marine Environmental Pollution. Elsevier Publishing Co., Amsterdam. Pp. 291-316.

Hudson, J.H. and D.M. Robbin. 1980. Effects of drilling mud on the growth rate of the reef-building coral, *Montastrea annularis*. In: R.A. Geyer (ed.). Marine Environmental Pollution, Vol. 1: Hydrocarbons. Elsevier Scientific Publishing Company, New York. Pp. 455-470.

Viada, S.T. 1980. Species composition and population levels of scleractinean corals within the Diploria-Montastrea-Porites zone of the East Flower Garden Bank., northwest Gulf of Mexico. M.S. Thesis Dept. of Oceanography, Texas A&M University, College Station, Texas. 96 pp.

Powell, E.N. and T.J. Bright. 1981. A thiobios does exist: Gnathostomulid domination of the canyon community at the East Flower Garden Brine Seep. Int. Rev. Ges. Hydrobiol. 66(5):675-683.

Powell, E.N., T.J. Bright, A. Woods, S.R. Gittings, and J. Johansen. 1981. The East Flower Garden Brine Seep: implications for benthic community structure. Rep. to U.S. Dept. of Commerce, NOAA Office of Coastal Zone Management. Contract No. NA80-AA-H-CZ118. Texas A&M University, Dept. of Oceanography Tech. Rep. No. 81-6-T.

Rezak, R. and T.J. Bright, eds. 1981a. Northern Gulf of Mexico topographic features study. (5 vol.). Final Report to the U.S. Dept. of the Interior, Bureau of Land Management. Contract #AA551-CT8-35.

Eiseman, N.J. and S.M. Blair. 1982. New records and range extensions of deepwater algae from East Flower Garden Bank, northwestern Gulf of Mexico. Contr. Mar. Sci. 25:21-26.

Kraemer, G.P. 1982. Population levels and growth rates of the scleractinian corals within the Diploria-Montastrea-Porites zones of the East and West Flower Garden banks. M.S. Thesis, Texas A&M University, College Station, Texas. 138 pp.

McGrail, D.W., R. Rezak and T.J. Bright. 1982c. Environmental studies at the Flower Gardens and selected banks. Northwest Gulf of Mexico, 1979-1981. Final Rept. to the U.S. Dept. of the Interior, Minerals Management Service, Gulf of Mexico OCS Region, New Orleans, Louisiana. Contract AA851-CT0-25. Available from NTIS, Springfield, Virginia: PB83-101303.

Woods, A. 1982. Effects of a sulfide system produced by a natural brine seep on sandy-bottom community structure at the East Flower Garden Bank, northwest Gulf of Mexico. M.S. Thesis, Texas A&M University, Dept. of Oceanography, College Station, Texas. 87 pp.

Boland, G.S., B.J. Gallaway, J.S. Baker,and G.S. Lewbel. 1983. Ecological effects on energy development on reef fish of the Flower Garden Banks. National Marine Fisheries, Galveston, Texas. Contract No. NA80-GA-C-00057. 466 pp.

Bright, T.J. 1983. Flower Garden reefs - fragile beauty. Texas Parks and Wildlife 41(4):8-11.

Dodge, R.E. and J.C. Lang 1983. Environmental correlates of hermatypic coral (*Montastrea annularis*) growth on the East Flower Garden Bank, northwest Gulf of Mexico. Limnol. Oceanogr. 28(2):228-240.

Gittings, S.R. 1983. Hard-bottom macrofauna of the East Flower Garden Brine Seep: impact of a long term, point-source brine discharge. M.S. Thesis, Texas A&M University, Dept. of Oceanography, College Station, Texas. 74 pp.

Powell, E.N., T.J. Bright, A. Woods, and S.R. Gittings. 1983. Meiofauna and the thiobios in the East Flower Garden Brine Seep. Mar. Biol. 73:269-283.

Rezak, R., T.J. Bright, and D.W. McGrail, eds. 1983. Reefs and banks of the northwestern Gulf of Mexico: their geological, biological, and physical dynamics. U.S. Dept. of the Interior, Minerals Management Service, Gulf of Mexico OCS Region, New Orleans, Louisiana. Dept. of Oceanography, Texas A&M University, Tech. Rept. No. 83-1-T.

Bright, T.J., G.P. Kraemer, G.A. Minnery and S.T. Viada. 1984. Hermatypes of the Flower Garden banks, northwestern Gulf of Mexico: a comparison to other western Atlantic reefs. Bull. Mar. Sci. 34(3):461-476.

