Contractor Report
USGS/BRD/CR--1997-0006
OCS Study MMS 97-0036

Cumulative Ecological Significance of Oil and Gas Structures in the Gulf of Mexico: Information Search, Synthesis, and Ecological Modeling; Phase I, Final Report

U.S. Department of the Interior
U.S. Geological Survey
Biological Resources Division

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

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Prepared under BRD contract
1445-CT96-0005
by
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in cooperation with the

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

PROJECT COOPERATION

This study was procured to meet information needs identified by the Minerals Management Service (MMS) in concert with the U.S. Geological Survey, Biological Resources Division (BRD).

DISCLAIMER

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Abstract. Bibliographic searches were made of eight databases for information and data describing the environmental characteristics and biota of the Gulf of Mexico. Nearly 400 references were obtained describing the biota, but fewer than half contained adequate information to characterize the life history of target species. The level of detail obtained, while informative, was not particularly useful for the modeling exercise. The environmental data yielded by the searches yielded much more useful information for modeling purposes, namely mapped coverages depicting environmental gradients. These coverages, along with the biological catch data contained in several extant biological databases are enabling the preparation of Habitat Suitability Index (HSI) models for selected key species. A significant finding of Phase I is that petroleum platform habitat is but a small fraction of the total reef habitat found in the central and western Gulf. However, the total numbers of red snapper estimated to occupy petroleum platforms correspond favorably to the Gulf of Mexico Fisheries Management Council's estimate of the total red snapper stock. Possible implications are that the total stock may be much larger than previously thought, or that platforms may be far more important than their area would imply, or that one or both the stock estimates are in error.

Key Words: oil and gas structures, Habitat Suitability Index, ecological models, Gulf of Mexico

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1.0 Introduction

On the order of 4,500 platforms have been placed in the Gulf since 1938 and are characterized by extensive biological communities (e.g. Gallaway and Lewbel 1982). Petroleum platform reefs differ from natural reefs in a number of significant ways, but two of the primary differences are that platforms span the entire water column and many, if not most, occur in areas where natural reefs are absent. It may prove more ecologically accurate to consider platform reefs as a new and distinct habitat rather than to assume that they are merely additions to existing reef systems. In either case, they have, over the decades, become a familiar and productive environment highly valued by man. After several decades, many of the offshore oil and gas fields areas are being exhausted, and the platforms are required to be removed. These removals have engendered a new controversy—what will the Gulf be like when the platforms are gone?

LGL Ecological Research Associates, Inc. (LGL) was awarded National Biological Service (NBS)[1] Contract No. 1445-CT96-005 on 27 February 1996 to conduct a study to address the above-stated question. Project team composition also include representatives of Science Applications International Corporation, Inc. (SAIC) and Louisiana State University (LSU). The purpose of the study is to model the cumulative ecological significance of offshore oil and gas structures in the Gulf of Mexico, with the particular goal of being able to provide a qualitative or semi-quantitative index to the effects of structure removals and/or relocation. The models are being developed for use by the Minerals Management Service (MMS) for evaluating effects of platform removals and making management decisions.

We are approaching the problem from a habitat perspective using Habitat Evaluation Procedures (HEP) developed by the U.S. Department of the Interior (USDI) (1980, 1982) to develop Habitat Suitability Index (HSI) models for key species. HSI models require a numerical rating of habitat under pre- and post-scenarios. An HSI is a unitless number bounded by 0 and 1, where 0 indicates unsuitable habitat and 1 indicates optimum habitat. Phase I has been dedicated to gathering the information necessary to develop the HSI models for the species or guilds in question. Development and use of HSI models require a clear understanding of environmental conditions in the modeled region and the habitat requirements of the species being evaluated. A literature and data search were conducted during Phase I to obtain this information.

The HSI modeling procedure we are using consists of five basic steps: 1) definition of system boundaries; 2) selection of marine guilds or evaluation species; 3) a determination of the total area and types of available habitats; 4) development of suitability indices for habitats and determination of the overall HSI for available habitat; and 5) prediction of future HSI's as platforms are removed and/or added. Of these, steps 1-3 have been largely accomplished and steps 4 and 5 are in progress.

This project is being conducted in two phases organized into five tasks (Fig. 1). This report covers Phase I activities consisting of three interrelated tasks: 1) Model Evaluation and Refinement, 2) Literature and Data Search, and 3) Development of Life History Syntheses and Environmental Characterizations. Two types of data and/or information were (are) needed for this project. The first type is the geographic distributions of physical habitat type (platforms, reefs, etc.), habitat variables of consequence (e.g., temperature, salinity, dissolved oxygen), and

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[1] NBS is presently equivalent to the Biological Resources Division of the U.S. Geological Survey, U.S. Department of the Interior.

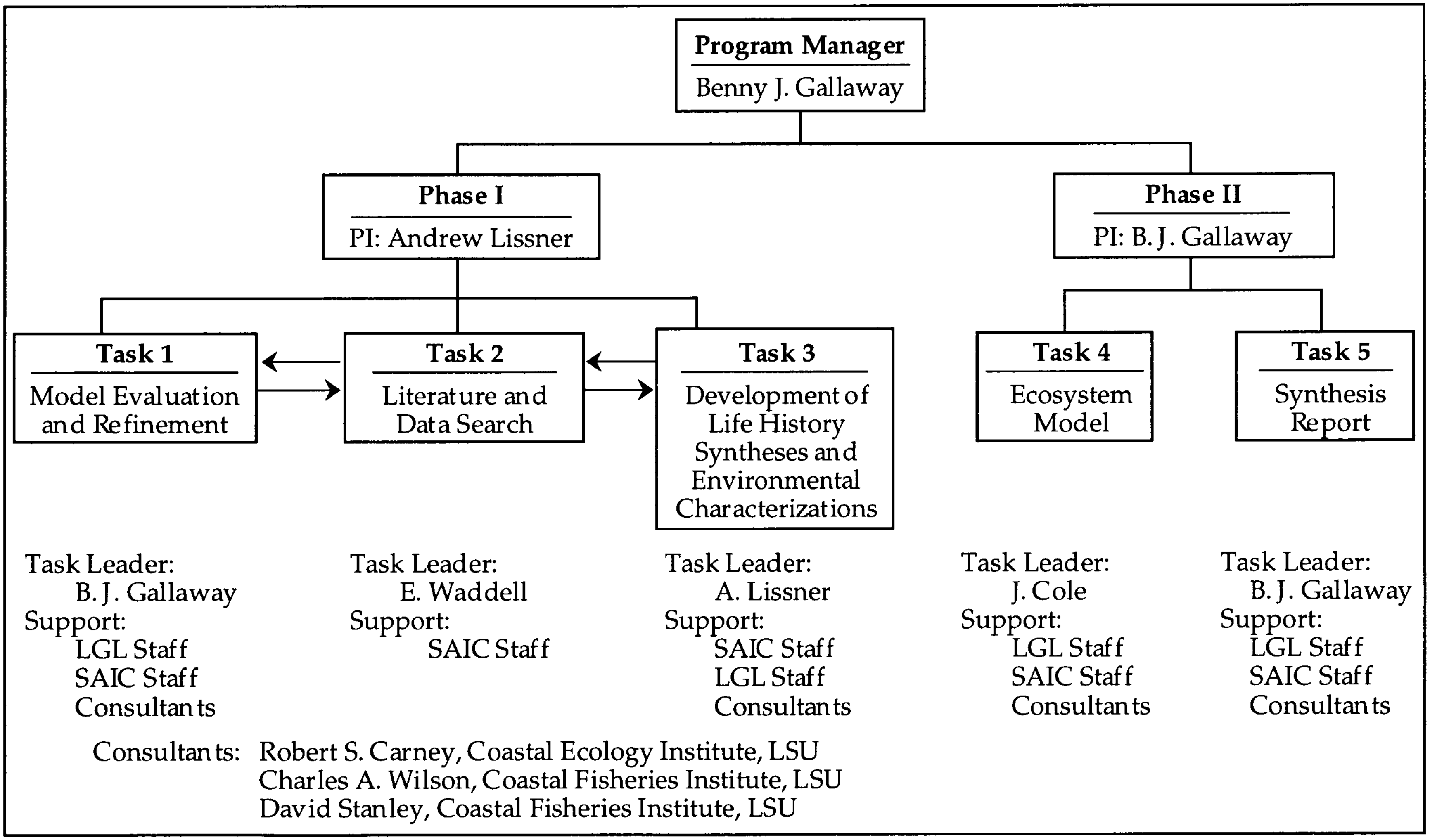


Figure 1. Project structure for first and second level elements of this study.

abundance of key organisms in the northern Gulf, all of which are necessary to model the relative value of regional habitats. The second type of data are those showing the relationships between key habitat variables and the abundance or standing stocks of the evaluation species. These data were considered necessary to bound the suitability index relationships.

Much of the required data of the first type were already directly available to the LGL team, having been acquired from previous projects. Additional data of this sort were obtained during Phase I including the raw data supporting the MMS Bio-Atlas for the northwestern Gulf (Darnell et al. 1983). A key source of distributional data are the SEAMAP and Fall Groundfish Survey data obtained from the National Marine Fisheries Service (NMFS). This data set is very large and has required a major effort to get it into usable form. By far the most incomplete data necessary for the habitat modeling at the start of the project were physical oceanographic coverages. Available data as of March 1997 are presented herein.

The second type of data demonstrating the dependencies of the evaluation species on key habitat factors such as temperature, salinity, and dissolved oxygen are scattered throughout the published and grey literature. Compiling and providing a synthesis of such data comprised a large part of work conducted during Phase I. Available data are summarized herein.

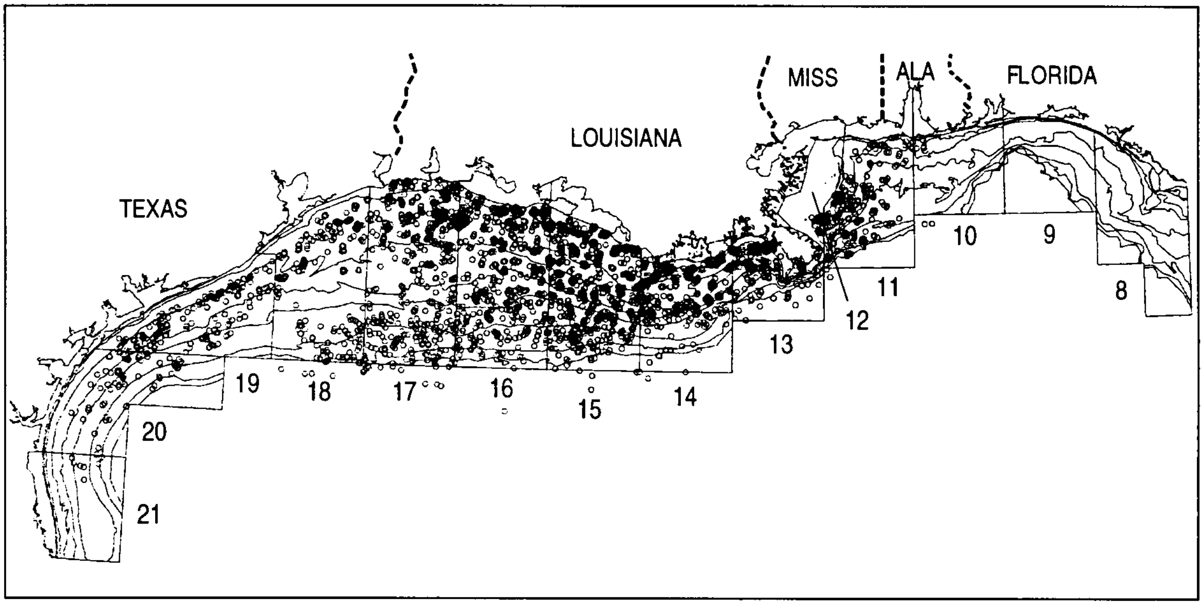
In this report, we first describe the development and status of the habitat models and provide a preliminary example for juvenile red snapper (Section 2). This section is followed by a description of the results of the directed information and data acquisition effort (Section 3). The information obtained is then summarized in the form of species accounts (Section 4) and descriptions of environmental features of the Gulf (Section 5). A summary of Phase I findings constitutes Section 6 and references are provided in Section 7.

2.0 Habitat Modeling

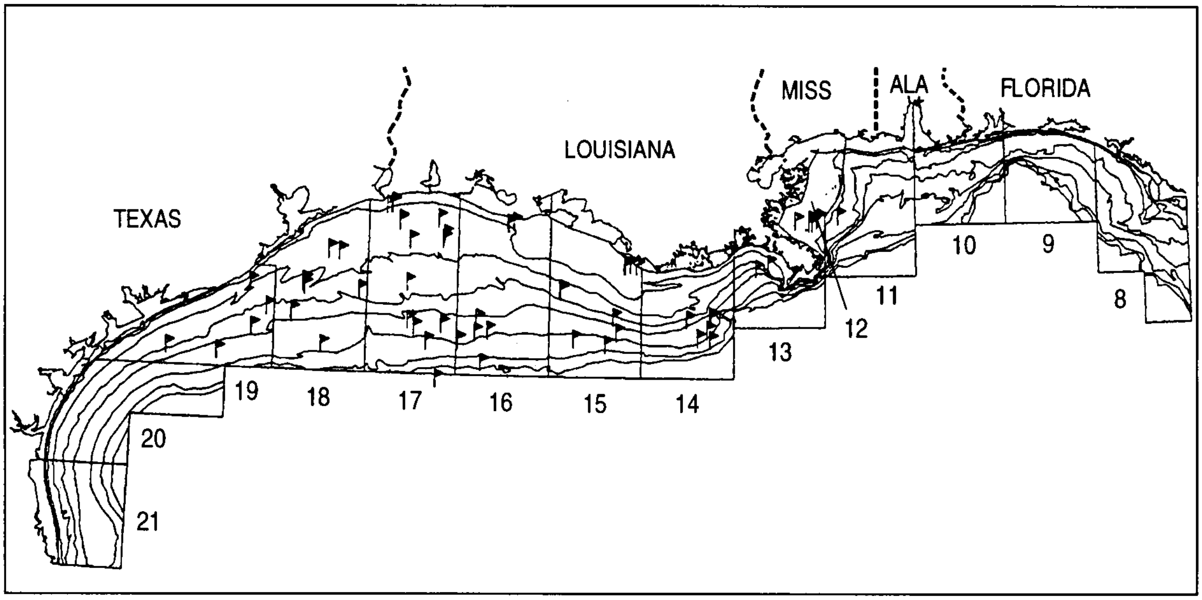
The first scheduled event of the project was an initiation meeting/workshop which was held in Bryan, Texas during 12-14 March 1996. This meeting was attended by Robert Meyer (NBS); Pat Roscigno (MMS); Van Waddell (SAIC); Robert Carney, Dave Stanley, and Chuck Wilson, LSU; and by LGL staff. The study area to be modeled was defined as the northern Gulf of Mexico characterized by the presence of offshore petroleum platforms, namely NMFS statistical reporting areas 10-21, or essentially that part of the offshore Gulf from the westernmost part of the Florida panhandle to the Texas-Mexico border ((Panel A, Fig. 2). Panel B of Figure 2 uses the 1994 data to show an example of the number and distribution of annual platform removals.

The databases to be used in the model that were already available in a Geographic Information System (GIS) coverage or that were obtained during Phase I by LGL are identified in Table 1. In the workshops, the group developed a preliminary list of potential evaluation species or guilds that might be modeled if sufficient data were available, and habitat factors of likely significance to these species. The preliminary key word lists focused on 1) communities, assemblages, and species of algae and invertebrates that colonize the platforms (the so-called fouling community), 2) specific species of fishes that might be modeled as the basis for habitat evaluations, and 3) a more general list including habitat factors that may prove of importance (Table 2).

In terms of diversity, the algal-invertebrate biota of the structures is the most complex of the petroleum platform ecosystems. However, we suspected that, from a structural and functional standpoint, knowledge of all this complexity was not necessary. In our view, structure biota acts as a filter removing matter actively and passively from the moving water



A) Distribution of offshore oil and gas structures in the federal waters of the Gulf of Mexico.



B) Offshore oil and gas structures removed from the Gulf of Mexico in 1994.

Figure 2. Distribution of oil and gas structures and the distribution of platforms removed in 1994. Source: LGL/TSA GOM GIS.

Table 1. GIS coverages and Oracle tables held by LGL.

Coverage	Coverage Source, Data Source
Shoreline Map, Gulf of Mexico (GOM)	NMFS
Statistical Area Map, GOM	NMFS
Statistical Area/Depth Zone Map, Western GOM	LGL, NMFS
Bathymetry, GOM	MMS
Dead Zones, 85, 86, 90-94, GOM	LGL, LUMCON
NMFS Shrimp Bycatch, GOM	
Characterization	
Turtle data	LGL, NMFS
Station data	LGL, NMFS
Evaluation	
Turtle data	LGL, NMFS
Station data	LGL, NMFS
NMFS Shrimp Catch, GOM	
White, 86-94	LGL, NMFS
Brown, 86-94	LGL, NMFS
Pink, 86-94	LGL, NMFS
Other, 86-94	LGL, NMFS
Shrimp Boat Aerial Surveys, 1994, GOM	LGL, USCG
NMFS Shrimping Effort, 82-94, GOM	LGL, NMFS
NMFS Shrimp Boat Observer Data	
Henwood and Stuntz	
Turtle data	LGL, NMFS
Effort data	LGL, NMFS
TED Studies	
1. Turtle data	LGL, NMFS
Effort data	LGL, NMFS
2. Turtle data	LGL, NMFS
Effort data	LGL, NMFS
STSSN Turtle Strandings, 80-95, GOM	LGL, NMFS
TAMU Turtle Satellite Tracks	LGL, TAMU
TAMU Turtle Radio Tracks, GOM	LGL, TAMU
Platforms in Federal Waters, GOM	MMS
Platforms in State and Federal Waters, GOM	LGL, NMFS, USCG
Removed Platforms, GOM 93-94	LGL, NMFS, MMS
Artificial Reef Permit Areas, GOM	MMS
Artificial Reef Planning Areas, GOM	MMS
Artificial Reef Sites, GOM	MMS
Topographic Features, Western GOM	MMS
Pinnacle Features, GOM	MMS
SEAMAP	NMFS
Fall Groundfish Survey	NMFS
Offshore and Nearshore "Hang" Books	Texas A&M Sea Grant

Table 2. Key words for platform habitat models.

A) Algal-Invertebrate Component

General Terms

Biofouling Community
Biofouling Assemblage
Marine Fouling Community
Marine Fouling Assemblage
Barnacle Community
Barnacle Assemblage
Bryozoa Community
Bryozoa Assemblage
Sponge Community
Sponge Assemblage
Hydroid Community
Hydroid Assemblage

Genus/Species

Haliclona
Syncorne eximia
Tubularia crocea
Anthopleura krebsi
Aiptasia pallida
Astrangea asteriformis
Bugula neritina
Balanus reticulatus
Balanus amphitrite
Balanus improvisus
Balanus tintinabulum
Ostrea equestris
Anadara transversa
Chama macerophylla
Isognomon bicolor

B) Fish Component

Species

Almaco jack (*Seriola rivoliana)*
Atlantic spadefish (*Chaetodipterus faber)*
Blennys (*Clinidae*)
Bluefish (*Pomatomus saltatrix*)
Blue runner (*Caranx crysos*)
Black drum (*Pogonias cromis*)
Cobia (*Rachycentron canadum*)
Cubbyu (*Equetus umbrosus*)
Gag (Mycteroperca microlepis)
Gray triggerfish (*Balistes capriscus*)
 Balistidae
Greater amberjack (*Seriola dumerili*)
Grouper (Serranidae)
Grunts (Haemulidae)
Jack crevelle (*Caranx hippos*)
Jacks (Carangidae)
King mackerel (*Scomberomorus cavalla*)
Labridae
Mackerels (Scombridae)
Little tunny (*Euthynnus alletteratus*)
Lookdown (*Selene vomer*)
Gray snapper (*Lutjanus griseus*)
Red snapper (*Lutjanus campechanus*)
Sailors choice (*Haemulon parra*)
Snappers (Lutjanidae)
Scamp (*Mycteroperca phenax*)
Sheepshead (*Archosargus probatocephalus*)
Butterfly fishes
Pomacentridae
Wrasses (Labridae)
Barracuda (Sphyraenidae)
Sparidae (porgys)
Bermuda Chub (Kyphosidae)
Parrotfishes (Scaridae)
Bigeyes (Pricanthidae)

General Terms

Abandonment**
Artificial reef
Aggregate/aggregation
Alabama
Angler
Assemblage
Attraction/production**
Barnacle
Benthos
Biofouling
Biogeography
Bioproductivity
Buccaneer Field
California
Carbonate Reefs
North/South Carolina
Caribbean*
Coal ash
Colonize
Reef Fish Community

Table 2 (cont'd)

Concentrate*/**
Loop Current
Longshore Transport
Diurnal Movement
Drilling muds/fluids/produced waters
Encrusting fauna /invertebrates /organisms
Epifauna
Non-Equilibrium Model
Explosive Removal
Florida*/**
Gulf of Mexico*/**
North Sea*/**
Nigeria*/**
Louisiana*/**
Texas*/**
Georgia*/**
Mississippi*/**
FAD (fish aggregating device)
Reef fidelity
Ichthyofauna*/**
Continental shelf*
EEZ*
Island biogeography
Japan (artificial reefs)
Macrocrustacean**
Macroinvertrbrate**
Nearshore*
NMFS*
NOAA*
MMS*
TPWD*
LDWF*
Oil and gas platforms
Petroleum platforms
Offshore development
Patch reefs
Pipeline*
Reeffish
Rubble reef
Rocky reef
Sanctuary*
Production/productivity**
Shipwrecks/wrecks
Hard substrate
TAMU*/**
Sea Grant*/**
Tire reef
concrete reef
Rigs to Reefs
Reef ecology
Reef assessment
Reef planning
Reef design

Other

Distance of platform to shore (or nearest port?)
Depth
Height above bottom for artificial reefs
DO regime
Temperature (temperature zone)
Size of platform (# legs, water enclosed, number of wells)
Submerged surface area
Structure manned
Type of production
Water quality
Distance to nearest platform and/or natural reef
Area in GOM (TX, LA, east/west of Miss?)
Structure age
Dominant current
Sediment type/size
Biological zone (coastal, offshore, blue water)

*or** should be cross-linked with reef/reefs and some should be cross-linked with each other.

around it. What happens to this material once removed depends upon the species composition of the biota which varies by region and depth. Secondarily, structures support primary production by attached algae. We believed that the relative importance of filtration versus primary production also varied across the ecological gradients of the study area. We have not attempted to model fouling community complexity or primary production.