Continental Shelf Associates, Inc. 1984. Impact assessment following an anchoring incident at the East Flower Garden Bank coral reef. Rept. to Mobil Producing Texas and New Mexico, Inc., Offshore Texas Division, The Woodlands, Texas.

Gittings, S.R., T.J. Bright, and E.N. Powell. 1984. Hard-bottom macrofauna of the East Flower Garden Brine Seep: impact of a long-term, sulfurous brine discharge. Contr. Mar. Sci. 27:105-125.

Minnery, G.A. 1984. Distribution, growth rates and diagenesis of coralline algal structures on the Flower Garden Banks, northwestern Gulf of Mexico. Ph.D. Dissertation, Texas A&M University, Dept. of Oceanography, College Station, Texas.

Zastrow, C.E. 1984. Age and growth of the red snapper, *Lutjanus campechanus*, and the vermilion snapper, *Rhomboplites aurorubens*, from the northwestern Gulf of Mexico. M.S. Thesis, Texas A&M University, Dept. of Oceanography, College Station, Texas.

Continental Shelf Associates, Inc. 1985. Environmental monitoring program for Platform "A," Lease OCS-G-2759, High Island Area, South Extension, East Addition, Block A-389, near the East Flower Garden Bank. Rept. to Mobil Producing Texas and New Mexico, Inc., The Woodlands, Texas. 353 pp. + appendices.

Baggett, L.S. 1985. Patterns of coral recruitment at the East Flower Garden bank. M.S. Thesis, Texas A&M University, Dept. of Oceanography, College Station, Texas. 55 pp.

Baggett, L.S. and T.J. Bright. 1985. Coral recruitment at the East Flower Garden Reef (northwestern Gulf of Mexico). Proc. 5th Int. Coral Reef Cong. 4:379-384.

Bright, T.J., D.W. McGrail, R. Rezak, G.S. Boland and A.R. Trippet. 1985. The Flower Gardens: a compendium of information. OCS Study MMS 85-0024. U.S. Dept. of the Interior Minerals Management Service, Gulf of Mexico OCS Region Office, New Orleans, Louisiana. 103 pp.

Dennis, G.D. 1985. Reef fish assemblages on hard banks in the northwestern Gulf of Mexico. M.S. Thesis, Texas A&M University, Dept. of Oceanography, College Station, Texas. 184 pp.

Gittings, S.R. 1985. Notes on barnacles (Cirripedia: Thoracica) from the Gulf of Mexico. Gulf Research Reports 8(1):35-41.

Jensen, P. 1985. The nematode fauna in the sulphide-rich brine seep and adjacent bottoms of the East Flower Garden, NW Gulf of Mexico. I. Chromadorida. Zool. Ser. 14:247-263.

McGowan, M.F. 1985. Icthyoplankton of the Flower Garden Banks, northwest Gulf of Mexico. Ph.D. Dissertation, University of Miami, Coral Gables, Florida.

Minnery, G.A., R. Rezak, and T.J. Bright. 1985. Depth zonation and growth form of crustose coralline algae: Flower Garden Banks, northwestern Gulf of Mexico. In: D.F. Toomey and M.H. Niteck (eds.). Paleoalgology: Contemporary Research and Applications. Springer-Verlag, Berlin. Pp. 237-246.

Nelson, R.S. 1985. Growth, mortality, and condition of cottonwick in the Gulf of Mexico. Proc. Ann. Conf. Southeast Assoc. Fish Wildl. Agencies 39:34-44.

Rezak, R., T.J. Bright, and D.W. McGrail. 1985. Reefs and banks of the Northwestern Gulf of Mexico: their geological, biological, and physical dynamics. New York: John Wiley and Sons. 259 pp.

Gittings, S.R. and T.J. Bright. 1986. Assessment of coral recovery following an incident of anchoring damage at the East Flower Garden Bank, northwest Gulf of Mexico. Final Report to NOAA National Marine Sanctuaries Division. Contract No. NA85AA-H-CZ015. 45 pp.

Gittings, S.R., G.D. Dennis, and H.W. Harry. 1986. Annotated Guide to the Barnacles of the Northern Gulf of Mexico. Sea Grant College Program, Texas A&M University, College Station, Texas. TAMU-SG-86-402. 36 pp.

Jensen, P. 1986a. The nematode fauna in the sulphide-rich brine seep and adjacent bottoms of the East Flower Garden, NW Gulf of Mexico. I. Chromadorida. Zool. Scr. 14:247-263.

Jensen, P. 1986b. The nematode fauna in the sulphide-rich brine seep and adjacent bottoms of the East Flower Garden, NW Gulf of Mexico. II. Monhysterida. Zool. Scr. 15:1-11.

Jensen, P. 1986c. The nematode fauna in the sulphide-rich brine seep and adjacent bottoms of the East Flower Garden, NW Gulf of Mexico. III. Enoplida. Zool. Scr. 15(2):93-99.

Jensen, P. 1986d. The nematode fauna in the sulphide-rich brine seep and adjacent bottoms of the East Flower Garden, NW Gulf of Mexico. III. Enoplida. Zool. Scr. 15:93-99.

Jensen, P. 1986c. The nematode fauna in the sulphide-rich brine seep and adjacent bottoms of the East Flower Garden, NW Gulf of Mexico. IV. Ecological aspects. Mar. Biol. 92:489-503.

Powell, E.N., T.J. Bright, and J.M. Brooks. 1986. The effects of sulfide and an increased food supply on the microfauna and macrofauna at the East Flower Garden brine seep. Helg. Meers. 40:57-82.

Gittings, S.R. and T.J. Bright. 1987. Mass mortality of *Diadema antillarum* at the Flower Garden banks, northwest Gulf of Mexico: effect on algae and coral cover. Benthic Ecology Meetings, Raleigh, North Carolina (abstract).

Dennis, G.D. and T.J. Bright. 1988. Reef fish assemblages on hard banks in the northwestern Gulf of Mexico. Bull. Mar. Sci. 43(2):280-307.

Martin, N. 1988. The Flower Gardens. Texas Shores (Texas A&M Sea Grant College Program). Volume 20, Number 4.

Gittings, S.R., K.J. Deslarzes, G.S. Boland, and T.J. Bright. 1989. Ecological monitoring at the Texas Flower Garden Banks. Oceans '89, Proceedings 1:59-62. IEEE Publ. No. 89CH2780-5.

Kendall, J.J. and T.J. Bright. 1989. An analysis of biotic interactions on the East Flower Garden Bank (Gulf of Mexico) using short-term time-lapse photography. Proc.: American Academy of Underwater Sciences, 9th Annual Symposium. Pp. 175-190.

Continental Shelf Associates, Inc. 1990. Environmental monitoring program for Exploratory Well #1, Lease OCS-G-6264, High Island Area, South Extension, East Addition, Block A-401, near the West Flower Garden Bank. Rept. to Union Oil Company of California, Houston, Texas. 35 pp. + appendices.

Gittings, S.R., G.S. Boland, B.S. Holland, and K.J.P. Deslarzes. 1990. Ecological monitoring program at the Flower Garden Banks. In: Proceedings: Tenth Annual Information

Transfer Meeting. OCS Study MMS 90-0027. U.S. Dept. of the Interior. Minerals Management Service, Gulf of Mexico OCS Region, New Orleans, Louisiana. Pp. 203-206.

Gittings, S.R., T.J. Bright, K.J.P. Deslarzes, and B.S. Holland. 1990. Ecological monitoring on the Flower Garden Banks: study design and field methods. Proc.: American Academy of Underwater Sciences, 10th Annual Symposium. Pp. 107-118.

Minnery, G.A. 1990. Crustose coralline algae from the Flower Garden Banks, northwestern Gulf of Mexico: controls on distribution and growth morphology. J. Sed. Pet. 60:992-1007.

Rezak, R., S.R. Gittings, and T.J. Bright. 1990. Biotic assemblages and ecological controls on reefs and banks of the northwest Gulf of Mexico. Am. Zool. 30:23-35.

Bright, T.J. 1991. First direct sighting of star coral spawning. Texas Shores (Texas A&M University Sea Grant Program) 24(1):2.

Bright, T.J., S.R. Gittings, and R. Zingula. 1991. Occurrence of Atlantic reef corals on offshore platforms in the northwestern Gulf of Mexico. NE Gulf Sci. 12(1):55-60.