For fish, our initial keywords included lists of species/families, general terms, and habitat factors we believed were important. We attempted to make these lists inclusive with few gaps. We are developing habitat models only for species where the information is sufficient for model development. As evidenced in Section 4.0, we suspect the list of final models will be much shorter than the initial lists of potential candidates shown by Table 2.

2.1 Platform Area Calculations

In addition to number and distribution of platforms, the models require estimates of total submerged surface area of the platforms since standing stock levels of reef fish can be a function of reef size. The number of platforms in the Gulf was obtained from the 1996 MMS list of platforms in federal waters. The first step was to delete the platforms which had been removed from the data set, after which the remaining platforms were divided into three size categories based on MMS criteria:

a) caisson platforms with a single pile and minor support structure;

b) four-leg platforms—designated as minor platforms in the MMS database;

c) major platforms—platforms with more than four legs.

These were further divided into three depth categories; 0-49 ft, 50-99 ft, and >99 ft. The numbers of platforms in each size and depth category are shown by Table 3.

For some of these platforms, one of the project team (Dr. Stanley), had blueprints, or estimates of submerged surface areas of platform legs and cross members, and footprint areas that have been provided to him by the offshore operators of the platforms for 290 structures. These included 87 caissons, 87 four-leg platforms, and 116 large platforms. The distribution of these platforms by size and depth are also shown by Table 3. The submerged areas of caissons were based on actually fewer than 87 blueprints. Most of the caisson measurements were approximated by dividing the data for four-legged platforms by four to estimate the area of a single pile structure. This may yield a slight overestimate of area attributable to these structures due to the increased bracing and cross members of a four-leg platform versus a single-pile structure. However, as will be evident, caissons contribute less than 3% of the total Gulf platform substrate. Thus, the overestimate is unlikely to substantially affect the overall estimate.

The estimates of total submerged surface areas were calculated by multiplying the mean area for a depth by the size category obtained from the samples by the total number of platforms in the same category. Similar calculations were performed to obtain the footprint (basal area) size estimates. These were then added to obtain an estimate of total hard substrate.

The total surface area of the 3,804 offshore petroleum platforms presently found in federal waters of the Gulf of Mexico is estimated to be about 1,170 ha (12 km^2) (Table 4). This compares to a 1982 estimate of about 1,600 ha (Gallaway and Lewbel 1982) and a 1981 estimate of about 1,500 ha Gallaway 1981, page 28)—results which we consider to be remarkably

Table 3. Number of platforms from MMS data and sample by category and water depth used in calculations for submerged surface and footprint area estimates.

Platform Category	Depth Category	Number Gulf	Sample Number
Caisson	<50	1061	38
	50-99	392	36
	>99	42	13
	Caisson Total	1495	87
Four Leg	<50	186	38
	50-99	129	36
	>99	133	13
	Four Leg Total	448	87
Major	<50	448	29
	50-99	491	35
	>99	922	52
	Major Total	1861	116
	Platform Total	3804	290

Table 4. Total submerged surface area estimates. All values are in ft^2 unless otherwise noted. Footprint refers to the bottom area covered by the platform and the submerged surface area refers to the area of underwater pipe and cross-bars.

	Footprint	St. Dev.	Submerged Surface Area	Std. Dev.
Caisson (water Depth)				
<50	318088	230874	1030231	750127
50-100	252448	176400	1447970	974120
>100	55251	20269	365984	312753
Caisson Total	625787	427543	2844185	2037000
Four Leg				
<50	223014	161876	722796	525822
50-100	332768	232613	1905975	1282260
>100	699859	256743	4645424	3961538
Four Leg Total	1255641	651232	7274195	5769620
Major				
<50	2972928	1897370	5940480	3476928
50-100	3861715	2063428	14604304	10347334
>100	11454822	6016381	75027936	68332928
Major Total	18289465	9977179	95572720	82157190

	Footprint	St. Dev.	Submerged Surface Area	Std. Dev.
Total	2017089311055954105691100		89963810	
	187.43 ha	102.73 ha	982.07 ha835.94 ha	
	1.874 km^2	1.027 km^2	9.821 km^2	8.359 km^2

	Surface Area	Std. Dev.
Grand Total (footprint + submerged surface area)	125,861,993 ft^2	101,019,764 ft^2
	1169.50 ha	938.67 ha
	11.70 km^2	9.39 km^2

consistent. Unfortunately, however, Gallaway (1981) also includes, on pages 53 and 54, an erroneous calculation yielding an estimate of 5,000 km^2 of platform habitat in snapper habitat in the central and western Gulf alone. The calculation was based on an assumed 2,000 platforms in snapper habitat, with each covering a bottom area of 2,500 m^2 (Gallaway et al. 1981). Multiplying 2,500 m^2 x 2,000 platforms does not yield an area of 5,000 km^2 as stated; or even 5,000 ha. The result of the calculation should have yielded either 5 km^2 or 500 ha depending on the unit of measure desired. The most widely-used figure for the area of petroleum platform habitat (even by the project team) has been the 5,000 km^2 estimate which is clearly in error. The best estimate is that petroleum platforms provide about 12 km^2 of hard substrate in the Gulf of Mexico. This compares to 2,780 km^2 of natural reef habitat that has been estimated to occur within the 18 to 91-m depth range between Pensacola, Florida and the Texas-Mexico border (Parker et al. 1983). Petroleum platform habitat is thus on the order of about 0.4% of the area of natural reef habitat; perhaps substantially less considering the differences in total area and the depth ranges covered by Parker et al. (1983) versus our area and depths.

2.2 Juvenile Red Snapper Model

Seasonal and spatial estimates of the abundance of juvenile reef fish (and other prey organisms of adult reef fish) having a benthic life stage over soft bottom habitat can be estimated from the NMFS Fall Groundfish and Summer SEAMAP surveys. Nichols and Pellegrin (1989) provide the details of the sampling program history for these data. In brief, this time series began in 1972 as the "Fall Groundfish Survey" and concentrated on the north-central region of the Gulf as described above. The "primary survey area" was 5 to 50 fm waters between 88° and 91°30'W. During some years, spring and summer samples were also taken. The goal was to obtain triplicate tows of 10-min duration at "stations", which were randomly-selected 2.5-minute latitude-longitude grids within a 10-minute block that had been randomly selected from a list of all blocks. The station selection procedure was changed in 1978 but random selection of stations remained the keystone of the sampling plan. In 1985 and 1986, single 15-minute tows were taken at each site, and the program was expanded geographically with the intention of covering the region from Pensacola, Florida, to Brownsville, Texas. In 1987, the SEAMAP procedure, as described below, was adopted and continues to the present. The region sampled extends from Pensacola to Brownsville.

Fall sampling has been generally restricted from October to November of each year. In the early years, sampling proceeded from east to west, so that missed samples were more frequent in the western part of the region sampled than the eastern part. Since 1987, fall sampling generally begins in mid-October in Statistical Zones 10 and 11, then shifts to Brownsville (Zone 21) and proceeds back towards Pascagoula. Typically, by the end of October sampling has reached the Galveston/Sabine region. The upper Texas coast and western-Louisiana are mainly sampled during the first 10 days of November, and sampling through the entire primary region occurs during 11-20 November. While the entire western Gulf region is sampled within about a 1-mo period, temporal variation may cloud spatial differences.

NMFS has participated in and coordinated federal, state, and university summer sampling efforts since 1982 as part of the Summer SEAMAP program (Goodyear 1995). The trawl sampling gear are the same as used in the Fall Groundfish Survey (Nichols and Pellegrin 1989). The survey covers the area between Pensacola and Brownsville, from 5 to 60 fathoms. Stations are selected in a stratified random design, with strata established alongshore (based on commercial shrimp statistical areas), and by depth. Trawling is conducted perpendicular to the depth contours. Duration of each trawl is set by the distance between the inner and outer depth boundary for each stratum. A station begins at the intersection of a depth contour and a randomly chosen alongshore location. Measurement of depth by fathometer in the field determines when the end of a station is reached. Since 1987, the temporal distribution of sampling in the June-July program is much like that described for fall in terms of sampling sequence.

We used the data from 1985 to 1995 to index mean annual abundance patterns. Following examination of the data, we determined that the finest spatial resolution that was practical for evaluating abundance patterns were blocks of 10 minutes of latitude by 10 minutes of longitude which created sample blocks of about 108 km^2. Mean catch per hour trawling with a 40-ft wide trawl was calculated for each of the 630 blocks.

Following Odum (1971) we defined habitat as the place where an organism lives, **or** the place one would go to find it. Thus, the quality of juvenile red snapper habitat should be reflected by the abundance of juvenile red snapper using particular blocks. Our abundance data for individual blocks were categorized into 5 initial classes. Of the 630 blocks, 147 were not trawled and were thus not considered in the analysis. An additional 135 blocks were trawled, but had no catch of red snapper. Quantiles of the abundance data were used to classify the remaining, or positive, catch values:

Catch Value Classification	n	Mean	Minimum	Maximum	Std. Error
0	135	0	0	0	-
1	87	0.89	0.09	1.82	0.05
2	87	3.98	1.83	5.37	0.12
3	87	9.28	5.38	14.68	0.27
4	87	29.68	15.0	99.69	1.84

We combined catch value classifications 0-2 to depict low-use habitat (mean CPUE ≤ 3.48 red snapper/hr) and high-use (mean CPUE ≥ 9.28 red snapper/hr) habitats (Fig. 3).

Bottom temperature values and depth of the sampling area were taken in conjunction with each tow taken within a sample block. In this analysis, we are using depth as a surrogate for salinity given the correspondence of salinity gradients to depth contours (see Section 5.0 and corresponding salinity plots in the Appendix). Each block was assigned to a 1°C temperature range and a 10-fathom depth range based upon the mean of all samples taken within each block over all seasons and years. A comparison of temperature and depth distributions in the high-use areas to the temperature and depth distributions in the low-use areas showed that juvenile red snapper selected for temperatures between 24 and 28°C and depths between 20 and 30 fathoms (Table 5). The suitability of the habitats based on these two environmental features was calculated by:

$$HSI = (SI_T \times SI_D)^{0.5}$$

The resulting values are shown by Table 6 and Figure 4. A key feature of Figure 4 is that the model relationships were based upon the Texas samples alone, and the results show the predicted habitat values for both Texas and Louisiana.

The next habitat feature added to the model was the presence of platforms and major topographic features. The presence of these features may index abundance centers for predators of juvenile red snapper, including sub-adult and adult red snapper. Each block was characterized by the number of relief features (platforms plus shelf edge banks and/or pinnacle features) and the mean number of relief features was calculated for each of the five catch value

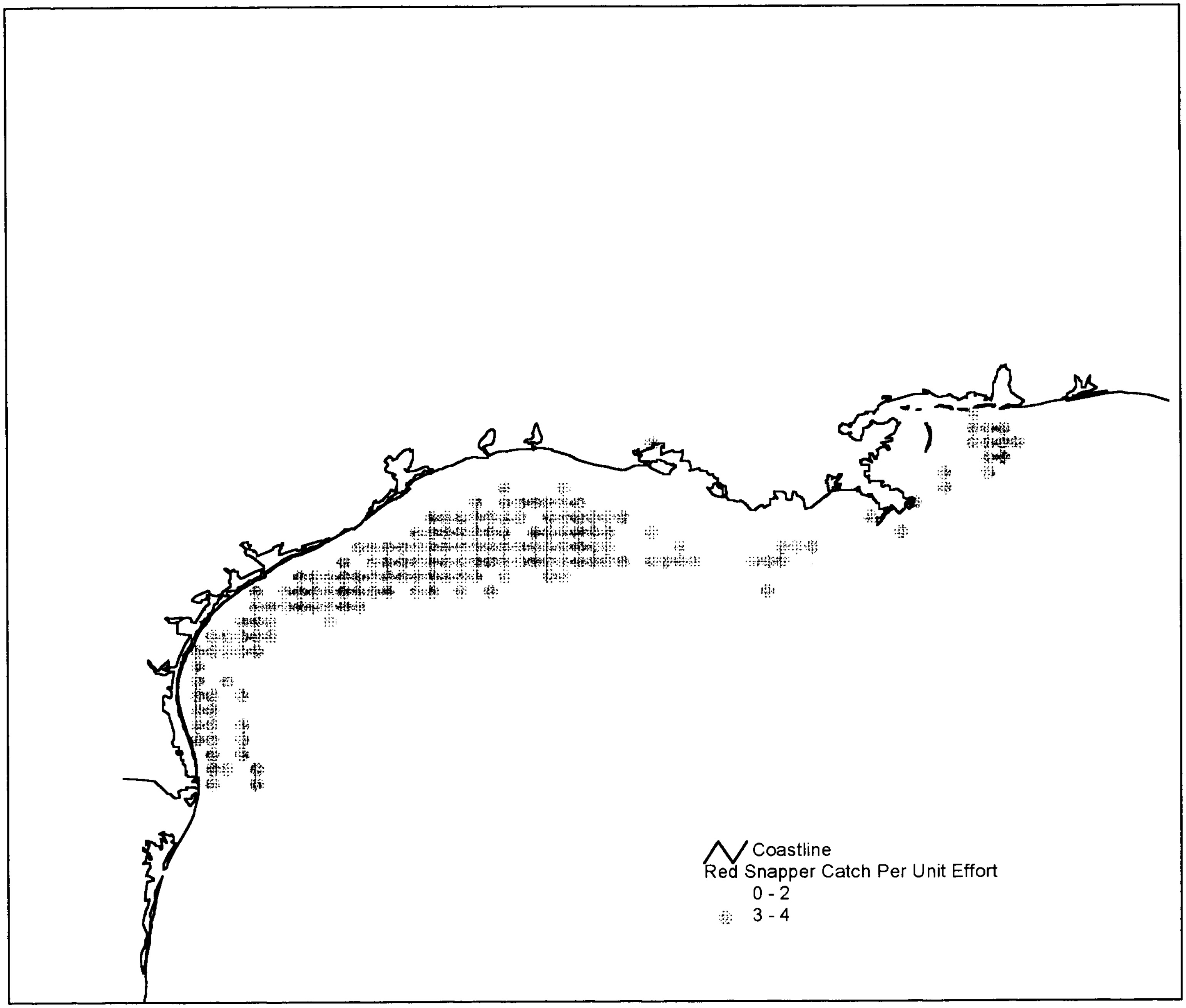


Figure 3. The distribution of high value and low value juvenile red snapper habitat in the Gulf based upon abundance quartiles.

Table 5. Suitability indices for temperature (SI_T) and depth (SI_D).

	FREQUENCY OF OCCURRENCE		PERCENT OCCURRENCE				
Temp	High use	Overall	High use	Overall	Difference	Scaled	SI_T
20	0	8	0.0%	5.8%	-5.8%	0.2%	0.000
21	1	8	1.1%	5.8%	-4.6%	1.4%	0.109
22	3	8	3.4%	5.8%	-2.3%	3.7%	0.290
23	5	9	5.7%	6.5%	-0.7%	5.3%	0.414
24	26	36	29.9%	25.9%	4.0%	10.0%	0.784
25	26	39	29.9%	28.1%	1.8%	7.8%	0.615
26	19	21	21.8%	15.1%	6.7%	12.7%	1.000
27	5	7	5.7%	5.0%	0.7%	6.7%	0.527
28	2	3	2.3%	2.2%	0.1%	6.1%	0.482
Depth	High use	Overall	High use	Overall	Difference	Scaled	SI_D
10	9	25	10.0%	17.1%	-7.1%	1.5%	0.056
20	50	55	55.6%	37.7%	17.9%	26.5%	1.000
30	24	33	26.7%	22.6%	4.1%	12.7%	0.478
40	6	17	6.7%	11.6%	-5.0%	3.6%	0.137
50	1	14	1.1%	9.6%	-8.5%	0.1%	0.005
60	0	2	0.0%	1.4%	-1.4%	7.2%	0.000
70	0	0	0.0%	0.0%	0.0%	8.6%	0.000
80	0	0	0.0%	0.0%	0.0%	8.6%	0.000

Table 6. Habitat suitability indices (HSI) for specific temperature and depth indices.

		Depth							
		10	20	30	40	50	60	70	80
Temp	Normalized	0.056	1.000	0.478	0.137	0.005	0.000	0.000	0.000
20	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
21	0.109	0.078	0.331	0.229	0.122	0.022	0.000	0.000	0.000
22	0.290	0.127	0.539	0.372	0.199	0.037	0.000	0.000	0.000
23	0.414	0.152	0.644	0.445	0.238	0.044	0.000	0.000	0.000
24	0.784	0.209	0.886	0.612	0.328	0.060	0.000	0.000	0.000
25	0.615	0.185	0.784	0.542	0.290	0.053	0.000	0.000	0.000
26	1.000	0.236	1.000	0.691	0.370	0.068	0.000	0.000	0.000
27	0.527	0.171	0.726	0.502	0.269	0.049	0.000	0.000	0.000
28	0.482	0.164	0.694	0.480	0.257	0.047	0.000	0.000	0.000

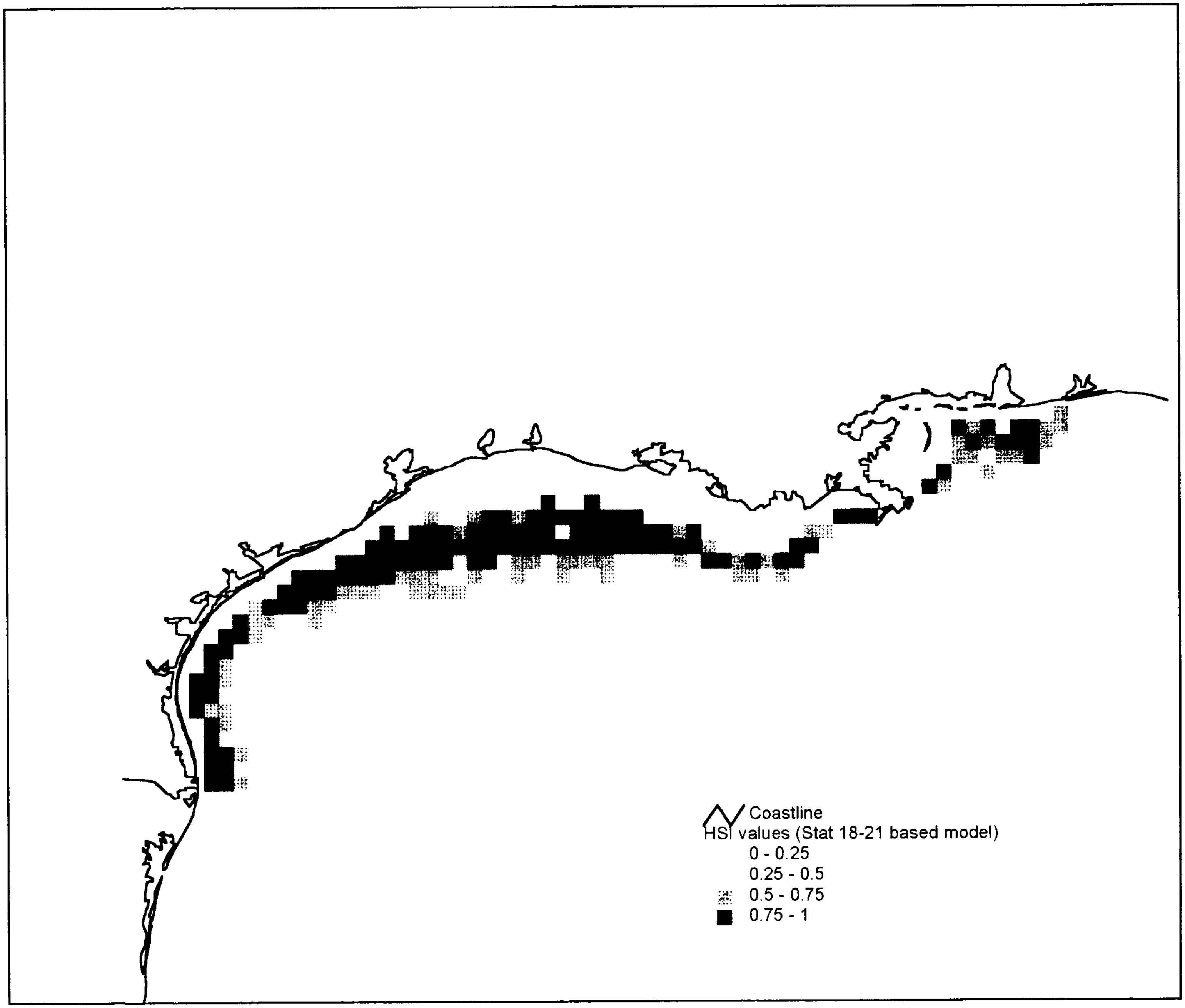


Figure 4. The distribution of high value and low value juvenile red snapper habitat in the Gulf based upon temperature and depth characteristics.

classifications. The hypothesized relationship shown by Figure 5 was used to assign a suitability index for relief features (SI_R). The SI_R scores were multiplied by HSI values for temperature and depth with the overall HSI being calculated as

$$HSI = (SI_T \times SI_D \times SI_R)^{0.33}$$

The resulting distribution of high-value versus low-value habitat for juvenile red snapper based on all three habitat variables (Fig. 6) now very closely approximates the observed abundance patterns (see Fig. 3). With no other terms in the model, Figure 4 would reflect the anticipated change in juvenile red snapper habitat should all the platforms within the study region be removed.