Gittings, S.R. and G.S. Boland. 1991. Long-term monitoring on the Flower Garden Banks: study design and field methods. In: Proceedings: Eleventh Annual Gulf of Mexico Information Transfer Meeting. OCS Study MMS 91-0040. U.S. Dept. of the Interior, Minerals Management Service, Gulf of Mexico OCS Region, New Orleans, Louisiana. Pp. 24-28.

Holland, B.S. 1991. Mitochondrial DNA sequence variation of the 16s rRNA gene from five Western Atlantic populations of the coral *Montastrea annularis*. M.S. Thesis, Department of Oceanography, Texas A&M University, College Station, Texas. 56 pp.

Bright, T.J., S.R. Gittings, G.S. Boland, K.J.P. Deslarzes, C.L. Combs, and B.S. Holland. 1992. Mass spawning of reef corals at the Flower Garden Banks, NW Gulf of Mexico. Proceedings: 7th International Coral Reef Symposium, Guam. 1:500 (abstract).

Deslarzes, K.J.P. 1992. Long-term monitoring of reef corals at the Flower Garden Banks (northwest Gulf of Mexico): reef coral population changes and historical incorporation of barium in *Montastrea annularis*. Ph.D. Dissertation, Texas A&M University, Dept. of Oceanography, College Station, Texas. 170 pp.

Gittings, S.R. 1992. Historic data on Gulf of Mexico reef shows compatibility with drilling, production. Offshore Incorporating The Oilman (May 1992). Pp. 33-36.

Gittings, S.R., G.S. Boland, K.J.P. Deslarzes, C.L. Combs, B.S. Holland, and T.J. Bright. 1992. Mass spawning and reproductive viability of reef corals at the East Flower Garden Bank, northwest Gulf of Mexico. Bull. Mar. Sci. 51(3):420-428.

Gittings, S.R., G.S. Boland, K.J.P. Deslarzes, D.K. Hagman, and B.S. Holland. 1992. Long-term monitoring at the East and West Flower Garden Banks. OCS Study MMS 92-0006. U.S. Dept. of the Interior, Minerals Management Service, Gulf of Mexico OCS Region, New Orleans, Louisiana. 206 pp.

Gittings, S.R., K.J.P. Deslarzes, and D.K. Hagman. 1992. Long-term monitoring on the Flower Garden Banks: preliminary results. In: Proceedings: Twelfth Annual Information Transfer Meeting, November 1991. OCS Study MMS 92-0027. U.S. Dept. of the

Interior, Minerals Management Service, Gulf of Mexico OCS Region, New Orleans, Louisiana. 560 pp.

Gittings, S.R., K.J.P. Deslarzes, D.K. Hagman, and G.S. Boland. 1992. Reef coral populations and growth on the Flower Garden Banks, northwest Gulf of Mexico. Proc. 7th Int. Coral Reef Symp., Guam. 1:90-96.

Hagman, D.K. 1992. Random transect photography: use in long-term monitoring of coral populations at the Flower Garden Banks. M.S. Thesis, Texas A&M University, Dept. of Oceanography, College Station, Texas. 105 pp.

Hagman, D.K. and S.R. Gittings. 1992. Coral bleaching on high latitude reefs at the Flower Garden Banks, NW Gulf of Mexico. Proc. 7th Int. Coral Reef Symp., Guam. 1:38-43.

Holland, B.S., S.R. Gittings, S.K. Davis, and T.J. Bright. 1992. Application of mitochondrial DNA sequencing to studies of scleractinian larval dispersal and gene flow. Proc. 7th Int. Coral Reef Symp., Guam. 2:657 (abstract).

Gittings, S.R., T.J. Bright, and D.K. Hagman. 1993. Protection and monitoring of reefs on the Flower Garden Banks, 1972-1992. In: Ginsburg, R.N. (compiler). Proc. Coll. on Global Aspects of Coral Reefs: Healths, Hazards and History. Miami, Florida. Pp. 181-187.

Gittings, S.R., G.S. Boland, C.R.B. Merritt, J.J. Kendall, K.J.P. Deslarzes, and J. Hart. 1994. Mass spawning by reef corals in the Gulf of Mexico and Caribbean Sea. A Report on Project Reef Spawn '94. Flower Gardens Fund Technical Series Report Number 94-03. College Station, Texas. 24 pp.

Gittings, S.R. and D.K. Hagman. 1994. Reef Research Rendezvous. A Report on Science in the Flower Garden Banks National Marine Sanctuary. Flower Gardens Fund Technical Series Report Number 94-02.