3.0 Information and Data Acquisition

3.1 Bibliographic Search

Tiered bibliographic searches were made of five data bases: Aquatic Science and Fisheries Abstracts, National Technical Information Service (NTIS), Oceanic Abstracts, Dissertation Abstracts, and Agricola. The primary searches were partitioned into separate categories: environmental/physical, biological, and habitat modeling. Each search initially focused on the shelf and slope in the Gulf of Mexico, specific coastal states (Texas, Louisiana, Mississippi, Alabama, and Florida), and the Caribbean region. For the biological search, these key words were supplemented with the terms "reef," "platform," "structure," "oil," and "gas." These primary environmental/physical and biological searches were also modified using key environmental words such as "temperature," "salinity," and "dissolved oxygen," and biological words such as "biofouling," "red snapper," "Lutjanus campechanus," "environmental influences," etc. The biological taxa were those known to be commonly associated with oil and gas structures and which represented a range of feeding types and habitats.

Few useful biological references were obtained from the "Gulf/Caribbean" limited search so the search was enlarged by removing the geographical area and other location parameters so that it incorporated a search of all available information concerning specific species of interest. These additional searches primarily utilized Aquatic Sciences and Fisheries Abstracts for journal articles; University of California's MELVYL library system for books and reports; and Stanford University's BIOSIS library database for both journals and books. These are cross-referenced in the PAPYRUS database, which will be provided as a separate document/deliverable.

3.2 Overview of Search Results

3.2.1 Environmental/Physical

A total of 409 references, most with abstracts, were obtained from the environmental/physical search. Thirty-three of these proved to be duplicates and so were eliminated, leaving a total of 376 directly relevant environmental/physical references.

3.2.2 Biological

Over 1,000 biological references were obtained (including some duplicates) in the first database search using the tiered approach. Of these 1,000 references, approximately 50% (~500) did not contain any relevant species information. The remaining 50% of these 500 hits contained only minimal usable information concerning the key species. The third (untiered)

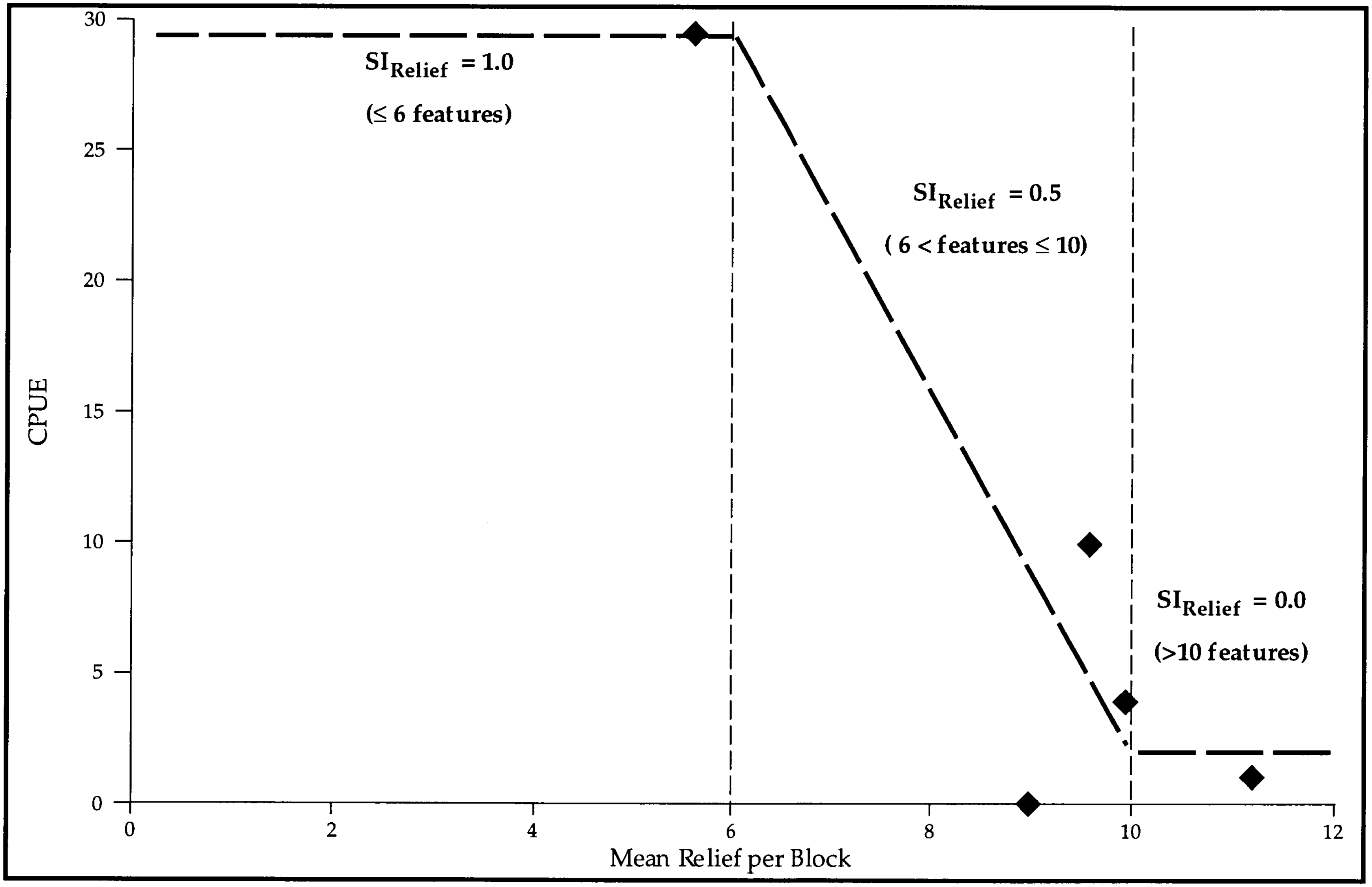


Figure 5. Hypothesized relationship between the defined quantiles of catch per unit effort and mean number of relief features within each quantile classification.

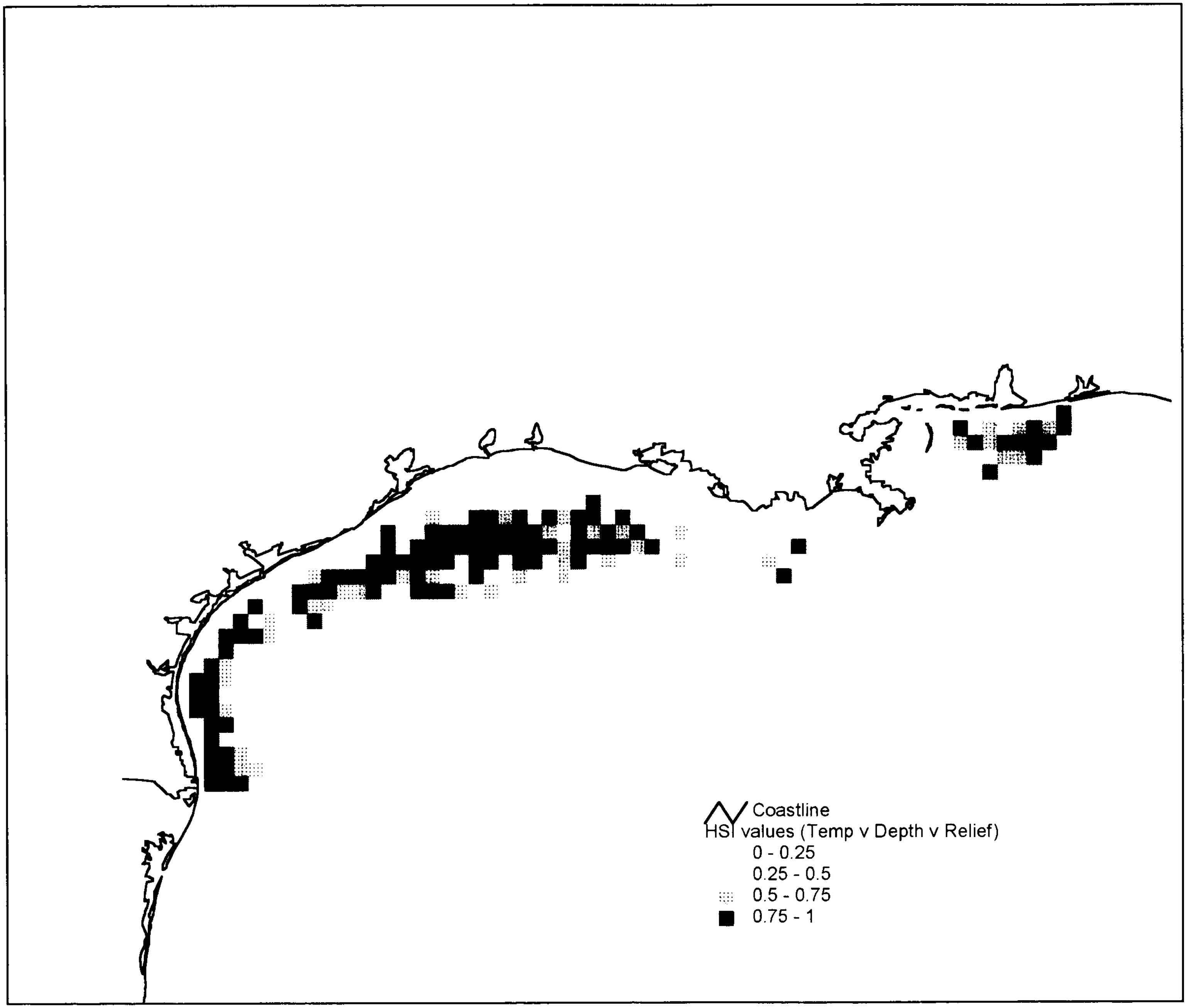


Figure 6. The distribution of high value and low value juvenile red snapper habitat in the Gulf based upon temperature, depth, and relief gradients.

search, however, resulted in approximately 200 references with adequate information to characterize life history information for many key species.

4.0 Species Accounts

The following fish (Section 4.1) and invertebrate (Section 4.2) species accounts provide information on distribution and movement patterns; environmental influences such as temperature, salinity, and dissolved oxygen; and life history information concerning reproduction, growth, and feeding. General information also is provided for key fish families (Clinidae, Pomacentridae, Chaetodontidae, and Haemulidae). No useful references were found for Bermuda chub (Kyphosus sectatrix), Creole fish (Paranthias fureifer), lookdown (Selene vomer), and bigeye (family Priacanthidae). Therefore, information on these species is not presented. Summary tables of species accounts for fishes are presented in Appendix A.

4.1 Fish

4.1.1 Red Snapper

Red snapper (Lutjanus campechanus) are one of the most highly prized and valued finfish by both recreational and commercial fishermen in the Gulf of Mexico (GOM) region (Workman and Foster 1994). This species, which ranges from Cape Hatteras south to the Yucatan, and throughout the Gulf of Mexico (Goodson 1976), has been significantly overfished in the GOM, with landings declining from 7 million pounds annually between 1964 and the mid 1970's to an average of 3.2 million pounds per year between 1988-1990 (Goodyear and Phanes 1990). Red snapper may reach lengths of 845 mm and weigh over 12 kg (Bradley and Bryan 1975), and have been aged to 42 years off Alabama (Szedlmayer and Shipp 1994) and 54 years in the northern GOM (Render 1995), a substantial increase over previous age estimates (13 years; Nelson and Manooch 1982). One of the most significant sources of mortality to juvenile red snapper populations is from commercial shrimp trawl bycatch (Bradley and Bryan 1975; Gutherz and Pellegrin 1988). For example, Nichols et al. (1990) reported an estimated 20 million juvenile red snapper were caught incidentally in 1989 by Gulf shrimp trawlers.

Distribution and Movement. Movement patterns of red snapper are well documented, with juveniles being widely dispersed within brown shrimp (Penaeus aztecus) grounds offshore, often extending into white shrimp (P. setiferus) grounds relatively close to shore. Peak abundances of juvenile red snapper occur in shallower waters (20-46 m), while adults are found in deeper water (> 46 m) and often will remain in their habitats with very little migration between depth intervals, particularly offshore. Adult red snapper typically remain in reef habitats (including oil platforms) during cooler winter months, sometimes moving into nearshore areas during warmer summer months (Moran 1988). Unlike other pelagic coastal species in the gulf, red snapper do not undergo along-shore seasonal migrations, but tend to exhibit short range movements and gradual dispersal from centers of abundance (Goodyear 1995).

Environmental Influences. Little information is available describing environmental requirements for red snapper. GMFMC (1981) reported a lower lethal temperature tolerance of 13°C for red snapper, an upper limit of 33.5°C (Rivas 1970), and an optimal activity temperature of 18°C (GMFMC 1981). Consistent with this trend, Rivas (1970) found the highest red snapper abundances in water temperatures of 24.4°C, the lowest abundances at the lowest temperatures (16.7°C), and average abundances at intermediate temperatures (20.6°C). The average winter water temperature over the shelf (along the 20-m depth contour) is often at lethal levels for red snapper, while offshore temperatures approach optimum levels at approximately 40 m depth. Therefore, red snapper distributional patterns change from nearshore to offshore in winter.

Red snapper commonly occur in salinities ranging from 33-37 ppt (Mosely 1966). Salinities of 60 ppt were lethal to 100% of the individuals in laboratory tests by Huff and Burns (1981), but no serious effects were reported at salinities of 45 ppt.

Hypoxic ($\leq$ 3 ml/l O_2) and anoxic ($\leq$ 1 ml/l O_2) conditions have been reported annually in the Gulf of Mexico since 1972 (Renaud 1985). These conditions have been concentrated along the Louisiana coastline, between the Mississippi River Delta and Marsh Island, LA. Recently, hypoxia has been reported off western Louisiana and the northern Texas coast. No data were identified on dissolved oxygen ranges or tolerances of red snapper, although it is likely that they would attempt to avoid regions of very low DO. Wakeman et al. (1979) reported laboratory oxygen consumption rates for red snapper (1-2 years old) swimming at 0.5 km per hour were 89 mg O_2 per kg per hour at 20°C. Since the estimated resting oxygen uptake was 62 mg O_2 per kg per hour, routine activity in this species appears to cause an increase in respiratory metabolism of nearly 43%.

Reproduction. In general, red snapper spawn in summer (May to July) and fall (November to December) off Texas, but off western Florida peak spawning occurs in summer (July to October) and from May to September off northwest Florida (Moran 1988). Individual snapper probably spawn several times during the spawning season (Collins et al. 1987), usually away from reefs (Bradley and Bryan 1975) over firm, sandy areas at typical depths of 18-37 m (Beaumariage and Bullock 1976). Red snapper produce eggs which are pelagic, spherical, unpigmented, transparent, have a single oil globule, and range in diameter between 0.77 and 0.85 mm (Rabalais et al. 1980). According to the Rabalais et al. study, newly hatched larvae in the laboratory averaged 2.2 mm (standard length), while field-collected samples of this size could only be identified to family (Collins et al. 1987).

Growth. Red snapper growth varies according to season and location, with underyearlings reported to grow at 25 mm/month in August and September (Bradley and Bryan 1975). Other growth studies of red snapper in the Gulf include Moseley (1966) in the Northwestern Gulf, Nelson and Manooch (1982) off Louisiana and western Florida, and Wade (1981) off Alabama. These studies reported that fishes 1-5 years of age ranged in length between 250 and 546 mm (total length). Nelson and Manooch (1982) found statistically significant differences in von Bertalanffy growth curves for Louisiana, western Florida, eastern Florida, and the Caribbean, but no spatial trends were evident. Nelson and Manooch (1982) concluded that differences between these locations probably have little (if any) biological significance. The smallest red snapper in trawl samples collected by Holt and Arnold (1982) along the Texas coast (33 m water depth) were generally 20-29 mm, with juveniles (<40 mm) caught in summer/fall (August-October). Holt and Arnold (1982) concluded that red snapper grow to 110-130 mm during the first year, reaching 220-230 mm by the second year. These findings are consistent with previously described ranges of growth rates of 60 mm (Bradley and Bryan 1975) and 90 mm per year (Moseley 1966) between the first and fourth or fifth year.

Feeding. Red snapper feeding patterns show distinct diurnal, seasonal, and habitat influenced variation in prey consumption (Nelson 1988). Juveniles and adults are carnivorous, preying primarily on shrimps, squid, and fishes, with juveniles (up to 150 mm fork length) preferentially select shrimps and squids, while adults tend to prey primarily on fishes (Bradley and Bryan 1975; Bortone and Williams 1986).

4.1.2 Cobia

Cobia (Rachycentron canadum) or ling, are pelagic fish having a nearly worldwide distribution in tropical, subtropical, and warm temperate seas. This species reaches lengths of 2 m, weighs up to 68 kg (~ 150 lb) (Wheeler 1975), and may live 15 years or more (GMSAFMC

1985). Throughout most of its range, cobia are collected incidentally by various fisheries, including shrimp trawlers. Methods used to catch cobia include poundnets, gillnets, and seines (Manooch 1984). In the Gulf of Mexico, cobia represent an important recreational fishery, however, these landings are not well-documented (GMSAFMC 1985). A synopsis of the biological data on cobia has been compiled by Shaffer and Nakamura (1989), as summarized below.

Distribution and Movement. Migrational patterns of cobia are well-documented. In the Gulf of Mexico, cobia winter in the Florida Keys, and move north and west along the Gulf coast in spring (Shaffer and Nakamura 1989). Some fish tagged off Florida have been recaptured in subsequent years off Florida and from Texas to Louisiana, while other individuals tagged off Florida have been recaptured off the Yucatan in Mexico (see Shaffer and Nakamura 1989). Adults are primarily found in coastal and continental shelf environments in 50 m water depth, while juveniles are primarily taken in farther offshore areas (Dawson 1971).

Environmental Influences. Little information exists describing the influence of environmental parameters such as temperature, salinity, and dissolved oxygen on cobia life history traits, although temperature and salinity are reported to primarily influence distributional patterns (Shaffer and Nakamura 1989). Generally, cobia are found in cooler waters during warmer summer months, migrating to deeper offshore areas during winter. Cobia have been collected at water temperatures ranging between 16.8-32°C (Dawson 1971; Milstein and Thomas 1976), with lethal lower and upper temperatures for juveniles of 17.7°C and 37.7°C, respectively (Hassler and Rainville 1975). During the Hassler and Rainville study, juveniles were observed to stop eating at 18.3°C.

Because cobia have a virtually worldwide distribution, this species can tolerate a fairly broad range of higher salinity conditions, such as 22.5-44.5 ppt (Christiansen 1965, Roessler 1967), but may be able to withstand slightly lower salinities. Hassler and Rainville (1975) successfully reared cobia larvae at salinities as low as 19 ppt.

No information is available on how changes in dissolved oxygen concentrations effects cobia life history parameters, although effects generally are expected to be minor since this species is pelagic and most DO problems are more common at mid- to bottom depths.

Reproduction. Spawning characteristics of cobia are well-documented. In the Gulf of Mexico, Finucane et al. (1979) noted that cobia spawn off the Texas coast in July and September. However, this was based on the collection of only 12 larvae over a two month period. Most cobia eggs and larvae are found in offshore waters. Juveniles move inshore to inhabit coastal areas, usually near beaches, river mouths, barrier islands, and lower reaches of bays and inlets (Benson 1982; Hoese and Moore 1977; McClane 1974; Swingle 1971); and therefore may experience hypoxic conditions. Ditty and Shaw (1992) suggested that cobia may spawn during the day, based on collection of similar developmental stages during day sampling events.

Fertilized cobia eggs are pelagic, and can be identified by their distinctive, large oil globule (Shaffer and Nakamura 1989). Embryos of late-stage Gulf cobia eggs are heavily pigmented, except for the caudal peduncle which is unpigmented (Ditty and Shaw 1992). Eggs hatch in about 24 hours at 29°C. In the Gulf, larvae are first observed during late May, with nearly 98% collected between June and September (Ditty and Shaw 1992). Cobia larvae during the Ditty and Shaw study occurred primarily (85%) at 25-30°C and greater than 27 ppt salinity. Most larvae (75%) also were taken at station depths less than 100 m.

Growth. Cobia undergo rapid growth and are generally long-lived, although no information exists describing growth in cobia from the Gulf of Mexico. Richards (1967, 1977) found midsummer scale annuli in cobia from Chesapeake Bay. Results of these studies using growth equations indicate one year old cobia reach 31-36 cm FL, 53-61 cm FL at two years, 69-82 cm FL at three years, 82-99 cm FL at four years, 91-112 cm FL at five years, 99-122 cm FL at six years, 104-131 cm FL at seven years, and 108-137 cm FL at eight years.

Feeding. Cobia are known to be voracious predators, often consuming their prey whole (Shaffer and Nakamura 1989). This species probably feeds near the bottom, preying extensively on crab, and other benthic invertebrates, and fishes. Cobia has often been called "crabeater" due to its preference for this food item (Randall 1997). Other common prey include squid and a variety of small fishes (eels, sea catfish, and sciaenids). Although little is known about the feeding habits of larval and juvenile cobia, Hassler and Rainville (1975) fed laboratory-reared larvae a diet of wild zooplankton which was dominated by copepods. A recent study by Franks et al. (1996) describes feeding habits for small cobia (236-440 mm FL) in the northern Gulf. Results of this study are similar to earlier studies, indicating crustaceans, fish, and cephalopods were important prey items for juvenile cobia. Meyer and Franks (1996) described similar prey items for adult cobia collected in the north-central Gulf.