Childs, J.N., E.L. Hickerson, and K.J.P. Deslarzes. 1996. Spatial and temporal resource use of the Flower Garden Banks by charismatic megafauna. In: Proceedings: Fifteenth Information Transfer Meeting, December 1995. OCS Study MMS 96-0056. U.S. Dept. of the Interior, Minerals Management Service, Gulf of Mexico OCS Region, New Orleans, Louisiana. Pp. 74-79.

Hagman, D.K. 1996. Mass spawning, in vitro fertilization, and culturing of corals at the Flower Garden Banks. In: Proceedings: Fifteenth Information Transfer Meeting, December 1995. OCS Study MMS 96-0056. U.S. Dept. of the Interior, Minerals Management Service, Gulf of Mexico OCS Region, New Orleans, Louisiana. Pp. 62-67.

Hagman, D.K., G.S. Boland, S.R., Gittings, and K.J.P. Deslarzes. 1997. Mass spawning in the Caribbean: an unfolding puzzle of variation by species, climate and geographic location. Proc. 8th Int. Coral Reef Symp., Panama. (abstract).

Pattengill, C.V., B.X. Semmens, and S.R. Gittings. 1997. Reef fish trophic structure of the Flower Gardens and Stetson Bank, NW Gulf of Mexico. Proc. 8th Int. Coral Reef Symp., Panama. 1:1023-1028.

Pattengill, C.V., B.X. Semmens, and C.L. Ostrom. 1996. Reef fish monitoring at the Flower Garden Banks National Marine Sanctuary and Stetson Bank, northwest Gulf of Mexico. In: Proceedings: Fifteenth Information Transfer Meeting, December 1995. OCS Study

MMS 96-0056. U.S. Dept. of the Interior, Minerals Management Service, Gulf of Mexico OCS Region, New Orleans, Louisiana. Pp. 67-74.

Viada, S.T. 1996. Long-term monitoring at the East and West Flower Garden Banks. In: Proceedings: Fifteenth Information Transfer Meeting, December 1995. OCS Study MMS 96-0056. U.S. Dept. of Interior, Minerals Management Service, Gulf of Mexico OCS Region, New Orleans, Louisiana. Pp. 55-62.

Childs, J.N. In press. Range extension of *Mobula tarapacana* in the northwestern Gulf of Mexico. Gulf of Mexico Science.

Rooker, J.R., G.J. Holt, C.V. Pattengill, and Q. Dokken. 1997. Fish assemblages on artificial and natural reefs in the Flower Garden Banks National Marine Sanctuary, U.S.A. Coral Reefs 16(2):83-92.

Geology

Shepard, F.P. 1937. Salt domes related to Mississippi submarine trough. Geol. Soc. Am. Bull. 48:1349-1361

Carsey, J.B. 1950. Geology of Gulf coastal area and continental shelf. AAPG Bull. 34:361-385.

Stetson, H.C. 1953. The sediments of the western Gulf of Mexico, Part 1 - The continental terrace of the western Gulf of Mexico: Its surface sediments, origin, and development. Papers in Phys. Oceanogr. Meteorol., M.I.T./W.H.O.I. 12(4):1-45.

Nettleton, L.L. 1957. Gravity survey over a Gulf coast continental shelf mount. Geophys. 22:630.

Curray, J.R. 1960. Sediments and history of Holocene transgression, continental shelf, northwest Gulf of Mexico. In: Shepard, F.P., F.B. Phleger, and T.H. Van Andel (eds.). Recent Sediments, Northwest Gulf of Mexico. AAPG, Tulsa, Oklahoma. Pp. 221-266.

Levert, C.F. and H.C. Ferguson, Jr. 1969. Geology of the Flower Garden Banks, northwest Gulf of Mexico. Trans. Gulf Coast Assoc. Geological Soc. 19:89-100.

Edwards, G.S. 1971. Geology of the West Flower Garden Bank. Texas A&M Sea Grant Publ., TAMU-SG-71-215. 199 pp.

Rezak, R. and G.S. Edwards. 1972. Carbonate sediments of the Gulf of Mexico. Texas A&M Ocean. Stud. 3:263-280.

Rezak, R. and W.R. Bryant. 1973. West Flower Garden Bank. Trans. Gulf Coast Assoc. Geol. Soc., Pp. 377-382.