4.1.3 Bluefish

Bluefish, Pomatomus saltatrix, are a migratory pelagic species which occurs in most temperate coastal regions of the world, except the north and central Pacific (Wilk 1977). Bluefish are abundant in estuaries and continental shelf waters from Nova Scotia to Florida, and in the Gulf of Mexico westward to Texas (Dahlberg 1975), but are most common along the coasts of North Carolina and Florida. This species can reach a length of 1.1 m (45 in) and weigh 12 kg (27 lbs) (Robins et al. 1986). Bluefish are an important recreational and commercial species along the distributional range, especially in the Atlantic region (Cape Cod, MA to Cape Hatteras, NC), where the recreational catch generally exceeds the commercial catch. For example, anglers caught more than 10 million bluefish in 1983, of which 8.2 million were from North Carolina, 1.4 million from Florida, and 0.2 million from Georgia (Holliday 1986). In the Gulf of Mexico, this species has been observed in large numbers at offshore oil platforms (NMFS 1980).

Distribution and Movement. Bluefish exhibit seasonal migrations along the Atlantic coast, moving northward in spring and summer and southward in fall and winter. In the Gulf of Mexico, bluefish are distributed from Florida westward to Texas, with approximately 72% of the standing stock occurring off Louisiana and Texas (Holliday 1986), but rarely in the eastern Gulf. Most of these bluefish (~90%) are caught in nearshore areas (within 3 miles of shore). Adult bluefish are caught primarily in the north-central and western Gulf and occur seasonally in large numbers near oil platforms such as the Bucaneer Gas and Oil Field (BGOF) (NMFS 1980). Previous studies have collected few larvae or juveniles; however, this seems to be a sampling artifact associated with collections during non-spawning months and eastern Gulf locations.

Environmental Influences. Surface water temperature and salinity are important environmental factors that influence larval bluefish production in the Gulf. Results from Ditty and Shaw (1995) for the northern Gulf coincided with data from spawning months reported by Barger et al. (1978) off Texas. Minimum surface water temperatures for the onset of bluefish spawning along the Atlantic coast are 17-18°C. The lower lethal temperature for bluefish (up to about 250 mm TL) is 10°C (Lund and Maltezos 1970), but they may be able to withstand brief periods as low as 7.5°C (Wilk 1977). Laboratory experiments found that adult bluefish can survive temperatures up to 30.4°C (Olla et al. 1985), although temperatures in nearshore habitats throughout the Gulf rarely exceed this level.

Salinity also is an important factor influencing spawning and survivorship of larval bluefish. Ditty and Shaw (1995) collected larvae in salinities greater than 30 ppt. Minimum salinities for bluefish spawning along the Atlantic coast have been reported at 26.6 ppt; however, no information on lethal salinity levels is available.

Data describing the environmental influences of dissolved oxygen on bluefish are not available. However, observational data indicate that bluefish may actively avoid areas of low dissolved oxygen concentration. For example, small bluefish were observed preying on spawning Atlantic silversides (Menidia menidia) in an area where DO concentrations ranged from 1-4 mg/l. However, the bluefish were feeding primarily on the outer edges of the school, where DO concentrations were greater than 4 mg/l (Middaugh et al. 1981). These data can be used to infer that bluefish prefer areas having DO concentrations greater than approximately 4 mg/l.

Reproduction. Information on early life stages of Gulf bluefish is limited to studies by Barger et al. (1978), Benson (1982), and Ditty et al. (1988). Details of larval bluefish occurrences in the Gulf comes from the collection of only 18 larvae from one transact off Texas and suggests spawning occurred during early November. Larval bluefish collections by Ditty and Shaw (1995) indicate bimodal spawning during April and again between October and November most likely occurs off Louisiana and Texas. Evidence for these seasonal spawning patterns is from extensive, targeted sampling of continental shelf waters during previously reported spawning periods, including March and between June and September. Thus, results from Ditty and Shaw (1995) support previous findings by Barger (1990) that bluefish do not spawn in summer in the Gulf. For the Atlantic coast, it is likely that two distinct populations exist (Oliver et al. 1989). One stock spawns during late summer in continental shelf waters in the Middle Atlantic Region, and the other spawns during spring at the margin of the Gulf Stream in the South Atlantic Region (Lassiter 1962; Kendall and Walford 1979). In the South Atlantic Region, spawning occurs primarily in spring, shoreward of the Gulf Stream, in coastal waters from southern North Carolina to Florida, while spawning in the Middle Atlantic Region occurs in summer (May-September) over the outer half of the continental shelf (Norcross et al. 1974). Following the completion of spawning (July/August), bluefish in the Middle Atlantic Region move inshore into bays and inlets of Long Island Sound and the New Jersey coast.

Growth. Larval bluefish development occurs in outer continental shelf waters, at water depths of less than 6 m, temperatures of 18-26°C, and salinities of 30-32 ppt (Kendall and Walford 1979). Young-of-the-year (YOY) bluefish undergo a habitat shift from offshore areas to inshore coastal and estuarine locations at approximately 40-70 mm total length (Nyman and Conover 1988; McBride and Conover 1991; Juanes and Conover 1994). Growth in these nearshore areas in usually rapid, allowing YOY to reach larger sizes at younger ages. Most of the data concerning bluefish growth comes from several Atlantic coast studies in which differences in aging techniques make comparisons difficult. For fish collected between Rhode Island and southern Florida, 1-5 year old fish measured 210-620 mm FL, 5-10 year old were 620-800 mm FL, and fish older than 10 years were greater than 800 mm FL (Wilk 1977).

Feeding. Feeding habits of adult bluefish are well documented. However, little information exists on the feeding ecology of early life stages of this species. Bluefish are visual predators, feeding most actively during daylight hours. Larval and postlarval bluefish most likely prey on copepods, cladocerans, and invertebrate eggs (Kendall and Naplin 1981). Along the Atlantic coast, juvenile bluefish consume shrimp (Panaeus spp.), squid (Loligo spp.), and fishes, including pinfish (Lagodon rhomboides) and Atlantic silversides (Menidia menidia). Adult bluefish along the Atlantic coast are predominately piscivores, preying on other bluefish, butterfish (Peprilus triacanthus), harvestfish (P. alepidotus), anchovies (Anchoa spp.), seatrout (Cynoscion spp.), spot (Leiostomus xanthurus), and Atlantic menhaden (Brevoortia tyrannus) (Lassiter 1962). Bluefish at BGOF fed mainly on fish during fall and winter, but preyed heavily on demersal macrocrustaceans during spring (NMFS 1980). Thus, there appears to be a ontogenetic shift in diet of bluefish from strictly zooplankton in newly hatched larvae to primarily fishes in juveniles and adults (Marks and Conover 1993).

4.1.4 King Mackerel

King mackerel (Scomberomorus cavalla) are commonly found in coastal waters from the Gulf of Maine to Rio de Janeiro, Brazil, including the Gulf of Mexico and Caribbean Sea. This species reaches a maximum size of nearly 1.7 m (66 in) and can weigh 45 kg (100 lb) (Robins et al. 1986). King mackerel are extremely important to recreational fisheries, with some of the largest concentrations occurring off the coastal Carolinas in spring, summer, and fall (Godcharles and Murphy 1986). In the Gulf of Mexico, the highest abundances of king mackerel are off Texas and northwest Florida in summer and off southern Florida and Louisiana in winter. The fishery for king mackerel is unique among fisheries in the Gulf of Mexico because it occurs year-round. Information concerning life history characteristics, including spawning cycles, migratory patterns, and effects of environmental parameters is well documented.

Distribution and Movement. Historical tagging studies (Williams and Godcharles 1983; Fable et al. 1987, Fable 1990; Sutter et al. 1991; Schaefer and Fable 1994) indicate king mackerel movement between south Florida and the north/northwest Gulf. Fable et al. (unpublished data) found young king mackerel that were tagged in northwest Florida moved and were subsequently recaptured in south Florida, while Sutherland and Fable (1980) showed that fish in the northeast Gulf also migrated to south Florida. Fable et al. (1987) concluded that larger king mackerel may be year-round residents in the northwest Gulf, mixing with smaller individuals from south Florida and Mexico in summer. Johnson et al. (1994) used electrophoretic techniques to provide further evidence for district king mackerel stocks in the Gulf of Mexico. Using circulation patterns, results from tagging studies, and recent results from electrophoretic studies, Johnson et al. (1994) suggest there is a western population of king mackerel that winters and spawns in the Gulf of Campeche. Young king mackerel are entrained by the Mexican Current, and as the young fish become older and larger, they are able to cross the region of offshore advection and utilize the northern Gulf (Texas to Florida) for summer feeding. A second stock utilizes the eastern and northern Gulf of Mexico, where young fish feed primarily in the northern Gulf (Florida to Texas) during summer and use south and southeast Florida for wintering grounds (Johnson et al. 1994). Between April and October, the eastern stock spawns in the northwest Florida-Louisiana area.

A third king mackerel stock that officially has been recognized by the Fishery Management Councils is referred to as the Atlantic Migratory Group. This group ranges from Virginia to southwest Florida depending on the season (GMSAFMC 1985), wintering in south Florida and moving northward to the Carolinas during summer, and spawning from May to October with a peak in July (Finucane et al. 1986). The percentage of cross-mixing between different king mackerel stocks is not known (Schaefer and Fable 1994).

The present management approach for mackerels specifies two migratory groups, Gulf and Atlantic, based on tagging results, growth rate differences, and temporal differences in fisheries (GMSAFMC 1996).

Environmental Influences. Temperature and salinity are probably the most important factors controlling the distribution and abundance of king mackerel. All life stages of king mackerel are most commonly found at salinities between 32 and 36 ppt (Godcharles and Murphy 1986). However, in the Gulf of Mexico, king mackerel larvae have been collected at surface salinities of 27-37 ppt and temperatures of 20-31°C (Dwinell and Futch 1973; McEachran et al. 1980). In contrast, south Atlantic juveniles are found at higher surface salinities (between 30-37 ppt) and at temperatures between 22-28°C. King mackerel generally remain within the 20°C temperature contour in the northern part of their home range, in approximately 18 m water depth (Berrien and Finan 1977). Thus, the arrival of king mackerel off western Florida in the spring is driven by water temperature and the preceding year's air temperature (Williams and Taylor 1980). Consequently, sport catches of this species increase following warm winters and are lower after colder winters (Fable et al. 1987).

No information was available for dissolved oxygen tolerances for this species, although they are expected to avoid hypoxic and anoxic regions as noted for other motile species.

Reproduction. King mackerel spawn in coastal waters of the northern Gulf of Mexico, south Florida, and probably in the Gulf of Campeche. This species has a protracted spawning season, with larvae collected from May through October and a peak in larval abundances in September. King mackerel larvae have been collected off northwest Florida and Texas in 35-183 m water depth (Dwinell and Futch 1973; McEachran et al. 1980), with most being collected in shallower nearshore waters. Beaumariage (1973) provides further evidence for protracted spawning due to the holding of vitellogenic eggs from May through October. The appearance of spent males in the Gulf from September through December coincided with increased abundances of vitellogenic eggs.

Growth. King mackerel growth is highly variable, with females growing faster, causing age and growth studies to differ significantly. For example, females 850 to 899 mm FL may be 1-8 years old, while males the same size could be 3-8 years old (Beaumariage 1973; Johnson et al. 1983). Johnson et al. (1983) suggested that slow growing individuals may compensate for earlier slow growth in their second year, when their growth increment surpasses that of fast growers.

Feeding. Feeding habits of king mackerel are well documented. This species feeds mostly on schooling fish, secondarily on crustaceans, and to a lesser extent on molluscs (Godcharles and Murphy 1986). Atlantic threadfin herring (Opisthonema oglinum) and scaled sardines (Harengula jaguana) are dominant prey items for king mackerel, comprising approximately 59% (by number) of their diet. Other common prey includes jacks (Carangidae), snappers (Lutjanidae), grunts (Haemulidae), porgies (Sparidae), and searobins (Triglidae). Invertebrates, including squid and shrimps (Panaeus spp.) make up nearly 33% of the king mackerel's diet (Beaumariage 1973). Saloman and Naughton (1983) indicated king mackerel off Florida fed primarily on ballyhoo (Hemiramphus brasiliensis), snapper, clupeids such as sardines, mackerel, and two species of mullet.

4.1.5 Sheepshead

Sheepshead, Archosargus probatocephalus, are commonly caught year-round in nearshore coastal areas by sport and recreational fisheries from Nova Scotia and the northern Gulf of Mexico to Brazil, although they are absent from West Indies and Bahamas (Robins et al. 1986). Within the Gulf, this species is found primarily in the western region, from Laguna Madre east past Apalachicola Bay off northwestern Florida, although they are common throughout the Gulf. Little information exists on the biology and population dynamics of this species.

Distribution and Movement. Sheepshead move seasonally between offshore areas and nearshore coastal habitats. In Texas and Louisiana, this species moves offshore in late fall (Kelly 1965). Off the Mississippi River Delta and the Mississippi and Alabama coasts, they aggregate in the vicinity of the oil platforms during cooler months in late fall and remain offshore until the onset of spawning in spring (Jennings 1985). After spawning, sheepshead return to nearshore coastal environments throughout the Gulf. Recruitment of sheepshead to the BGOF appears to be a seasonal event, with numbers increasing in spring due to spawning aggregations (NMFS 1980).

Environmental Influences. Sheepshead have been collected over a wide range of temperatures and salinities. Some sheepshead have been caught in water temperatures from 5°C (Christmas and Waller 1973, Perret 1971) to 35°C (Johnson 1978). In the Gulf, juveniles are most commonly collected in temperatures between 8-30°C.

Sheepshead are a euryhaline species, tolerating a wide range of salinities (Gunter 1956). For example, Perret and Caillouet (1974) collected sheepshead at salinities ranging between 5.3 and 25 ppt, while other studies have caught this species in salinities as low as 0.0 (Kelly 1965, Perret 1971, and Tarver and Savoie 1976).

Limited data exists on the effects of dissolved oxygen on the survival of larval, juvenile, or adult sheepshead. However, Adkins and Bowman (1976) reported sheepshead die-offs in closed canals in coastal Louisiana during severe oxygen depletion. The dissolved oxygen lethal lower concentration for this species is unknown.

Reproduction. Sheepshead spawning patterns are relatively well known. This species spawns in spring at most locations within the Gulf, including in the Mississippi Sound (Christmas and Waller 1973). Spawning most likely occurs in offshore areas due to the lack of larvae collected in shallow nearshore areas and estuarine habitats during spring. In March through May, sheepshead probably congregate in nearshore areas, migrate to offshore locations to spawn, and return to nearshore areas in late summer (Swingle 1977). Yolk-sac larvae of this species measure 2.0-4.5 mm TL (Johnson 1978). According to Hildebrand and Cable (1938), McClane (1974), and Burgess (1980), sheepshead eggs hatch in offshore waters and the larvae or post-larvae move inshore along beaches and into estuaries before being transported onshore. Juveniles are collected in seagrass beds and around structures such as jetties and pilings.

Growth. Sheepshead are relatively long-lived (Johnson 1978), with an estimated maximum life span of at least 20 years (Beckman et al. 1991). Because sheepshead growth can be highly variable, size is not a good indication of age. For example, Beckman et al. (1991) found that sheepshead over 400 mm FL or 1.5 kg weight can range in age between 3 to 20 years.

Regional size differences also have be reported. Hildebrand and Schroeder (1927) collected sheepshead in Chesapeake Bay weighing between 11 and 33 kg, while individuals weighing 0.5-1.0 kg were caught off the North Carolina coast (Hildebrand and Cable 1938). In coastal Mississippi waters, a sheepshead weighing over 5 kg is considered large, although larger individuals are common off Louisiana (Jennings 1985).

Feeding. Sheepshead are omnivorous, preying on a wide variety of food items, including plant material, invertebrates, and small fishes (Overstreet and Heard 1982). Larval and small juveniles prey primarily on zooplankton such as copepods and amphipods, while larger juveniles and adults consume molluscs and crustaceans (e.g., blue crabs, barnacles, young oysters, and clams), as well as small fishes, usually Atlantic croaker (Benson 1982; Odum et al. 1982).

Regional differences in sheepshead diets have been reported. For example, Springer and Woodburn (1960) found sheepshead in Tampa Bay consumed plant material, molluscs, crustaceans, and polychaetes, while Overstreet and Heard (1982) listed a variety of invertebrates (polychaetes, molluscs, and crustaceans) in addition to small fishes in the diet of individuals from Mississippi Sound. Ogburn (1984) reported that the diet of sheepshead off some North Carolina jetties was comprised mainly of intertidal algae and molluscs. Sedberry

(1987) found sheepshead in the South Atlantic Bight preyed on bryozoans (largest proportion), followed by bivalves, echinoderms, and ascidians. Other prey items included barnacles, crabs, foraminiferans, cnidarians, polychaetes, gastropods, and small arthropods. Food habits of sheepshead at BGOF varied seasonally, with portunid crabs comprising a large part (~67%) of their diet in summer, while biofouling species were more important food sources in fall and winter (NMFS 1980).

4.1.6 Atlantic Spadefish

Atlantic spadefish, Chaetodipterus faber, are the only member of the family Ephippidae native to the western Atlantic Ocean (Hayse 1990). Spadefish are a schooling fish ranging from Massachusetts, Bermuda, and the northern Gulf of Mexico to Brazil (Robins et al. 1986). Spadefish inhabit coastal waters and are rarely collected north of Chesapeake Bay (Johnson 1978). Until recently, this species has been poorly represented in the recreational and sport fisheries. Little information exists concerning many life history parameters, including distribution, abundance, and seasonal occurrence of larvae, juveniles, and adults.

Distribution and Movement. Atlantic spadefish inhabit coastal waters over its entire range. Most spadefish occupy shallow coastal areas, including mangroves, sandy beaches, wrecks, and harbors (Robins et al. 1986). Large spadefish (up to 9 kg) have been observed at nearshore oil and gas structures, but appear to be relatively rare at deeper structures (NMFS 1980). In the north-central Gulf, larvae are collected between May and September, but are most common (i.e., highest densities) in June (Ditty et al. 1994). Larvae were especially abundant off the Mississippi River Delta during August, with nearly 86% of all the larvae being collected in less than 25 m water depth. Because most larvae are found in coastal waters during spawning periods, juvenile and adults probably have limited offshore movements.

Environmental Influences. Limited information exists on environmental influences on juvenile and adult spadefish. Ditty et al. (1994) found that greater than 85% of the larvae collected in the Gulf between June and August were at surface water temperatures ranging from 25°C to 32.2°C.

The highest abundances of spadefish larvae were at salinities between 26.7 and 31.3 ppt (Ditty et al. 1994), although some larvae were collected at slightly higher salinities (N=1; 34.2 ppt off Florida).

No data exists describing influences of dissolved oxygen on any life stages for spadefish. However, it is expected that adults and juveniles would try to avoid hypoxic and anoxic areas.

Reproduction. Few studies have addressed the reproductive biology of this species. Hayse (1990) reported spadefish off North Carolina spawn between May and October, with some females spawning more than once (i.e., serial spawning). Along the east coast of Florida, Herrema et al. (1985) found spadefish spawning between March and June, while Chapman (1978) observed spawning aggregations during late July off Georgia. More studies are needed to understand spawning and reproductive patterns in this species.

Growth. Overall, little information is available on spadefish age and growth. Spadefish off North Carolina probably reach lengths between 55 and 100 mm by the end of their first summer, and up to 135 mm by the second summer (type of measurement unknown; Hildebrand and Cable 1938). Hayse (1990) calculated asymptotic growth (maximum total length) for spadefish off South Carolina to be 490 mm, which is small compared to reported total lengths of 900 mm for some tropical regions (Johnson 1978).

Feeding. Very little information concerning the feeding habits of Atlantic spadefish was found. This species occupies shallow coastal areas, including mangroves and is believed to prey primarily on various shellfish species (Robins et al. 1986).

4.1.7 Gray Snapper

Gray snapper, Lutjanus griseus, are one of the most common recreational and commercial species in Florida's snapper fishery (Bortone and Williams 1986; Rutherford et al. 1989). In Florida, landings of gray, mutton, lane, and yellowtail snapper are only exceeded by red and vermilion snapper (NMFS 1979). The snapper genus Lutjanus (Family Lutjanidae) is represented by 65 species in tropical and subtropical seas (Allen 1987). Members of this genus primarily inhabit shallow coral reefs, although some species can be found in water depths up to 265 m. Gray snapper are generally found over reef habitats; however, both adults and juveniles also have been found in estuarine areas. This species can reach a length of 60 cm (2 ft) and weigh up to 4.5 kg (10 lbs).

Distribution and Movement. Gray snapper are primarily found in inshore areas of the eastern Gulf off Florida, but are distributed from Massachusetts, Bermuda, and the northern Gulf of Mexico to southeast Brazil (Robins et al. 1986). Juvenile gray snapper usually occupy different habitats than adults. Adults display little movement after becoming established in an area. Juveniles are generally found in nearshore grass beds and along mangrove edges, while adults tend to occupy deeper channels and offshore reefs (Starck and Schroeder 1971). However, both adults and juveniles probably utilize shallow estuarine areas as nursery grounds. Gray snapper have been collected at water depths between 0 and 180 m (Thompson and Munro 1974; Fischer 1978).

Environmental Influences. Since gray snapper occupy such diverse habitats, this species has a high tolerance for environmental changes, including temperature and salinity. Gray snapper have been collected over a broad temperature range between 13.4-32.5°C (Springer and Woodburn 1960; Rivas 1970), while Starck and Schroeder (1971) reported the lower lethal temperature for gray snapper ranged between 11°C and 14°C. As expected based on this range, Chester and Thayer (1990) found no significant differences in gray snapper abundances among stations off south Florida as a function of temperature.

In addition to their typical marine habitat, gray snapper have been collected in both estuarine and freshwater lakes and streams in South Florida (Gunter and Hall 1963). Thus, salinity tolerance ranges between 1.0 to 35 ppt (Springer and Woodburn 1960). Consistent with this wide tolerance range, Chester and Thayer (1990) found no significant differences in gray snapper abundances among stations off south Florida as a function of salinity.

No information on environmental influences of dissolved oxygen was available, although snapper likely would avoid hypoxic or anoxic regions, as expected for most motile species.

Reproduction. Grimes (1987) reviewed the reproductive biology of tropical snappers. Most snappers, including grays spawn in groups (Starck and Schroeder 1971), and typically in offshore areas (Springer and Woodburn 1960). Spawning patterns vary among snapper species, but most have a protracted spawning period with seasonal peaks, and longer spawning periods in warmer areas (Erdman 1976). Gray snapper probably spawn more than once during a single spawning season (Starck and Schroeder 1971). Eggs are small (between 0.4 and 0.6 mm diameter) and probably non-adhesive, with one central oil globule.

Little information is available on gray snapper larvae. However, similar to other snapper, gray snapper larvae are probably planktonic at lengths less than 10 mm TL (Barans and Powles 1977), and transform to juveniles between 6.3 and 9.6 mm SL (Richards and Saksena 1980).

Growth. Little information exists describing length-weight relationships for gray snapper. However, similar to other snapper species, gray snapper growth is most likely influenced by temperature and diet. Starck and Schroeder (1971) used fish scales and Manooch and Mason (1984) used otoliths to age gray snapper. According to estimates by Bohlke and Chaplin (1993), Thompson and Munro (1974), and Manooch and Mason (1984), gray snapper can reach maximum lengths between 500 and 900 mm TL. However, differences in growth rates at various locations has led to a general disagreement over their growth. For example, annual growth rings on otoliths (annuli) occur between February and July off Cuba, and between February and March off south Florida. This alone has led to major differences in calculated growth rates among researchers. Manooch and Matheson (1981) used the von Bertalanffy Growth Function to describe estimated maximum lengths and ages in gray snapper off Florida's east coast. Results of the Manooch and Matheson study indicated this species can live up to at least 21 years and reach a maximum total length of nearly 900 mm.

Feeding. Feeding habit data for gray snappers is limited, but this species can probably be classified as a euryphagic (i.e., generalist) carnivore (Bortone and Williams 1986). Starck and Schroeder (1971) found adult gray snappers to be nocturnal predators, foraging away from their reef habitats, while juveniles tend to feed diurnally within seagrass beds.

Gray snapper diets also differs among regions. For example, Longley et al. (1925) found gray snapper in the Dry Tortugas fed primarily on portunid and spider crabs, and other crustaceans. Off south Florida, Croker (1962) reported that gray snapper diets consisted mostly of fishes and crustaceans, including grapsid crabs and panaeid shrimp. Similar results were reported by Starck and Schroeder (1971), and Hettler (1989). Juvenile gray snapper feed primarily on crustaceans (~93%) and fishes (5%), and shift their diet from amphipods, shrimp, and small crabs in the seagrass beds to fish and larger crabs in channels and reefs as adults.

4.1.8 Great Barracuda

The Great barracuda (Sphryraena barracuda) is found throughout most tropical and subtropical regions of the world. This species is popular in sport and recreational fisheries along most of its range (Robins et al. 1986), primarily due to its large size (Schmidt 1989). Very little information is available concerning the biology and general ecology of this species. Most of the available data on great barracuda comes from commercial and recreational fisheries off Miami, Florida (de Sylva 1963).

Distribution and Movement. Great barracuda are members of the family Sphyraenidae, which are medium to large-sized predators having long jaws and large canine teeth (Robins et al. 1986). The great barracuda is distributed in warm waters from Massachusetts to southeast Brazil, including most areas of the Gulf of Mexico. Young barracuda inhabit inshore seagrass beds, while adults range from inshore channels to the open ocean. Barracuda are seasonal migrators, moving along both coasts of Florida to southern Florida in winter and returning north in summer to areas in the northeastern Gulf and northern Atlantic coast (de Sylva 1963).

Environmental Influences. No information was available describing how changes in environmental parameters including temperature, salinity, and dissolved oxygen influence great barracuda populations. However, because barracuda are pelagic species which undergo seasonal migrations and are found in warmer seas, it is likely that they avoid areas with low temperatures, lowered salinity, and low dissolved oxygen concentrations. These unfavorable conditions are seasonally typical of shallower nearcoastal areas, particularly in the northern and western Gulf.

Reproduction. No information was found concerning reproduction (spawning) patterns.

Growth. No information was available describing growth of larvae, juveniles, or adult barracuda. Because this species is a voracious predator, it is likely they are fast growers. The largest individual reported in Robins et al. (1986) was 2 m long (6.5 ft) and weighed 48 kg (106 lbs).

Feeding. No information on feeding habits of this species in the Gulf of Mexico was available. Most of the available information on this species concerns food habits of juvenile barracuda in the Florida Everglades (Schmidt 1989). Young barracuda in the Everglades fed almost exclusively on killifishes (Cyprinodontidae), with mojarras (Gerreidae) as the second most important prey item. Although the Schmidt study targeted juvenile barracuda, some food habit data that were collected on adults indicated they preyed on mullet (Mugil spp.) and striped anchovy (Anchoa hepsetus).

4.1.9 Gray Triggerfish

Gray triggerfish, Balistes capriscus, are found near coral reefs, oil rigs, and jetty habitats in the eastern Atlantic ocean, from Nova Scotia and Bermuda, through the Caribbean (including the northern Gulf of Mexico) to Argentina (Hoese and Moore 1977; Robins et al. 1986). This species can reach up to 30 cm (1 ft) in length. Little information exists on the distribution, movement, environmental influences, reproduction, or growth, and only limited data are available on gray triggerfish feeding habits.

Distribution and Movement. Little information exists on the distribution and movement patterns of gray triggerfish. This species is widely distributed and is most likely one of the few "resident" triggerfish in the northern Gulf (Walls 1975).

Environmental Influences. No information was identified concerning environmental influences on gray triggerfish in the Gulf of Mexico.

Reproduction. No information is available on reproduction, including temporal and spatial spawning patterns.

Growth. No information is available concerning growth of gray triggerfish in the Gulf of Mexico.

Feeding. Triggerfish (Balistidae) feed diurnally (Randall 1997) on hard-shelled invertebrates, including molluscs and echinoderms. Gray triggerfish have been reported by Frazer et al. (1991) to prey on sea urchins (Arbacia punctulata), while Kurz (1995) observed predation on sand dollars near artificial reefs in the northeastern Gulf. This species was observed by Frazer et al. foraging over sandy bottom areas. This may provide a direct link between soft-bottom and reef dwelling communities (Frazer et al. 1991).

4.1.10 Blue Runner

Blue runner (Caranx crysos) are a migratory pelagic species occurring from Nova Scotia to Brazil, including areas of the northern Gulf of Mexico, and in some areas of the eastern Atlantic (Robins et al. 1986). Fishery surveys in the Gulf have reported jacks (family Carangidae, subfamily Caranginae), including blue runner to be very abundant (Klima 1971). This species is likely taken by recreational and sport fisheries throughout its range.

Distribution and Movement. Blue runner are found in pelagic zones (0-250 m) from Nova Scotia to Brazil, throughout the Gulf of Mexico, and in the north Atlantic (Robins et al. 1986). Off coastal Louisiana, young blue runner (1.5-13.0 mm SL) juveniles are distributed across continental shelf waters, except east of the Mississippi River Delta (Shaw and Drullinger 1990). Larval blue runner are most common at depths less than 40 m in summer (June-July), but have been collected at depths greater than 182 m. Adults are likely found at similar depths.

Environmental Influences. Detailed information on environmental influences of temperature, salinity, and dissolved oxygen on blue runner life history parameters are limited. Larvae were most abundant in June off Louisiana, where surface water temperatures ranged between 23.3-32.0°C (Shaw and Drullinger 1990). Because this species is highly motile, it is likely that it encounters a wide range of temperatures and has a high tolerance for different temperature regimes.

Similar to information on temperature, limited information exists for salinity. Larval blue runner were collected off Louisiana at salinities ranging between 24.8-37.7 ppt, with most larvae being collected at salinities below 33 ppt (Shaw and Drullinger 1990).

No information exists on effects of dissolved oxygen on blue runner juvenile and adults. However, similar to other highly motile species, it is likely that this species is able to avoid anoxic and hypoxic areas.

Reproduction. Detailed information on reproduction (spawning patterns) of blue runner is not available. This species has a summer spawning period, with maximum spawning usually occurring in July (Shaw and Drullinger 1990). It is likely that spawning occurs in offshore areas (Robins et al. 1986), followed by a general movement (migration) into shallower nearshore coastal areas.

Growth. No information was available on age and growth of blue runner in the Gulf of Mexico. According to Robins et al. (1986), this species can reach a length of 50 cm (20 in.) and weigh 1.8 kg (4 lbs.).

Feeding. No detailed feeding habit studies were found for blue runner. However, TPW (1971) reports that off Texas, this species eats small fish, shrimp, and crabs.

4.1.11 Greater Amberjack

The greater amberjack, Seriola dumerili, is a pelagic species in the family Carangidae (jacks) which is found in pelagic waters from Massachusetts to southeast Brazil, and throughout the Gulf of Mexico (Robins et al. 1986). This species is the largest amberjack and is an important component of both sport and recreational fisheries throughout its range (Robins et al. 1986). However, greater amberjack flesh is one of a variety of jacks that is known to be toxic (ciguatera poisoning).

Distribution and Movement. Greater amberjack have a nearly worldwide, warm water distribution, most commonly found in water depths between the surface and 70 m (200 ft) (IRC 1997). Little information exists on movement and migration patterns for this species. However, similar to most of its relatives, greater amberjack likely undergo seasonal migrations, moving to warmer waters (e.g., off south Florida) to winter, and returning to nearshore areas in the Gulf during summer. Information from Gulf of Mexico commercial catches indicates that the highest numbers of greater amberjack are taken on the west coast of Florida and off Louisiana (McClellan and Cummings 1996). Tagged fish from all areas of the Gulf of Mexico region were captured after short periods of time closer to tagging locations than compared to fish tagged in other areas of the Atlantic Ocean (Cummings and McClellan 1996).

Environmental Influences. No information is available concerning environmental influences on amberjack life history characteristics. Similar to other jacks, it is likely that greater amberjacks are able to tolerate a wide range of temperatures and salinities. Also, it is likely that this species is able to avoid anoxic and hypoxic regions of the Gulf.

Reproduction. No information is available on greater amberjack spawning. However, greater amberjacks may be similar to other jacks and spawn in offshore areas during winter and move into warmer, shallow areas in summer.

Growth. No information was located on age and growth of greater amberjack. However, Beasley (1993) may have some information for the northern Gulf.

Feeding. Little information is available describing feeding habits of greater amberjacks. IRC (1997) reports that this species consumes squid, fish, and crustaceans.

4.1.12 Additional Fish Families

Clinidae. Blennies are one group of fishes in the family Clinidae. This family is composed primarily of small fishes inhabiting coral reefs, rocky shores, and seagrass beds (Robins et al. 1986). Most clinids live in holes or tubes which they often defend against other fishes and invertebrates. The crested blenny, Hypleurochilus geminatus, is abundant on Texas jetties living among empty barnacle shells (Fotheringham and Brunenmeister 1989), and at oil platforms in shallow regions of the Gulf (NMFS 1980). According to NMFS (1980), densities of H. geminatus are highest at the Bucaneer Oil Field in the northwestern Gulf during summer. Spawning of the crested blenny likely occurs from spring to August, with eggs being brooded in empty barnacle shells (NMFS 1980). Blennies feed primarily on small crustaceans and molluscs. No detailed information was available concerning environmental influences for this family.

Pomacentridae. Damselfishes are found in tropical marine habitats throughout the world, but are most common in the Indo-Pacific (Nelson 1994). This family is comprised of 28 genera, representing 315 species. The most species are found in the region from the Philippines to Australia. Members of this family form mating pairs. Females deposit adhesive eggs on hard surfaces (nests), which are then guarded by the males (Robins et al. 1986). Ten damselfish species have been commonly observed in the Gulf of Mexico, including Flower Garden Banks, Mississippi-Alabama hard banks, and Florida Middle Ground (MMS 1991). Fishes in this family most likely eat algae, small crustaceans, and small fishes. No information on environmental influences of temperature, salinity, and dissolved oxygen on damselfishes was available.

Haemulidae. Grunts are medium-sized, perch-like fishes inhabiting tropical and subtropical coastal regions throughout the world (Robins et al. 1986). Generally, adults feed at night over sandy, muddy, or grassy bottoms. Members of this family (especially juveniles) have been reported to congregate in large numbers on reefs, harbors, bays, and other protected areas (Robins et al. 1986). Grunts comprise 17 genera, representing approximately 150 species (Nelson 1994). In the Gulf of Mexico, three species are commonly observed in areas such as Flower Garden Banks, Mississippi-Alabama hard banks, and Florida Middle Ground (MMS 1991). These species include tomtate (Haemulon aurolineatum), cottonwick (H. melanurum), and white grunt (H. plumieri). These species prey primarily on bottom organisms, including polychaetes and molluscs (Paxton and Eschmeyer 1994). No information was available on environmental influences on grunts.

Chaetodontidae. Butterflyfishes are one of the most recognized of all the tropical reef fishes because of their bright patterns (Nelson 1994). This family is comprised of 10 genera with 114 species inhabiting tropical marine habitats in the Atlantic, Indian, and Pacific oceans. Butterflyfishes are most abundant in the tropical Indo-West Pacific (Nelson 1994). Butterflyfishes generally occur on coral reefs, at depths less than 20 m, but some are found to depths of at least 200 m. These fishes are known to consume different prey according to the size and shape of their jaws (Paxton and Eschmeyer 1994). For example, butterflyfishes with short jaws feed by nipping off the ends of coral polyps, while long-nosed butterflyfishes pick small invertebrates from sea urchin spines and coral crevices (Paxton and Eschmeyer 1994). Six butterflyfishes are commonly observed in the Gulf of Mexico, including Flower Garden Banks, Mississippi-Alabama hard banks, and Florida Middle Ground (MMS 1991). These species include longsnout (Chaetodon aculeatus), bank (C. aya), foureye (C. capistratus), spotfin (C. ocellatus), reef (C. sedentarius), and banded (C. striatus) butterflyfishes (MMS 1991). No information was available on environmental influences of temperature, salinity, and dissolved oxygen.

4.2 Invertebrates

Species accounts for common invertebrates representative of oil and gas structures in the Gulf region are presented below. Gulf-relevant information concerning distribution and movement, environmental influences, reproduction, growth, and feeding is not available for several index species, including Syncorne exima, Anthopleura krebsi, Bugula neritina, Balanus reticulatus, B. tintinnabulum, Anadara transversa, Chama macerophylla, and Isognomon bicolor. Information also is not presented for general invertebrate genera, such as Haliclona, Halichondria, Membranipora, Obelia, Clytia, and Ophiothrix, because of their broad-scale distribution and primary data records that apply to areas outside the GOM (i.e., not relevant to this study).

4.2.1 Stone Crab

Stone crabs, Menippe mercenaria, are large coastal decapods ranging from North Carolina southward in the Atlantic to Cuba and Jamaica, including most areas throughout the Gulf of Mexico (Williams 1984; Bert et al. 1978). This species supports an important commercial and sport fishery, especially off southern Florida (Lindberg and Marshall 1984). This fishery is unique in that only the claws are harvested from the live crabs. Following removal of the claws, the crabs are returned to the sea to allow females to continue spawning. In 1979, the Gulf of Mexico stone Crab Fishery Management Plan was implemented which set minimum claw lengths for harvest, trap types, and closed seasons to help manage the fishery (NMFS 1992). The taxon Menippe mercenaria was recently divided into two species based on morphology and coloration (Williams and Felder 1986). The first, M. mercenaria (Say), occurring from North Carolina and Northern Florida and throughout the Caribbean has a spotted carapace and banded legs. The other species, M. adina, a dark form with no spotting or banding, is distributed along entire Gulf of Mexico, from the State of Tamaulipas, Mexico, eastward to northwest Florida (Apalachee Bay) (Wilber 1989). These species interbreed along the northeastern coast of the Gulf of Mexico, producing hybrids with intermediate levels of spotting and banding (Williams and Felder 1986).

Distribution and Movement. Stone crabs are distributed in shallow subtidal habitats throughout their range, but some occur intertidally within the hybrid zone (northeastern GOM). Seasonal migrations from intertidal to subtidal habitats have been well documented for some decapod crustaceans (including stone crabs) and is usually associated with reproduction (Allen 1966; Cooper and Uzmann 1971; Boddeke 1975; Moore and MacFarlane 1984) or survival (Edwards 1958; Bainbridge 1961; Rebach 1974; Fotheringham 1975; Herrnkind 1980). In the fall, many marine crustaceans, such as stone crabs, in shallow, temperate regions, experience numerous physical changes, that serve as movement or migration cues. These cues include photoperiod, temperature, and fluctuating salinities and turbulence (Wilber and Herrnkind

1986). Stone crabs commonly inhabit intertidal areas in the northern Gulf, except during winter. Wilber and Herrnkind (1986) demonstrated that stone crabs displayed two seasonal patterns of movement: the immigration of adult females to intertidal areas in early fall, followed by the emigration of most crabs to subtidal areas in late fall and early winter. This decline in crab density in their native habitat (oyster reefs) indicates crabs move offshore into subtidal regions rather than alongshore in the intertidal zone.

Seasonal migrations involving one sex and/or size class have been reported (Bert et al. 1978). Females appear to be year-round residents of seagrass beds, but move into deeper water as temperatures increase in the spring (Bender 1971). Male stone crabs usually live farther offshore, moving at the end of the spawning season into shallow seagrass habitats to mate with freshly molted females.

Environmental Influences. Adult stone crabs are considered eurythermal and can be found in temperatures ranging between 8-32°C (Bender 1971). Observations of crab behavior at lower temperature limits indicated they were usually inactive, while at higher temperatures the crabs moved to cooler, deeper waters (Lindberg and Marshall 1984). Similarly, changes in temperature have a profound effect on crab reproduction and development, as well as migratory behavior (Sullivan 1979; Wilber and Herrnkind 1986). Sullivan (1979) noted that optimal spawning temperatures were above 22°C (usually after March), with decreases in spawning activity when temperatures dropped in October. No information on lethal temperatures was found.

Although adult and juvenile stone crabs are euryhaline, they are typically found in salinities approaching full seawater. In contrast, larval stone crabs appear to prefer much narrower temperature and salinity ranges. Ong and Costlow (1970) showed that no larval crabs survived at salinities of 10 ppt. The Ong and Costlow study suggested that the optimal combination of temperature and salinity for larval stone crabs was 30°C and 30-35 ppt. Stone crabs are able to adapt to gradual changes in salinity. For example, Karandeyeva and Silva (1973) reported stone crabs were tolerant of salinities between 6.0-7.5, and over 40 ppt over a three week period with no changes in oxygen consumption.

Adult stone crabs seem to be tolerant of reduced dissolved oxygen concentrations, although the prolonged effects on viability and reproduction are unknown (Lindberg and Marshall 1984). Karandeyeva and Silva (1973) reported that in the absence of all oxygen, stone crabs could survive 17-21 hours and could completely recover when placed in oxygenated water. Leffler (1973) described constant metabolic rates for stone crabs exposed to oxygen levels between 0.8 and 5.6 ml/l. Thus, it is postulated that stone crabs in the Gulf are able to tolerate a wide range of dissolved oxygen concentrations.

Reproduction. The reproductive biology of stone crabs has been well-documented, but copulation is infrequently observed in the field since it takes place within burrows and crevices (Bert et al. 1978). Spawning primarily occurs between May and July. During a single mating season, a female may produce four (Porter 1960) to six (Binford 1913) egg masses or "sponges". After hatching (9 days to 2 weeks after spawning), larvae are released into the water column. Development of these first stage larvae takes 27-30 days in the laboratory (Mootz and Epifanio 1974), and can be altered by changes in temperature, salinity, and diet (Ong and Costlow 1970; Scotto 1979). After a series of molts and megalopae stages, juvenile crabs (less than 3.0 cm carapace width) develop color patterns, which they can change according to their habitat.

Growth. Stone crab growth can be characterized by the frequency of molting and intermolt intervals, and by the incremental increase in size per molt (Lindberg and Marshall 1984). Larval growth involves metamorphosis through five to six zoel and megalopa stages. Transition of stone crabs between juvenile and adult takes place at approximately 35 mm CW (carapace width) (Lindberg and Marshall 1984). At this size, the shape of the carapace changes to resemble the adult (Manning 1961), with the carapace-width versus claw-size relationship diverging between male and females (Savage and Sullivan 1978). In general, males are heavier and grow faster than females of the same carapace width. This is because the male crabs have greater chelae (claw) growth (Sullivan 1979), which accounts for almost 51% of the live weight in adult stone crabs. Size frequency distributions from field collections indicated Year I crabs were 45-60 mm CW, Year II averaged 80 mm CW, and Year III (some Year IV) crabs were approximately 100 mm CW (Sullivan 1979). Since claw length (not carapace width) defines the harvestable size in this species, males reach harvestable size at 80 mm CW (Year II), while females are harvestable at about 87 mm CW (between Year II and III) (Sullivan 1979).