Sidner, B.R. and C.W. Poag. 1973. Foraminiferal evidence of late quaternary sea level fluctuations from the West Flower Garden Bank. Texas A&M University Sea Grant College, College Station, Texas. TAMU-SG-73-213. 124 pp.

Rezak, R. 1977. West Flower Garden Bank, Gulf of Mexico. Stud. Geol. 4:27-35.

Rezak, R. and T.J. Bright, eds. 1981a. Northern Gulf of Mexico topographic features study. (5 vol.). Final report to the U.S. Dept. of the Interior, Bureau of Land Management, New Orleans, Louisiana. Contract No. AA551-CT8-35.

Rezak, R. and T.J. Bright. 1981b. Seafloor instability at the East Flower Garden Bank, northwest Gulf of Mexico. Geo-Marine Lett. 1(2):97-103.

McGrail, D.W., R. Rezak and T.J. Bright. 1982c. Environmental studies at the Flower Gardens and selected banks. Northwest Gulf of Mexico, 1979-1981. Final report to the U.S. Dept. of the Interior, Minerals Management Service, Gulf of Mexico OCS Region, New Orleans, Louisiana. Contract AA851-CT0-25. Available from NTIS, Springfield, Virginia: PB83-101303.

Stafford, J.M. 1982. An evaluation of the carbonate cements and their diagenesis on selected banks, outer continental shelf, northern Gulf of Mexico. M.S. Thesis, Texas A&M University, Dept. of Oceanography, College Station, Texas. 78 pp.

Rezak, R., T.J. Bright, and D.W. McGrail, eds. 1983. Reefs and banks of the northwestern Gulf of Mexico: their geological, biological, and physical dynamics. U.S. Dept. of the Interior, Minerals Management Service, Gulf of Mexico OCS Region, New Orleans, Louisiana. Dept. of Oceanography, Texas A&M University, Tech. Rept. No. 83-1-T.

Bright, T.J., D.W. McGrail, R. Rezak, G.S. Boland, and A.R. Trippet. 1985. The Flower Gardens: a compendium of information. OCS Study MMS 85-0024. U.S. Dept. of the Interior, Minerals Management Service, Gulf of Mexico OCS Region, New Orleans, Louisiana. 103 pp.

Rezak, R., T.J. Bright, and D.W. McGrail. 1985. Reefs and banks of the Northwestern Gulf of Mexico: their geological, biological, and physical dynamics. New York: John Wiley and Sons. 259 pp.

Geochemistry

Bernard, B.B., J.M. Brooks, and W.M. Sackett. 1976. Natural gas seepage in the Gulf of Mexico. Earth Planet Sci. Lett. 31:47-54.

Jorgensen, B.B. 1977. Bacterial sulfate reduction within reduced microniches of oxidized marine sediments. Mar. Biol. 41:7-17.

Brooks, J.M., T.J. Bright, B. Bernard, and C. Schwab. 1979. Chemical aspects of a brine seep at the East Flower Garden Bank, northwestern Gulf of Mexico. Limnol. Oceanogr. 24(4):735-745.

Lauer, R.D. 1979. Sulfur deposition in the East Flower Gardens, Gulf of Mexico. M.S. Thesis, Florida State University, Tallahassee. 33 pp.

Deslarzes, K.J.P., P.N Boothe, and S.R. Gittings. 1992. Incorporation of trace elements in the coral Montastraea annularis at the West Flower Garden Bank, northwest Gulf of Mexico. In: Proceedings: Twelfth Annual Information Transfer Meeting, November 1991. OCS Study MMS 92-0027. U.S. Dept. of the Interior, Minerals Management Service, Gulf of Mexico OCS Region, New Orleans, Louisiana. 560 pp.

Deslarzes, K.J.P., P.N. Boothe, B.J. Presley, and G.L. Steinmetz. 1995. Historical incorporation of barium in the reef building coral Montastrea annularis at the Flower Garden Banks, northwest Gulf of Mexico. Mar. Poll. Bull. 30(11):718-722.

Slowey, N.C. and T.J. Crowley. 1995. Coral cores from the Flower Gardens: a new tool for studying climate. Quarterdeck (Texas A&M Dept. of Oceanography) 3(3):4-7.

Slowey, N.C. and T.J. Crowley. 1995. Interdecadal variability of Northern Hemisphere circulation recorded by Gulf of Mexico corals. Geophysical Research Letters 22(17):2345-2348.

Physics

Etter, P.C and J.D. Cochrane. 1975. Water temperature on the Texas-Louisiana shelf. Marine Advisory Bull., Texas A&M Sea Grant Publ., TAMU-SG-75-604.

McGrail, D.W. 1977. Shelf edge currents and sediment transport in the northwest Gulf of Mexico. Trans. Am. Geophys. Union 58:1160 (abstract).

McGrail, D.W. and R. Rezak. 1977. Internal waves and the nepheloid layer on continental shelf in the Gulf of Mexico. Trans. Gulf Coast Assoc. Geol. Soc. 27:123-124.

McGrail, D.W. 1978. Boundary layer processes, mixed bottom layers, and turbid layers on continental shelves. Trans. Am. Geophys. Union 59:1110 (abstract).

McGrail, D.W. and D.W. Huff. 1978. Shelf sediment and local flow phenomena: in situ observations. Program AAPG-SEPM Ann. Conv. 93 pp.

Rezak, R. and T.J. Bright, eds. 1981a. Northern Gulf of Mexico topographic features study. (5 vol.). Final report to the U.S. Dept. of the Interior, Bureau of Land Management, New Orleans, Louisiana. Contract No. AA551-CT8-35.

McGrail, D.W. 1982. Anomalous flow on the outer continental shelf in the Gulf of Mexico and its effects on sediment transport. Trans. Am. Geophys. Union 63(3):65 (abstract).

McGrail, D.W., T.M. Cecil, and F.B. Halper. 1982a. Stacking of nepheloid and boundary layers at the shelf edge in the Gulf of Mexico. Trans. Am. Geophys. Union 63:988 (abstract).

McGrail, D.W., F. Halper, D. Horne, T. Cecil, and M. Carnes. 1982b. Time series data report. Northern Gulf of Mexico topographic features study. U.S. Dept. of the Interior, Bureau of Land Management. Contract No. AA851-CT0-25. Dept. of Oceanography, Texas A&M University, Tech. Rep. 82-5-T. 155 pp.

McGrail, D.W., R. Rezak, and T.J. Bright. 1982c. Environmental studies at the Flower Gardens and selected banks, northwest Gulf of Mexico, 1979-1981. Final report to the U.S. Dept. of the Interior, Minerals Management Service, Gulf of Mexico OCS Region, New Orleans, Louisiana. Contract No. AA851-CT0-25. Available from NTIS, Springfield, Virginia: PB83-101303.

McGrail, D.W. and M.R. Carnes. 1983. Shelf edge dynamics and the nepheloid layer. In: D.J. Stanley and G.T. Moore (eds.). Shelf break: critical interface on continental margins. Soc. Econ. Paleontol. Mineral., Special Pub. No. 33. Pp. 251-264.

Rezak, R., T.J. Bright, and D.W. McGrail, (eds.). 1983. Reefs and banks of the northwestern Gulf of Mexico: their geological, biological, and physical dynamics. U.S. Dept. of the Interior, Minerals Management Service, Gulf of Mexico OCS Region, New Orleans, Louisiana. Dept. of Oceanography, Texas A&M University, Tech. Rept. No. 83-1-T.

Bright, T.J., D.W. McGrail, R. Rezak, G.S. Boland, and A.R. Trippet. 1985. The Flower Gardens: a compendium of information. OCS Study MMS 85-0024. U.S. Dept. of the

Interior, Minerals Management Service, Gulf of Mexico OCS Region, New Orleans, Louisiana. 103 pp.

Rezak, R., T.J. Bright, and D.W. McGrail. 1985. Reefs and banks of the northwestern Gulf of Mexico: their geological, biological, and physical dynamics. New York: John Wiley and Sons. 259 pp.

Management

Archer, J.H. 1988. The proposed Flower Garden Banks Marine Sanctuary: protecting marine resources under international law. Oceanus 31(1):54-58.

Kendrick, A.W. 1991. Designating marine protected areas in the United States and Ecuador: understanding the decision-making process. M.S. Thesis, Dept. of Wildlife and Fisheries Sciences, Texas A&M University, College Station, Texas. 88 pp.

U.S. Dept. of Commerce, National Oceanic and Atmospheric Administration. 1991. Final environmental impact statement and management plan for the proposed Flower Garden Banks National Marine Sanctuary. Sanctuaries and Reserves Division, Office of Ocean and Coastal Resource Management, 1825 Connecticut Ave., Suite 714, Washington, D.C. 20235. 145 pp.