Feeding. Limited information is available concerning the natural diet of stone crabs. This species is a carnivore with high energy requirements for growth. Opportunistic feeding habits enhance its ability to meet these requirements (Bert et al. 1978). Juvenile crabs are believed to be primarily carnivorous. Survivorship in the laboratory was high when fed shrimp nauplii (Artemia spp.) (Porter 1960; Mootz and Epifanio 1974; Scotto 1979; Sulkin and Van Heukelem 1980), but was lowered when fed exclusively algae or rotifers (Porter 1960; Sulkin and Van Heukelem 1980). Although no studies are available on the diet of planktonic stages of stone crabs, it is likely that crab larvae feed almost exclusively on other planktonic larvae and zooplankton. Similarly, no feeding habit studies are available concerning the diet of juvenile stone crabs. Laboratory studies have shown that juvenile crabs will eat almost anything, including polychaetes, small bivalves, oyster drills, fish, chicken parts, and each other (Savage and McMahan 1968; Bender 1971). Adult stone crabs probably use their chelae to cut through the shells of various molluscs (Bender 1971).

4.2.2 Sea Urchin

The sea urchin, Arbacia punctulata, occurs on coral reefs and sandy and rocky bottoms along the Atlantic coast of North America (including most areas of the Gulf of Mexico), south to Cuba (but not in most Caribbean islands) (Kaplan 1982) and has historically been utilized as a key laboratory animal for cell biology studies (Harvey 1956). This species is known by various common names, including purple sea urchin (Fox and Ruppert 1988; Martinez and Harlow 1994) and brown rock urchin (Kaplan 1982). In the Gulf of Mexico, this species is typically found on hard-bottom substrates in shallow water coastal areas. Most of the information below comes from a single, seminal reference on Arbacia punctulata (Harvey 1956).

Distribution and Movement. Arbacia punctulata ranges from Cape Cod along the U.S. Atlantic coast south to Florida and Cuba, and westward throughout the Gulf of Mexico to Yucatan, but is not found in most Caribbean islands (Kaplan 1982). This species is usually found in shallow water, but has been collected at depths up to 700 ft (~ 230 m). Since the early 1930's, abundances of Arbacia have fluctuated, with numbers generally decreasing in the early and mid 1940's and then increasing in the late 1940's. No information is available concerning movement or migration patterns for this species.

Environmental Influences. No information is available on how environmental parameters such as temperature, salinity, and dissolved oxygen influences Arbacia juveniles or adults. Early studies on egg development found that the size of the urchin egg was not effected by temperatures between 5.4 and 29.3° C or at pH levels between 4.0 and 9.8 (Lucké 1935).

The effects of dissolved oxygen also were not tested in these early studies. However, Kitching and Moser (1940) found that in the absence of oxygen, Arbacia sperm became non-motile. Thus, egg fertilization may be reduced or prevented in low oxygen conditions such as anoxic and hypoxic areas of the Gulf.

Reproduction. The breeding season for Arbacia varies seasonally according to water temperature, but occurs off Woods Hole primarily between June and August (Harvey 1956). During May and June, the gonads are small and indeterminate between the sexes. The males ripen earlier and remain in good condition longer than females. The eggs mature in the ovary and are shed during the spawning season, losing their polar bodies prior to fertilization and development. Eggs are fertilized and begin to ripen towards the end of the spawning season (September to June off Florida).

Growth. Little information is available concerning growth and age in Arbacia. In the laboratory, fertilization through metamorphosis can occur in four months (at 23°C), producing an individual 1 mm in diameter (Harvey 1956). The smallest field-collected urchin was 6 mm diameter with spines (3.6 mm without spines). This species has been collected at sizes ranging between 3.6-56 mm diameter (without spines), with collections of adults being more common than the youngest individuals.

Feeding. In the laboratory, Arbacia punctulata eats almost anything (Harvey 1956). In their native habitats, Arbacia have been observed consuming algae (e.g., Fucus, Laminaria, and Ulva), coral polyps, sponges, mussels, sand dollars, and other Arbacia. Parker (1932) reported this species eating killifish (Fundulus spp.), which probably were dead or dying. Arbacia survive in aquaria for long periods of time when fed Fucus and Laminaria, and shells infested by the sulphur-boring sponge Cliona celata (Harvey 1956).

4.2.3 Hydroid

The hydroid, Tubularia crocea, grows subtidally in dense clumps on hard substrates (Martinez and Harlow 1994). This species can be found from Nova Scotia south to Florida, including oil platforms in the Gulf of Mexico. Although general information is available describing some life history parameters in hydroids, detailed information on this species is limited.

Distribution and Movement. Tubularia crocea are distributed throughout the Atlantic coast of North America, from Nova Scotia south to Florida. This species is a common inhabitant on rock jetties, floating docks, pilings, and other hard surfaces year-round (Fox and Ruppert 1988). T. crocea is most abundant at depths between 0 and 10 m.. The species grows in colonies several centimeters in diameter and 2-5 cm thick on sponges and substrate not covered by sponges throughout the Gulf (Fotheringham and Brunenmeister 1989).

Environmental Influences. Limited information is available describing potential impacts from temperature, salinity, or dissolved oxygen changes. Fotheringham and Brunenmeister (1989) report Tubularia crocea is tolerant of low temperatures (not specified), while Fox and Ruppert (1988) indicate T. crocea does not occur in salinities lower than 2/3 seawater salinity. No information is available on how changes in dissolved oxygen affects life history parameters of this species.

Reproduction. No information was available describing reproduction in this hydroid species. However, the generalized life cycle of the genus Tubularia is well documented. This genus undergoes sexual reproduction, with the medusae remaining attached to the parent hydroid, and displaying various stages of development (Barnes 1987). The egg then develops into a planula (planktonic form) within the attached parent medusa prior to being released. The actinula larva is later released from the medusa and eventually settles to the bottom or on a hard substrate, developing into a new hydroid colony.

Growth. The most common form of growth for cnidarians such as Tubularia is through asexual budding (Sherman and Sherman 1976). Colony formation occurs when buds remain attached to the parent body.

Feeding. Tubularia crocea is a filter (Fotheringham and Brunenmeister 1989). Filtering of particles is done by using two rows of tentacles from the feeding polyp or gastrozooid (Russell-Hunter 1968).

4.2.4 Acorn Barnacles

Barnacles of the order Thoracica ("shelled barnacles") are found throughout the Gulf of Mexico, in most habitats, including freshwater, intertidal marine, and in deeper offshore waters (Gittings et al. 1986). Species comprising this order are a predominant part of the fouling community in the Gulf, occurring on man-made structures such as ship bottoms, pilings, buoys, and oil platforms.

Distribution and Movement. Balanus improvisus has a worldwide distribution in tropical and temperate seas (Gittings et al. 1986). In the Gulf of Mexico, this species is most abundant in estuaries. In the northwestern Gulf, B. improvisus dominates nearshore fouling communities in the coldest months (January to March) (Gittings et al. 1986).

Balanus amphitrite is considered cosmopolitan species, being distributed in tropical and warm temperate seas (Gittings et al. 1986). In the Gulf of Mexico, this species is most abundant in coastal waters. This species has not been reported in the northern Gulf, between Redfish Bay, Texas, and Panama City, Florida. However, it is likely that this species does occur throughout the Gulf, from bays in south Texas, along the west coast of Florida, and in the Florida Keys (Gittings et al. 1986).

Environmental Influences. No information was available on temperature limits for adults of this species. However, based on their broad distributional range, it is likely that B. improvisus and B. amphritrite would be able to withstand temperature changes occurring in most parts of the Gulf. The effects of environmental parameters on the settlement and attachment of larval barnacles is well documented. O'Connor and Richardson (1994) found that attachment of B. improvisus larvae was reduced at lower temperatures (~6°C). O'Connor and Richardson (1994) found that attachment of B. amphitrite larvae was unaffected by storage temperatures of 6 or 27°C. Low temperatures and high salinity may have no effect or sometimes reduce the viability of B. amphitrite larvae (Patarnello et al. 1991).

Similarly, little information exists on ranges of salinity and how changes in salinity may affect this species. However, because B. improvisus occurs over a large distributional range and habitats, it is likely that this species tolerates most salinities throughout the Gulf. In Chesapeake Bay, B. improvisus occurs over a wide range of salinities (0.8-17.9 ppt) (Kennedy and DiCosimo 1983), and also is able to withstand very low salinities for several weeks (Gittings et al. 1986). O'Connor and Richardson (1994) found that larval attachment for B. improvisus was greatly affected by salinity. For example, attachment of cyprids to both polystyrene and glass substrata was significantly higher at 10 ppt and 20 ppt than at 30 ppt. Somewhat in contrast, O'Connor and Richardson (1994) found salinity had no effect either on the initial attachment or temporal pattern of attachment for B. amphitrite. Therefore, it is likely that this species would be able to withstand or adapt to most salinities with the Gulf.

No information is available concerning potential influences on life history parameters from changes in dissolved oxygen concentration. Because adults of this species are sessile, it is likely that they occupy areas with adequate DO levels.

Reproduction. Furman and Yule (1990) indicated this species is capable of self-fertilization. Furman et al. (1989) found B. improvisus self fertilized two weeks later than cross-fertilization. This suggests that barnacles first try to copulate with a neighbor, but isolated individuals resort to self-fertilization as the threshold for copulation decreases.

B. amphitrite is hermaphroditic, yet generally refrains from fertilizing its own eggs. There is evidence that barnacles can store sperm (Holm 1990). Egg development occurs within the shell in four phases prior to the release of microscopic, free swimming, naupliar larvae.

Growth. General growth characteristics for barnacles consists of a series of naupliar stages and a pre-settling cyprid stage.

Barnacle cyprids tend to settle according to a variety of substrate characteristics, including surface texture, contour, presence of adults and chemical cues (Mullineaux and Butman 1991). Once a site is chosen, the larva cements itself to the substrate with a secretion from its antennae. Soon after attachment, the cypris turns over, loses its planktonic appearance, and begins to surround itself with a wall of calcareous plates.

Feeding. Barnacles possess modified oral appendages for suspension feeding (Barnes 1987). There are typically six pairs of long, thoracic appendages (cirri) capturing food by moving the cirri through the water and capturing fine food particles, including plankton.

4.2.5 Northern Star Coral

The genus Astrangia includes over 30 recent nominal species within the family Rhizangiidae (Peters et al. 1988). Until recently, this genus had never been properly reviewed and it was estimated that many species were synonyms. After proper review of this genus, it was determined that A. astreiformis and A. danae were synonyms (the same species) and the name which these types reverted to was A. poculata, the Northern star coral (Peters et al. 1988).

Distribution and Movement. Astrangia poculata is found at water depths between 0 and 263 m along the Atlantic and Gulf coasts of North America, ranging from off Maine and Cape Cod, south to Florida, and within the Gulf of Mexico, from the southern coast of Texas and Mexico to Florida and Puerto Rico (Peters et al. 1988).

Environmental Influences. Throughout its range, A. poculata is relatively tolerant of a wide range of environmental conditions (Peters et al. 1988). In laboratory experiments, respiration of A. danae varied at temperatures between 11.5 and 23°C (Jacques et al. 1983). Also, photosynthesis in zooxanthellae was directly correlated to temperature, with *in-vivo* photosynthesis occurring at temperatures between 6.5 and 27°C. Results of the Jacques et al. study also indicated that calcification was a linear function of temperature between 15 and 27°C. No significant changes in calcification occurred at or below 15°C. No information was available concerning influences of salinity or dissolved oxygen on northern star coral, although most corals are sensitive to low salinity and low oxygen conditions.

Reproduction. Little information is available on reproduction of Astrangia poculata. Generally, sexual reproduction in corals such as Astrangia is similar to sea anemones, with both having dioecious and hermaphroditic forms (Barnes 1987). Generally, polyps from the adult develop at the base or edge of the colony (Alexander 1979).

Growth. The skeletal configurations of various corals are due to growth patterns of the colony and in part to the arrangement of polyps (Barnes 1987). When the polyps are well separated, the coral skeleton has a "pitted" appearance, such as that of stony corals, including

Astrangia poculata. This species expands the colony by budding of new polyps from the base of the old polyps (Barnes 1987).

Feeding. Little information is available on feeding habits of Astrangia, although feeding habits are expected to be similar to other stony coral and anemones. Astrangia likely uses its tentacles to capture food particles in the water column, including small zooplankton.

4.2.6 Brown Anemone

The brown sea anemone, Aiptasia pallida, is found in most shallow, warm water areas from North Carolina to Florida, and throughout the Gulf of Mexico (Meinkoth 1981). Brown anemones occur on well-established floating docks, as well as attached to rocks, oyster shells, and jetties (Meinkoth 1981; Fox and Ruppert 1988). Most of the available information focuses on changes which influence the distribution and abundance of the unicellular photosynthetic alga, Symbiodinium microadriaticum, or zooxanthellae, which gives this anemone its color.

Distribution and Movement. The brown anemone is commonly found in shallow waters along the east coast of North America, from North Carolina south to Florida (including the Caribbean) and in the Gulf of Mexico (Meinkoth 1981). In the Gulf, this species is most abundant on rocks, jetties, and attached to oil platform pilings. The highest abundances of Aiptasia are found in shallow (well-lighted) areas, but also has been known to occur in dark areas, although there it is pure, pallid white in color.

Environmental Influences. No information was available concerning environmental influences on the brown anemone. However, information concerning effects of temperature changes to zooxanthellae of Aiptasia is available. For example, Muscatine et al. (1991) indicated that when tropical sea anemones such as A. pallida are exposed to subnormal temperatures (i.e., cold shocked) and then rewarmed to ambient conditions, they release a large proportion of their zooxanthellae. The Muscatine et al. study reported that following a 4-hour exposure to cold temperatures (4°C), 40-55% of the zooxanthellae were released within a 12 hour period. This figure increased to almost 87% within 72 hours after the same 4 hour exposure period. Rewarming to at least 17.5°C was critical to envoke the maximum release of zooxanthellae. Thus, large temperature changes may influence anemone feeding and overall health of the organism.

No information was available on how changes in salinity or dissolved oxygen may affect the brown anemone.

Reproduction. No information on Aiptasia pallida reproduction was identified. However, many cnidarians (including A. pallida) asexually reproduce through budding. Polyps are formed at the base of the anemone and "bud-off" as the colony grows. Individual polyps then grow to later reproduce in the same manner.

Growth. Clayton and Lasker (1985) found individual and population growth of Aiptasia pallida was dependent on the feeding regime of the zooxanthellae. For example, if A. pallida was fed once per week, the zooxanthellae enhanced individual growth, pedal laceration, and population growth. Growth rates were lower when A. pallida was fed less frequently. Thus, individual growth was highly correlated to feeding frequency.

Feeding. No information was available describing the feeding habits of Aiptasia pallida. It is likely that this species feeds on zooplankton and other small marine organisms captured by injecting venom into prey items with its nematocysts (Alexander 1979). In the laboratory, Clayton and Lasker (1985) fed A. pallida almost entirely newly hatched brine shrimp (Artemia salina).

5.0 Environmental Features

5.1 Background

For shelf waters in the northern Gulf of Mexico a seasonal temperature signal is consistently present from Texas, eastward to Florida. This annual pattern is generally driven by cooler air temperatures during fall and winter, and warmer air temperatures and increased insolation in spring and summer. This exchange of heat between the atmosphere and shelf waters is affected by the presence of a large, regularly renewed, and consistently warm reservoir of water just offshore of the shelf.

From spring to summer, the pattern of shelf water temperatures is such that local vertical stratification increases while horizontal stratification decreases. In fall, shelf surface waters begin to cool and mix vertically as a result of relatively cool, dry continental air masses and associated frontal wind patterns moving over the shelf. This produces weaker vertical temperature gradients and stronger horizontal gradients between the cooler inner shelf and the seasonally moderated, but warm water seaward of the shelf break.

These seasonal patterns in average temperatures are illustrated in data taken from several shelf locations in the northern Gulf of Mexico. In Figure 7, Panel A, temperature time series, filtered to suppress daily or higher frequency variations, show vertically uniform temperatures from approximately October through February, as measured at mid-shelf offshore Louisiana in approximately 60 m[1] of water. In February, the near-surface and mid-depth temperatures increased slowly, producing a progressively stratified temperature field. Near-surface waters warmed at a fairly consistent rate while, in July, mid-depth temperatures warmed rapidly, resulting in decreased temperature gradients in the upper half of the water column between July and September. However, during this general warming, the near-bottom temperatures increased relatively little.

The annual pattern of across-shelf temperatures is illustrated in Figure 7, Panel B showing filtered near-surface temperature time series from inner, mid- and outer-shelf sites along 92°W. A sine curve has been fitted to the inner- and outer-shelf records to illustrate more clearly the horizontal temperature gradients and the diminished amplitude of the seasonal signal with increased distance offshore. (Note that the time scales in Panels A and B of Figure 7 are different.) The horizontal gradients were relatively small from spring (approximately March) to fall (October) coinciding with the interval of vertical temperature stratification described previously.

A record similar to that in Figure 7 is shown in Figure 8 which presents monthly mean near-surface temperatures at (A) inner-, (B) mid- , and (C) outer-shelf locations offshore Alabama. The original time series were taken by Texas A&M University (TAMU) as part of the MMS-funded Mississippi-Alabama Marine Ecosystem Study (MAMES) (Brooks 1991). Also shown is the sine curve, fit to the concurrent near- surface temperatures measured at mid-shelf offshore Louisiana, west of the delta (Figure 7, panel B). Note the similarity of the record from west and east of the delta for the mid-shelf, near-surface data. The winter horizontal stratification is clearly evident. Also shown in Figure 8 is the average monthly air temperatures measured at NDBC Buoy 42015, located approximately six miles offshore of Dauphin Island at the entrance to Mobile Bay The direction of heat flux on the inner shelf is clearly illustrated by the average air temperatures which are cooler than the underlying water from approximately September through February/March.

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[1] This section of the report is supported by extensive graphics. For convenience, these figures are provided in Appendix B.

To evaluate these patterns over more of the Gulf of Mexico shelf, mean near-surface temperatures were computed for locations on the west Florida shelf offshore Fort Meyer, Florida (26°N) and are presented in conjunction with mid-shelf observations from offshore Louisiana and Alabama in Figure 9. Although for different intervals, these records display similar amplitudes in the seasonal signal, even though the more southern observations on the west Florida shelf may be somewhat moderated by an air-water temperature difference that decreased as the atmospheric boundary layer was modified (warmed) by passage over warmer Gulf waters.

Elements of these general patterns are evident in hydrographic data taken along 92°W. In Figure 10, the vertically isothermal conditions are evident in winter, as is across-shelf warming. Figure 11 shows fairly strong vertical stratification in summer in conjunction with weak to absent across-shelf temperature gradients. These data help illustrate the consistency of the mean conditions with those occurring at specific times. As is evident from temperature data in Figure 7, there can be considerable variability at periods of less than one month, although this is superimposed on the substantial annual signal illustrated using monthly means.

5.2 Seasonal Temperature and Salinity Patterns

5.2.1 Introduction

The recently completed, MMS-funded LATEX-A program (1997) conducted by TAMU provides an extensive documentation of temperature and salinity conditions for the region containing most of the oil and gas activity in U.S. Gulf of Mexico waters (Figure 12). Two different types of data help provide insight to patterns of shelf water mass characteristics: temperature time series from moorings distributed across and along the shelf and hydrographic cruises conducted seasonally to provide comprehensive and spatially detailed documentation of temperature (T), salinity (S), and DO patterns. Although other variables were measured during these cruises, the present discussion is limited to T, S, and DO.

5.2.2 Annual Temperature Patterns (in-situ observations)

Introduction. Temperature time series used to compute monthly mean near-surface and near-bottom temperatures were measured approximately 10 m below the sea surface and 5 m or less above the local bottom from April 1992 through November 1994. To compute the means, all available observations from a measurement location during that month were pooled and averaged. Depending on the continuity of observations, the same measurement intervals may not have been used for all sites. Further, due to differences in the overall measurement period, data for some months represent averages for two years (December-March) while other months incorporate observations from three years (April-November). Note that temperature time series from the innermost shelf off western Louisiana and eastern Texas were not available. Stations used to develop the contoured maps are shown as small "x"s in the figures referenced below.

Near Surface Temperature Patterns. Shaded contour plots of monthly mean near-surface temperatures are shown in Figures 13 (January) to 24 (December). In January, the strong across-shelf gradient is clearly evident with 14°C on the inner shelf off Galveston and 16°C water up- and down coast of that central location. Along the shelf break, 22°C water was found consistently over the study area. In February, patterns did not change substantially with contours generally occurring parallel to local isobaths.

In March, slight warming is evident as the coolest inshore temperatures increased. In April, inner- and mid-shelf waters warmed. Between March and April, almost the entire shelf had temperatures greater than 18°C. In May, warming of shelf waters continued with shelf-break temperatures also showing an increase from 22°C to 24-25°C. Cross- shelf temperature differences were only 1-2°C. In June, the pattern of temperature contours that generally follow isobaths breaks down. Offshore western Louisiana, relatively cool water persists with inner- and mid-shelf temperatures increasing downcoast; much of the shelf is between 26°C and 27°C. Off south Texas, a tongue of relatively warm water (>27°C) is evident well across the shelf. The continued seasonal warming of surface waters continues in July. The central part of the study area has temperatures between 28°C and 29.4°C. To the east and west of these warm temperatures are local pools of cooler water (<28°C). This pattern of warmer temperatures in the central portion of the study area and slightly cooler temperatures up- and downcoast continues in August and September with both months having weak spatial gradients.

In October, fall cooling of surface water is evident with temperatures ranging from 25°C off Sabine Pass to greater than 27°C over the outer shelf in the western two thirds of the study area. In November, inner shelf temperatures decreased to 20°C off western Louisiana. This average temperature was last evident on the inner shelf in April. In November, offshore waters had cooled slightly but were still 3-4°C warmer than in April. Continued cooling is evident with the 18°C isotherm extending from Louisiana to south Texas. Off Galveston, there was a small zone of temperatures that averaged 16°C, while shelf-break temperatures continued to decrease.

Because of their ecological importance, special focus is placed on the 13°C and 18°C isotherms. For the study area, average near-surface temperatures did not reach 13°C; however, in January and February, the regions offshore Galveston and Sabine Pass, respectively, had average temperatures less than 14°C. It is quite probable that shallower inshore waters, especially between Galveston and central Louisiana, had means less than 13°C at least during these months. Average temporal values do not show episodes during which instantaneous temperatures might have been below 13°C. However, the spatial distribution of means does provide an indicator of the general pattern of temperatures that might be expected. It should be noted that this pattern may be altered if longer and different measurement periods were evaluated.

Near-Bottom Temperature Patterns. Since near-bottom temperatures were measured just above the local bottom, the depth below the surface of these measurements increased with increasing across-shelf water depth. This adds an additional influence on the monthly patterns of mean temperatures shown in Figures 25 (January) to 36 (December).

In January, near-bottom temperatures ranged between 10°C at the shelf break off Brownsville to 20°C in a mid-shelf pool of bottom water off western Louisiana. Inner-shelf bottom temperatures were at a minimum of 14°C for a region centered on Sabine Pass and increased up- and downcoast. These latter magnitudes and patterns were consistent with that of January near-surface temperatures. A fairly large pool characterized by bottom water greater than 18°C occurred in the eastern half of the study area. At the bottom, this was isolated from the shelf break by bands of cooler bottom water. However, higher in the water column, temperatures greater then 18°C extended to the shelf break.

A similar pattern of relatively warm mid-shelf bottom waters persisted through March, although it was diminished in area. In March, coolest inner-shelf temperatures were 16-17°C off Sabine Pass. Along the shelf break, temperatures ranged from 12-14°C. In April, the inner half (south Texas) to two-thirds of the shelf had bottom waters greater than 18°C. Between May and December the general pattern of the 18°C bottom isotherm did not change substantially as it tended to follow the local isobaths on the outer third of the shelf.

In May, as vertical stratification intensified and isotherms tended to be relatively horizontal across the shelf, bottom isotherms paralleled the isobaths as they decreased across the shelf. Even with the varying shelf width, isotherms tended to maintain a normalized across-shelf position. Through September, inner-shelf bottom waters continued to warm while outer-shelf bottom waters showed relatively little variability, thus creating greater bottom water temperature gradients.

In October, bottom temperatures from east Texas to Louisiana cooled on the inner half of the shelf. In November, the cooling extended further offshore with the majority of the shelf being 20-25°C. In December, the pattern returned to one similar to January, although the 20°C isotherm in the eastern portion of the study area was opened at the boundary of LATEX-A study area.

The presence of temperatures less than about 15°C at the 200 m isobath implies upwelling or raised isotherms that may be associated with slope cyclonic (cold core) eddies which often occur in this region. The fairly consistently cold bottom temperatures in the vicinity of the shelf break off Brownsville (south Texas) was probably an artifact of the contouring routine. This routine interpolates between measurement sites along the shelf break as it turns from approximately east-west to north-south.

5.2.3 Seasonal Temperature/Salinity Patterns from Surveys

Introduction. As part of the LATEX-A Program, four half-shelf and six full-shelf LATEX-A hydrographic surveys were combined with other appropriate archived survey data (GUS cruises from 1960s) to develop a seasonal characterization of the along- and cross-shelf distribution of near-surface and near-bottom mean temperatures and salinities and associated standard deviations (Figure 37). To integrate profile data from cruises having different station locations and spacing, observations were interpolated to a standard grid. Details of the cruise selection process and gridding procedures are presented in Lei et al. (1997). The near-surface data were taken at approximately one meter below the surface, and thus are at a depth different than for the time series data described above.

Salinity patterns on the Louisiana/Texas shelf reflect the combined influence of fresh water contributions along the coast, especially off Louisiana (a relatively consistent source of salinity over the shelf) and transport and mixing of these different water masses. A key factor affecting the seasonal patterns is the timing and magnitude of the freshwater from coastal estuaries and rivers. Typically, the Mississippi River system (including the Atchafalaya) provides the vast majority of the freshwater released to this shelf (Lei et al. 1997). While this flow occurs throughout the year, spring discharge is generally much larger than that occurring during the remainder of the year.

Mixing and transport are affected by spatial density patterns and hence the combined influence of temperature and salinity. This gravity driven flow is combined with the affects of wind stress acting on the water surface and velocity shear at the shelf break, resulting from slope eddies with a range of spatial scales. A summary of observed transport patterns on the Louisiana Texas shelf is provided by LATEX-A (1997). A discussion of slope eddies is presented by Berger et al. (1996).

Fall Patterns (November)

Near surface

Temperature—Near the surface, isotherms tended to be aligned parallel to the coast and ranged between 21°C on the inner shelf to 25°C at the shelf break (Figure 38). Relatively low between-cruise variability was evident.

Salinity—The presence of salinities ≥30 ppt along the inner shelf reflects the lower contribution of freshwater during the fall (Figure 39). Isohalines of mean surface salinities tended to align with the bathymetry/coastline. Open Gulf salinities occurred at and shoreward of the shelf break, reflecting a contribution of more saline slope water to the shelf. Generally, higher variability tends to coincide with lower salinities.

Near bottom

Temperature—As shown in Figure 40, near-bottom temperatures were still fairly warm in fall, even nearshore where 21°C and 22°C water was common all along the Louisiana and Texas shelf. An isolated mass of relatively cold bottom water was centered on 94°W along the 200 m isobath. At the center of this cold pool, temperatures as low as 14°C were measured, in contrast to the 21-22°C bottom water that occurred along the remainder of the shelf break. This cold water could be associated with the presence of a slope cyclone which produced raised isotherms. Since these cyclonic features are not permanent or stationary, evidence of such a feature in the mean field suggests that it may have occurred in more than one year, or have been strong enough to influence the overall means in that locale. In the lower panel (Figure 40), the variation in values contributing to the means plotted in the upper panel do not increase in the vicinity of this cold pool. This may indicate that these cooler temperatures occurred fairly commonly at this site during the six cruises used to compute the mean fields.

By comparing the near-surface and near-bottom temperatures, it is evident there was a relatively weak vertical gradient in mean temperatures. As seen previously from the time series temperature observations, a pool of relatively warm (≥23°C) water occurred over the mid-shelf off western Louisiana centered around 93°W and extending eastward to the inner shelf in the vicinity of 91°W.

Salinity—Contours of average salinities tended to parallel the coast and isobaths with lowest salinities (~31 ppt) occurring in the shallow water off Sabine Pass (94°W) in the middle of the study area (Figure 41). The 36 ppt isohaline occurred approximately one third of the local shelf width onshore from the shelf break. Although relatively low standard deviations resulted from these data, the higher values (between 1-2 ppt) were on the inner shelf where lowest mean salinities occurred.

Spring Patterns (May)

Near surface

Temperature—Spring average surface temperatures ranged from 23.6°C to about 25°C, with relatively cooler water off Louisiana and warmer water further to the west off Texas (Figure 42). The standard deviation of values contributing to the mean varied from 1.5-2.4°C.

Salinity—Low average salinities (≤26 ppt) occurred over the inner shelf off Louisiana and east Texas with a gradual increase downcoast (Figure 43). Open Gulf salinities of approximately 36 ppt occur along the shelf break. Isohalines which tended to follow the bathymetry/coastline show a regular salinity decrease onshore. As a reflection of the interannual variability, the surface salinities used to compute this mean field varied from 4 psu to less than 1 psu. Given variations in the timing and transport of large freshwater discharges, such variability is common, particularly on the inner shelf.

Near bottom

Temperature—As shown in Figure 44, mean bottom temperatures ranged from about 25°C over the shallow inner shelf to as low as 14°C at the shelf break (91°W). Generally, near-bottom mean temperatures decreased regularly and consistently across the shelf so that locations normalized by the shelf width had similar bottom temperatures. The relatively local cooler temperatures along the 200 m isobath could have been associated with slope circulation features, such as slope cyclones.

Salinity—Gulf salinities (≥36 ppt) extended approximately half way across the shelf with lowest salinities (<30 ppt) occurring off Sabine Pass in the central part of the study area (Figure 45). Average bottom salinities increased slightly both up- and downcoast; however, the inner shelf was consistently ≤30 ppt. Similarly, the highest variability occurred where average salinities were lowest, reflecting variability in distribution of water masses diluted by estuarine/riverine discharges.

Summer Patterns (July/August)

Near surface

Temperature—Summer surface temperature patterns incorporate profiles measured in either July or August during seven cruises. As shown in Figure 46, a broad area of the shelf had temperatures between 29°C and 29.6°C. Off south Texas, temperatures cooled to between 28°C and 29°C. The lower panel in this Figure indicates the standard deviation of individual values used to compute the means. All are less than 1°C, with the highest variability offshore Louisiana.

Salinity—The summer average salinity field is shown in Figure 47. Mean salinities were lowest over the inner shelf offshore of the Louisiana estuaries and decreased downcoast and offshore. Mean salinities at the shelf break off Louisiana were diluted by this contribution of freshwater. Generally, isohalines were oriented across the shelf with salinities of ≥36 ppt occurring south and east of Corpus Christi, Texas. Maximum variability of the contributing observations coincided with the lowest mean salinities, indicating the importance of this freshwater source.

Near bottom

Temperature—As shown in Figure 48, the warmest bottom temperatures (≥29°C) occurred off western Louisiana and eastern Texas, centered around Sabine Pass (94°W). Mean temperatures over the entire study area decreased regularly offshore until 16-18°C bottom waters were found near the 200 m isobath. These mean shelf-break bottom temperatures were similar to those computed from both the spring and summer observations. This relative constancy occurred because the bottom is below the normal seasonal thermocline.

Salinity—The area of lower salinity water decreased in summer (Figure 49) as compared to spring (see Figure 45) due to reduced coastal fresh water discharge. The inner shelf between the Mississippi Delta and approximately Galveston had salinities of 34 ‰ or less. Over half of the shelf had bottom salinities of ≥36 ppt Thus, dilute bottom waters were limited to locations close to the Mississippi River/Atchafalaya River discharge. The low standard deviations reflect the relatively small variability in salinity patterns among the cruise years.

5.3 Dissolved Oxygen

5.3.1 Introduction

The timing, duration, and spatial extent of dissolved oxygen levels which may be low enough to impact biological organisms are the key considerations for habitat suitability. As such, the present discussion focuses on the temporal and spatial extent of hypoxic and anoxic conditions (defined as <3 ml/l and <1 ml/l, respectively) as documented by some of the observations taken during the recently completed LATEX-A hydrographic field measurement program. Because the lowest DO values are consistently found near the bottom, an evaluation of those data provides a preliminary screening method for selecting intervals when DO concentrations may have been sufficiently low to influence the composition, abundance, and distribution of biological communities.

Because oxygen is exchanged with the atmosphere at the water surface as well as produced by photosynthesis, values at or near saturation levels generally occur near the air/water interface. For the relatively cool seasons (nominally October-February) during which vertical stability decreases or is neutral, vertical mixing and associated DO transport is expected to be more prevalent and low near-bottom DO values are less likely to occur. In contrast, during warming and warm-water seasons, vertical temperature and density stratification intensifies associated with increased water column stability and reduced vertical transport/mixing. With this reduced renewal of subsurface DO, in conjunction with continued and often increased biological and chemical oxygen demand, DO concentrations can erode, reaching levels low enough to have significant impacts on local fauna, particularly those species that are sedentary or slow moving.

The sequence of physical conditions and processes would suggest that low DO levels are possibly expected during spring, with increasing likelihood during periods of greatest vertical stratification and least mechanical energy available to drive overturning, that is, late summer (July/August). The stronger stability of this interval was evident from the prior discussion of seasonal salinity and temperature patterns.

5.3.2 Seasonal Dissolved Oxygen Patterns

As an example of more dynamic vertical exchange conditions and a corresponding absence of shelf hypoxia, a cross-shelf profile of DO concentrations off Terrebonne Bay, Louisiana, (90°45′W) is shown in Figure 50. Only in deeper water over the outer shelf are DO levels below 3.5 ml/l. A similar pattern is seen in February (Figure 51).

Figure 52 documents an example of late spring/early summer conditions when inputs of lower salinity water from the Mississippi River were large and a vertically stratified temperature field was fairly well developed, resulting in local hypoxia over the inner shelf in the lower approximately 5 m. The remainder of the cross-shelf section had concentrations ≥ 3 ml/l. This pattern of hypoxia, located in a relatively narrow inner- shelf band off Louisiana, was seen in a number of April/May cruises (Figure 52).

DO profiles taken along this same cross-shelf transect in late summer (Figure 53) show an expanded near-bottom hypoxic region that extended approximately 60 km offshore. Over the inner shelf DO of <3 ml/l extended vertically approximately 10m or half the water column. Cross-shelf sections around 94°W (off Sabine Pass) and further downcoast only occasionally showed a narrow inner shelf region of near-bottom hypoxia.

An example of the horizontal and spatial scales of slope hypoxia documented during LATEX-A is shown by the 3.0 ml/l contours of bottom DO in Figures 54-56. In spring, hypoxia was generally confined to the inner half of the shelf, off Louisiana, east of 94°W. In late summer (Figure 55 and 56), a substantially greater area was hypoxic as compared to earlier or later seasons. The presence of slope water on the outer shelf/upper slope results in bottom DO of < 3 ml/l along the shelf break. Generally, these outer shelf values are the result of slope and deeper water processes occurring below the permanent thermocline. Off Louisiana, hypoxic regions resulting from shelf processes coalesce with reduced oxygen from over the slope such that the entire shelf bottom has DO <3 ml/l (Figure 56).

6.0 Summary and Conclusions

During Phase I bibliographic searches were made of eight databases for information and data describing the environmental characteristics of the Gulf and the biota. A total of 376 relevant environmental references were obtained as compared to approximately 200 references with adequate information to characterize the life history information for our target index species. Life history accounts were prepared for nine species and four families of fishes, and for six taxa of invertebrates. The level of detail obtained, while informative, was not particularly useful for the modeling exercise. For example, food habits were often characterized to include small fishes and crustaceans but food preferences by specific species of small fishes and crustaceans were seldom encountered.

The environmental data yielded by the bibliographic and information searches yielded much more useful information for modeling purposes, namely the mapped coverages depicting environmental gradients. These coverages, along with the biological catch data contained in several of our extant biological databases, will enable us to construct HSI models for several of the key index species. A preliminary example of such a model is provided for juvenile red snapper. The habitat model results obtained appear reasonable as compared to the distribution of high-use red snapper habitat, and suggest that an increase in high-use juvenile red snapper habitat would occur in association with platform removals. We note, however, that neither DO nor food has been incorporated in the model at this time. Much of the area of increased habitat resulting from platform removals may be negated by adverse DO levels. If so, little or no gain in habitat would occur.

The most significant result of the Phase I effort is that petroleum platform habitat has been found to constitute only a small fraction of the total reef habitat found in the central and western Gulf of Mexico. Previous claims that the ratio of petroleum platform habitat to natural reef habitat in this region was on the order of 2:1 is simply in error (Gallaway 1981, Gallaway and Lewbel 1982, this study). The actual ratio is on the order of 12 km^2 petroleum platform habitat: 2,780 km^2 natural reef habitat, or 1:232. Thus, about 0.43% of the total reef habitat is represented by petroleum platforms.

This finding raises some very interesting questions. For example, the average number of Age 2 red snapper at a Louisiana offshore platform in winter of 1992 was 5,307 (± 2,756). There are 1,051 platforms within the same depth range as the study site. If all had similar numbers of red snapper, the mean population would be 5.6 million fish with the 95% CI being from 2.7 to 8.5 million fish.

The total population of Age 2 red snapper in the Gulf at the beginning of 1992 has been independently estimated to have been between 4.2 million fish (assuming a natural mortality rate of 0.10) and 8 million fish (assuming M=0.20). It is highly unlikely that 100% of the Age 2 population is found at petroleum platforms which constitute only about 0.4% of the total available reef habitat. Assuming the platform estimates are representative, and that the area of habitat is proportional to population size, the total Age 2 standing stock would have been on the order of 977 million fish for M = 0.10, to 1.9 billion fish for M = 0.20. While these estimates do not appear reasonable to the project team, it is clear that additional work is needed to define standing stocks of red snapper.

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APPENDIX A

FISH SPECIES ACCOUNT SUMMARY TABLES

Note: See text in Section 4.0 for specific references. Empty boxes in tables indicate no data available.

SPECIES ACCOUNT TABLE (Template)

Common Name **Scientific Name**

	Larvae	Juvenile	Adult
Depth Range (m)			
Size (mm)			
Age (years)			
Environmental Influences:			
Temperature (°C)			
Salinity (ppt)			
Dissolved Oxygen (mg/L)			
Reproduction/Spawning	N/A	N/A	
Egg Type			
Growth Rate (mm)			
Food Habits (Prey)			

SPECIES ACCOUNT TABLE A-1

Red Snapper	*Lutjanus campechanus*
Common Name	**Scientific Name**

	Larvae	Juvenile	Adult
Depth Range (m)	surface	20-46	>46
Size (mm)		250-546	up to 845
Age (years)			up to 54
Environmental Influences:			
Temperature (°C)	13-33.5		
Salinity (ppt)	33-37		
Dissolved Oxygen (mg/L)			
Reproduction/Spawning	N/A	N/A	summer: May-July fall: Nov.-Dec.
Egg Type	spherical, unpigmented, single oil globule		
Growth Rate (mm)	25/month	year 1: 60 /year year2-5: 90/year	
Food Habits (Prey)		squid, shrimp, fishes	

SPECIES ACCOUNT TABLE A-2

Cobia	*Rachycentron canadum*
Common Name	**Scientific Name**

	Larvae	Juvenile	Adult
Depth Range (m)		offshore	most in 50 m
Size (mm) **(data from Chesapeake Bay fishes)**		year 1:310-360 FL year 2:530-610 FL year 3: 690-820 FL year 4:820-990 FL year 5:910-1120 FL year 6:990-1220 FL year 7:1040-1310 FL year 8:1080-1370 FL	up to 2000
Age (years)			up to 15
Environmental Influences:			
Temperature (°C)	16.8-32		
Salinity (ppt)	22.5-44.5		
Dissolved Oxygen (mg/L)			
Reproduction/Spawning	N/A	N/A	July-September
Egg Type	pelagic, large oil globule		
Growth Rate (mm)			
Food Habits (Prey)		crustaceans, especially crab, squid, fishes	

SPECIES ACCOUNT TABLE A-3

Bluefish	*Pomatomus saltatrix*
Common Name	**Scientific Name**

	Larvae	Juvenile	Adult
Depth Range (m)		nearshore areas (within 3 miles)	
Size (mm)		year 1-5: 210-620 FL	year 5-10: 600-820 FL >year 10: >800 FL
Age (years)			
Environmental Influences:			
Temperature (°C)	10-30.4		
Salinity (ppt)			
Dissolved Oxygen (mg/L)			
Reproduction/Spawning	N/A	N/A	bimodal: April and Oct.-Nov.
Egg Type			
Growth Rate (mm)			
Food Habits (Prey)	copepods, cladocerans	shrimp, squid, fishes	primarily fishes

SPECIES ACCOUNT TABLE A-4

King Mackerel — *Scomberomorus cavalla*
Common Name — **Scientific Name**

	Larvae	Juvenile	Adult
Depth Range (m)	surface		
Size (mm)			up to 1700
Age (years)			
Environmental Influences:			
Temperature (°C)	20-31	22-28 (S. Atl.)	
Salinity (ppt)	27-37	30-37 (S. Atl.)	32-36
Dissolved Oxygen (mg/L)			
Reproduction/Spawning	N/A	N/A	May-Oct.
Egg Type			
Growth Rate (mm)		highly variable	
Food Habits (Prey)		schooling fishes, crustaceans, molluscs	

SPECIES ACCOUNT TABLE A-5

Sheepshead
Common Name

Archosargus probatocephalus
Scientific Name

	Larvae	Juvenile	Adult
Depth Range (m)			
Size (mm)	highly variable; over 400 FL could be 3-20 yr. old		
Age (years)			up to 20
Environmental Influences:			
Temperature (°C)		8-30	5-35
Salinity (ppt)	5.3-25		
Dissolved Oxygen (mg/L)			
Reproduction/Spawning	N/A	N/A	March-May
Egg Type			
Growth Rate (mm)	highly variable		
Food Habits (Prey)	zooplankton	molluscs, crustaceans, fishes, and some plants	

SPECIES ACCOUNT TABLE A-6

Atlantic Spadefish	*Chaetodipterus faber*
Common Name	**Scientific Name**

	Larvae	Juvenile	Adult
Depth Range (m)	< 25 m	shallow coastal areas	
Size (mm)			
Age (years)			
Environmental Influences:			
Temperature (°C)	25-32.2		
Salinity (ppt)	26.7-31.3		
Dissolved Oxygen (mg/L)			
Reproduction/Spawning	N/A	N/A	May-October
Egg Type			
Growth Rate (mm)		year 1: 55-100 year 2: up to 135 mm	
Food Habits (Prey)	little information; probably shellfish		

SPECIES ACCOUNT TABLE A-7

Gray Snapper	*Lutjanus griseus*
Common Name	**Scientific Name**

	Larvae	Juvenile	Adult
Depth Range (m)	surface	nearshore areas	up to 180
Size (mm)			500-900
Age (years)			up to 21
Environmental Influences:			
Temperature (°C)	13.4-32.5		
Salinity (ppt)	1-35		
Dissolved Oxygen (mg/L)			
Reproduction/Spawning	N/A	N/A	offshore, in groups
Egg Type	small, non-adhesive, single oil globule		
Growth Rate (mm)	variable		
Food Habits (Prey)		variable; feed within seagrass beds on crustaceans	variable; nocturnal predators on fishes and crustaceans