Gittings, S.R., T.J. Bright, and D.K. Hagman. 1993. Protection and monitoring of reefs on the Flower Garden Banks, 1972-1992. In: Ginsburg, R.N. (compiler). Proc. Coll. on Global Aspects of Coral Reefs: Healths, Hazards and History. Miami, Florida. Pp. 181-187.

Gittings, S.R. and C.L Ostrom. 1994. Handshakes curb heartaches: cooperation the key to conservation at the Flower Gardens. In: Proceedings: Fourteenth Information Transfer Meeting, 1994. OCS Study MMS 96-0024. U.S. Dept. of the Interior, Minerals Management Service, Gulf of Mexico OCS Region, New Orleans, Louisiana. Pp. 49-54.

Gittings, S.R. 1995. Conserving marine biodiversity: the potential and limitations of protected areas. Current: The Journal of Marine Education 13(2):22-25.

Gittings, S.R. 1995. Down under . . . out yonder: Texas A&M scientists immersed in history, protection, and research at the Flower Gardens. Quarterdeck (Texas A&M Dept. of Oceanography) 3(3):8-11.

Gittings, S.R., C.L. Ostrom, and K.J.P. Deslarzes. 1997. Regulation by reason: science and management in the Flower Gardens Sanctuary, northwest Gulf of Mexico. Proc. 8th Int. Coral Reef Symp., Panama.

Lugo-Fernandez, A. 1996. The Minerals Management Service Flower Garden Banks National Marine Sanctuary oil spill risk assessment: an example of partnership. In: Proceedings: Fifteenth Information Transfer Meeting, December 1995. OCS Study MMS 96-0056. U.S. Dept. of the Interior, Minerals Management Service, Gulf of Mexico OCS Region, New Orleans, Louisiana. Pp. 79-80.

Ostrom, C.L. and S.R. Gittings. 1996. Flower Garden Banks National Marine Sanctuary: platform, partnerships, and resource protection. MTS Journal 30(2):3-7.

APPENDIX 2. Gulf of Mexico Explosive Removal of Structures (Biological Opinion by the National Marine Fisheries Service)

From: U.S. Dept. of the Interior, Minerals Management Service. 1990. Gulf of Mexico Sales 131, 135, and 137: Central, Western, and Eastern Planning Areas. Final Environmental Impact Statement. Volume II: Sections IV.D. through IX. OCS EIS/EA MMS 90-0042. U.S. Dept. of the Interior, Minerals Management Service, Gulf of Mexico OCS Region, New Orleans, Louisiana. Pp. B-21 through B-27. Available for NTIS, Springfield, Virginia: PB90-273590.

MARCH 3, 1849

The Department of the Interior Mission

As the Nation's principal conservation agency, the Department of the Interior has responsibility for most of our nationally owned public lands and natural resources. This includes fostering sound use of our land and water resources; protecting our fish, wildlife, and biological diversity; preserving the environmental and cultural values of our national parks and historical places; and providing for the enjoyment of life through outdoor recreation. The Department assesses our energy and mineral resources and works to ensure that their development is in the best interests of all our people by encouraging stewardship and citizen participation in their care. The Department also has a major responsibility for American Indian reservation communities and for people who live in island territories under U.S. administration.

The Minerals Management Service Mission

As a bureau of the Department of the Interior, the Minerals Management Service's (MMS) primary responsibilities are to manage the mineral resources located on the Nation's Outer Continental Shelf (OCS), collect revenue from the Federal OCS and onshore Federal and Indian lands, and distribute those revenues.

Moreover, in working to meet its responsibilities, the **Offshore Minerals Management Program** administers the OCS competitive leasing program and oversees the safe and environmentally sound exploration and production of our Nation's offshore natural gas, oil and other mineral resources. The MMS **Royalty Management Program** meets its responsibilities by ensuring the efficient, timely and accurate collection and disbursement of revenue from mineral leasing and production due to Indian tribes and allottees, States and the U.S. Treasury.

The MMS strives to fulfill its responsibilities through the general guiding principles of: (1) being responsive to the public's concerns and interests by maintaining a dialogue with all potentially affected parties and (2) carrying out its programs with an emphasis on working to enhance the quality of life for all Americans by lending MMS assistance and expertise to economic development and environmental protection.

Minerals Management Service
Gulf of Mexico Region

Managing America's offshore energy resources

Protecting America's coastal and marine environments