SPECIES ACCOUNT TABLE A-8

Great Barracuda — *Sphryraena barracuda*
Common Name — **Scientific Name**

	Larvae	Juvenile	Adult
Depth Range (m)			
Size (mm)			up to 2000
Age (years)			
Environmental Influences:			
Temperature (°C)			
Salinity (ppt)			
Dissolved Oxygen (mg/L)			
Reproduction/Spawning	N/A	N/A	
Egg Type			
Growth Rate (mm)			
Food Habits (Prey)			fishes

SPECIES ACCOUNT TABLE A-9

Gray Triggerfish
Common Name

Balistes capriscus
Scientific Name

	Larvae	Juvenile	Adult
Depth Range (m)			
Size (mm)			up to 300
Age (years)			
Environmental Influences:			
Temperature (°C)			
Salinity (ppt)			
Dissolved Oxygen (mg/L)			
Reproduction/Spawning	N/A	N/A	
Egg Type			
Growth Rate (mm)			
Food Habits (Prey)			molluscs, echinoderms

SPECIES ACCOUNT TABLE A-10

Blue Runner	*Caranx crysos*
Common Name	**Scientific Name**

	Larvae	Juvenile	Adult
Depth Range (m)	usually < 40 m	Cont. shelf	up to 182
Size (mm)		1.5-13 SL	up to 500
Age (years)			
Environmental Influences:			
Temperature (°C)	23.3-32.0		
Salinity (ppt)	24.8-37.7		
Dissolved Oxygen (mg/L)			
Reproduction/Spawning	N/A	N/A	July
Egg Type			
Growth Rate (mm)			
Food Habits (Prey)			shrimp, squid, crabs

SPECIES ACCOUNT TABLE A-11

Greater Amberjack	*Seriola dumerili*
Common Name	**Scientific Name**

	Larvae	Juvenile	Adult
Depth Range (m)	surface to 70 m		
Size (mm)			
Age (years)			
Environmental Influences:			
Temperature (°C)			
Salinity (ppt)			
Dissolved Oxygen (mg/L)			
Reproduction/Spawning	N/A	N/A	offshore in winter?
Egg Type			
Growth Rate (mm)			
Food Habits (Prey)			squid, fishes, crustaceans

APPENDIX B

SUPPLEMENTAL FIGURES

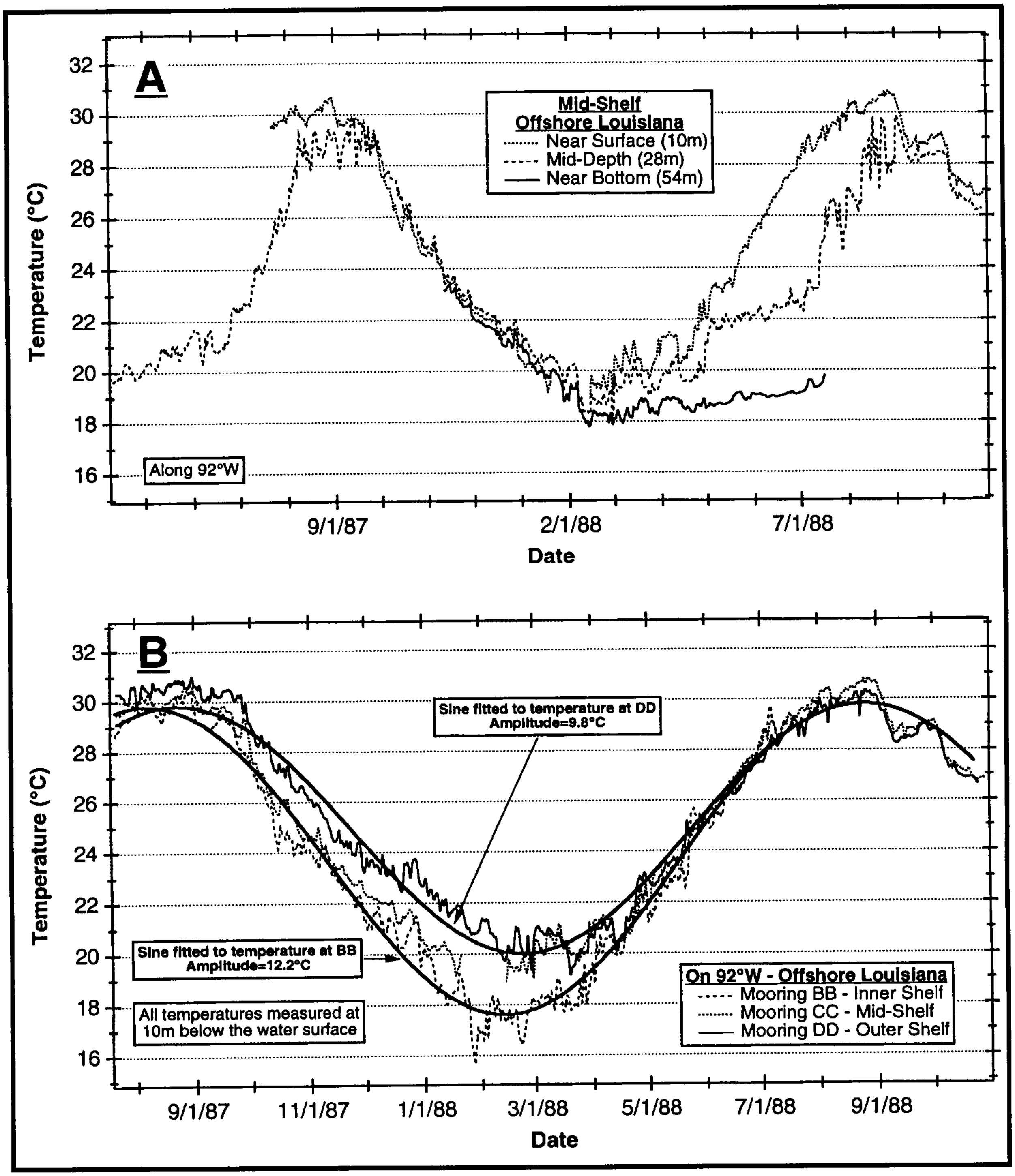

Figure 7. Time series of water temperatures at indicated sites on Louisiana shelf west of the delta. (A) shows temperatures over the water column at mid-shelf. (B) shows near surface temperatures at locations across the shelf.

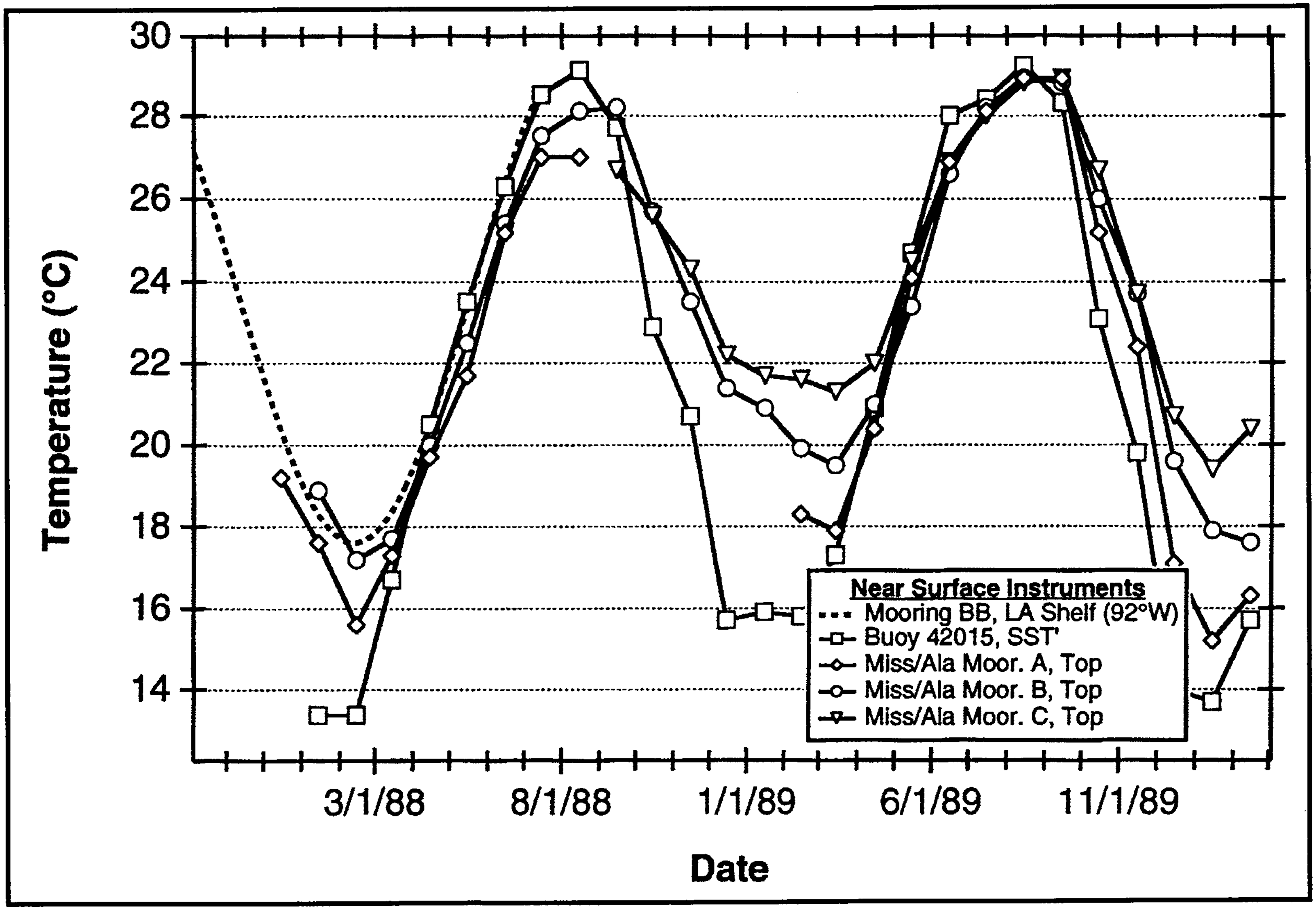

Figure 8. Time series of monthly averaged temperatures at indicated locations and variables. Air temperature was measured at NDBC Buoy 42015 that was located just offshore of Dauphin Island, Alabama.

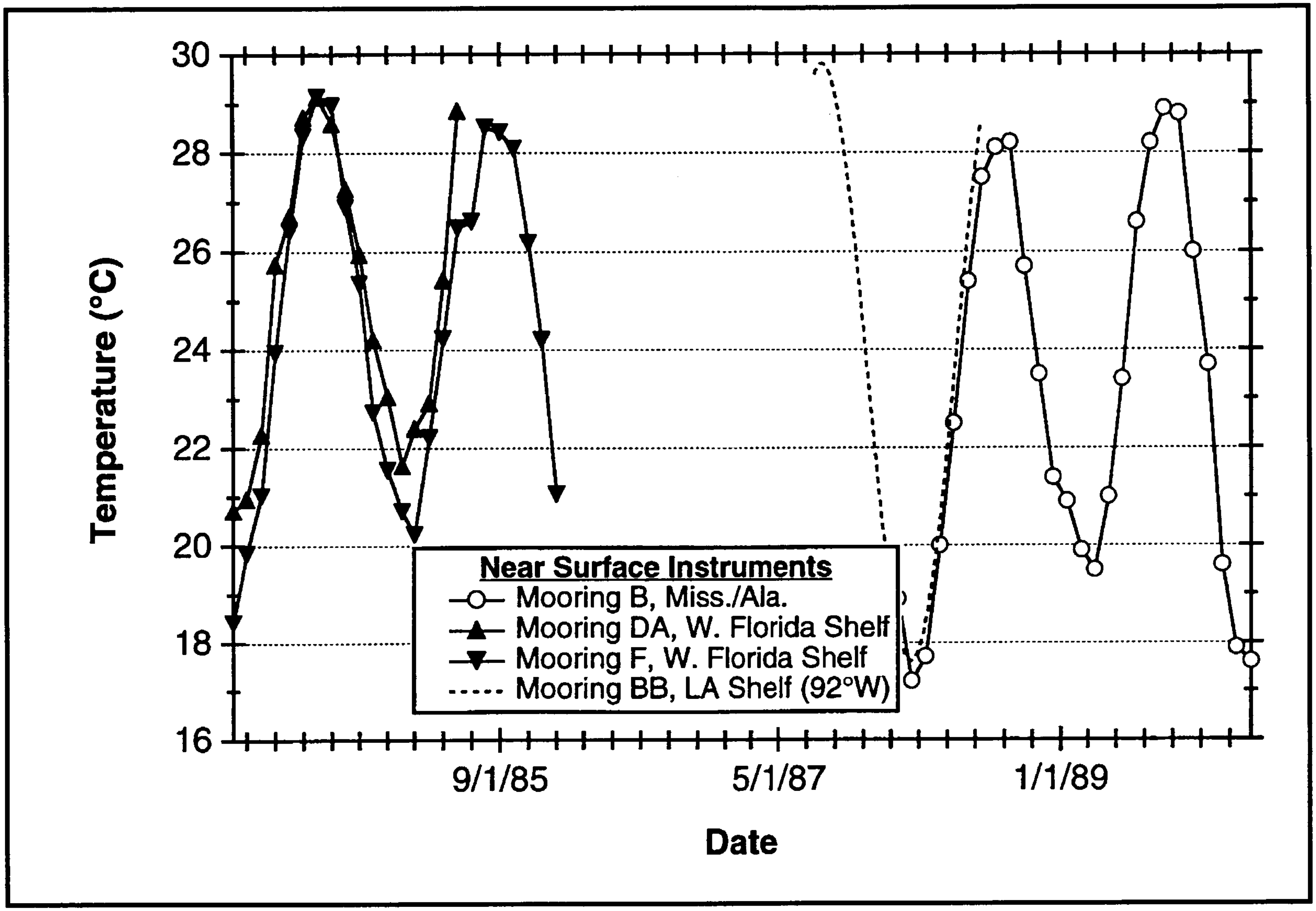

Figure 9. Time series of monthly averaged near-surface ocean temperatures at the indicated sites off western Louisiana, Alabama/Florida Panhandle, and the west Florida shelf.

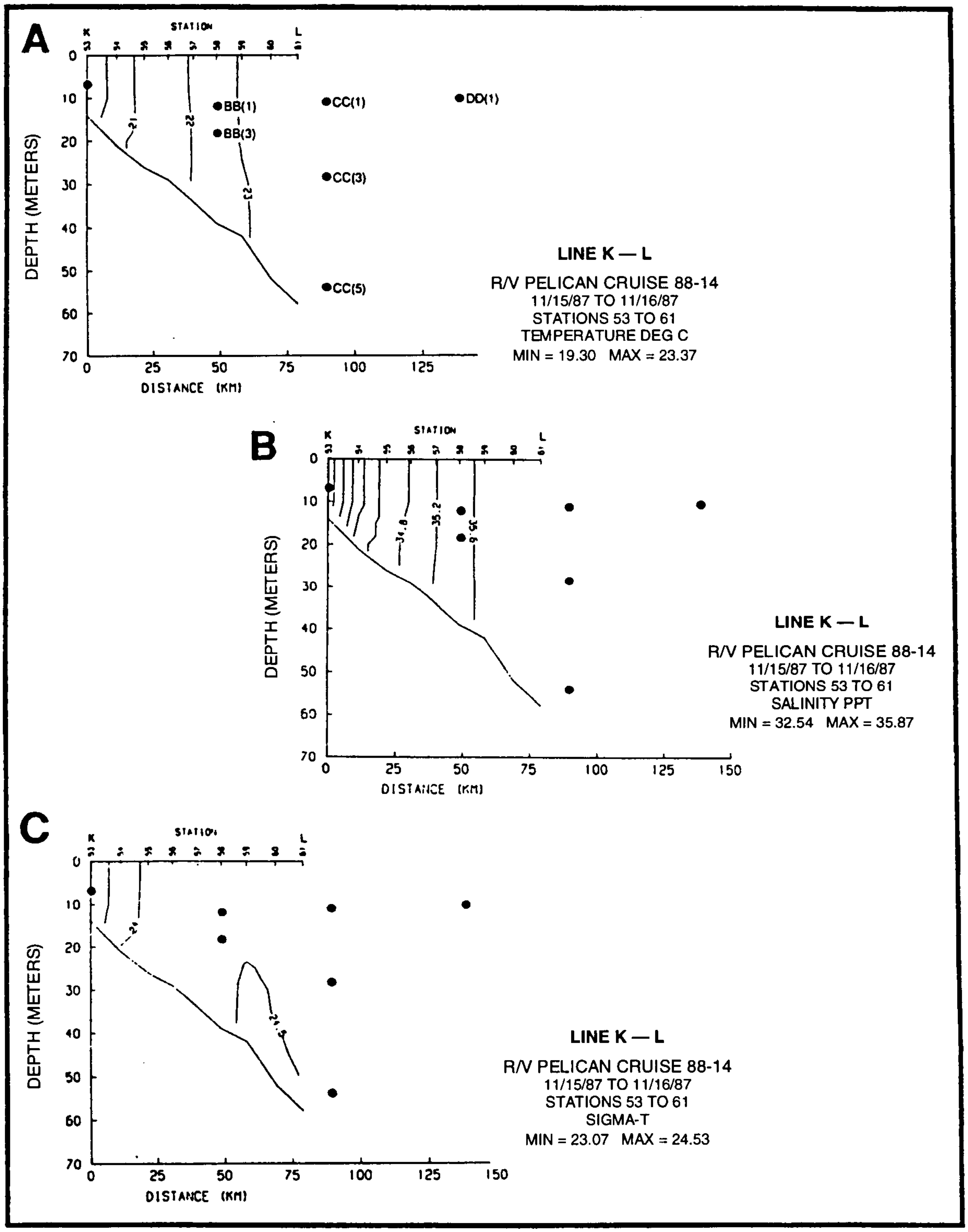

Figure 10. Cross shelf sections of (A) temperature, (B) salinity, and (C) sigma-t (density) taken along 92°W in fall (November 15-16, 1987). Dots indicate locations of current meters along this transect.

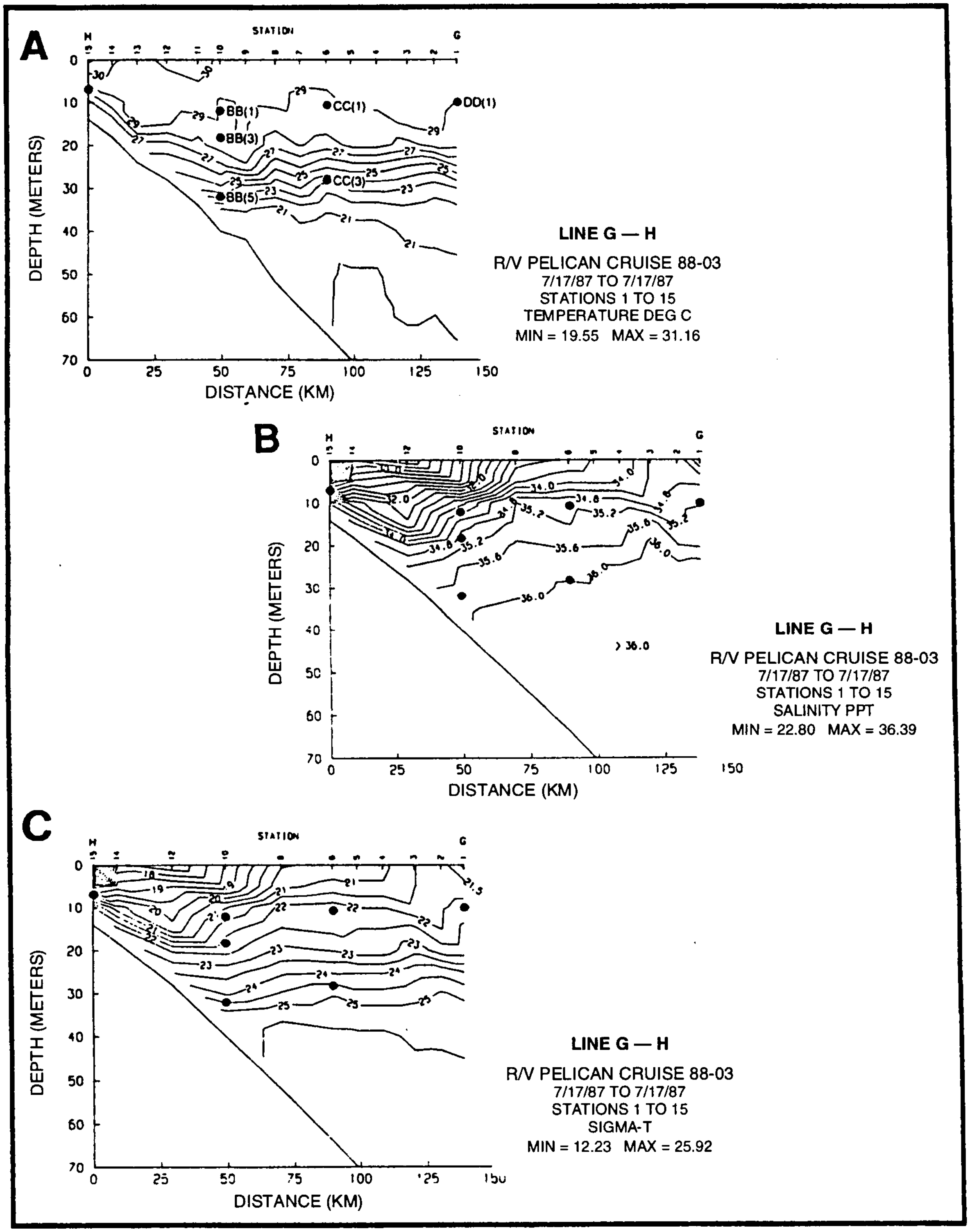

Figure 11. Cross shelf sections of (A) temperature, (B) salinity, and (C) sigma-t (density) taken along 92°W in summer (July 17, 1987). Large dots indicate locations of current meters. Note the vertical temperature stratification and the inner shelf lower salinities.

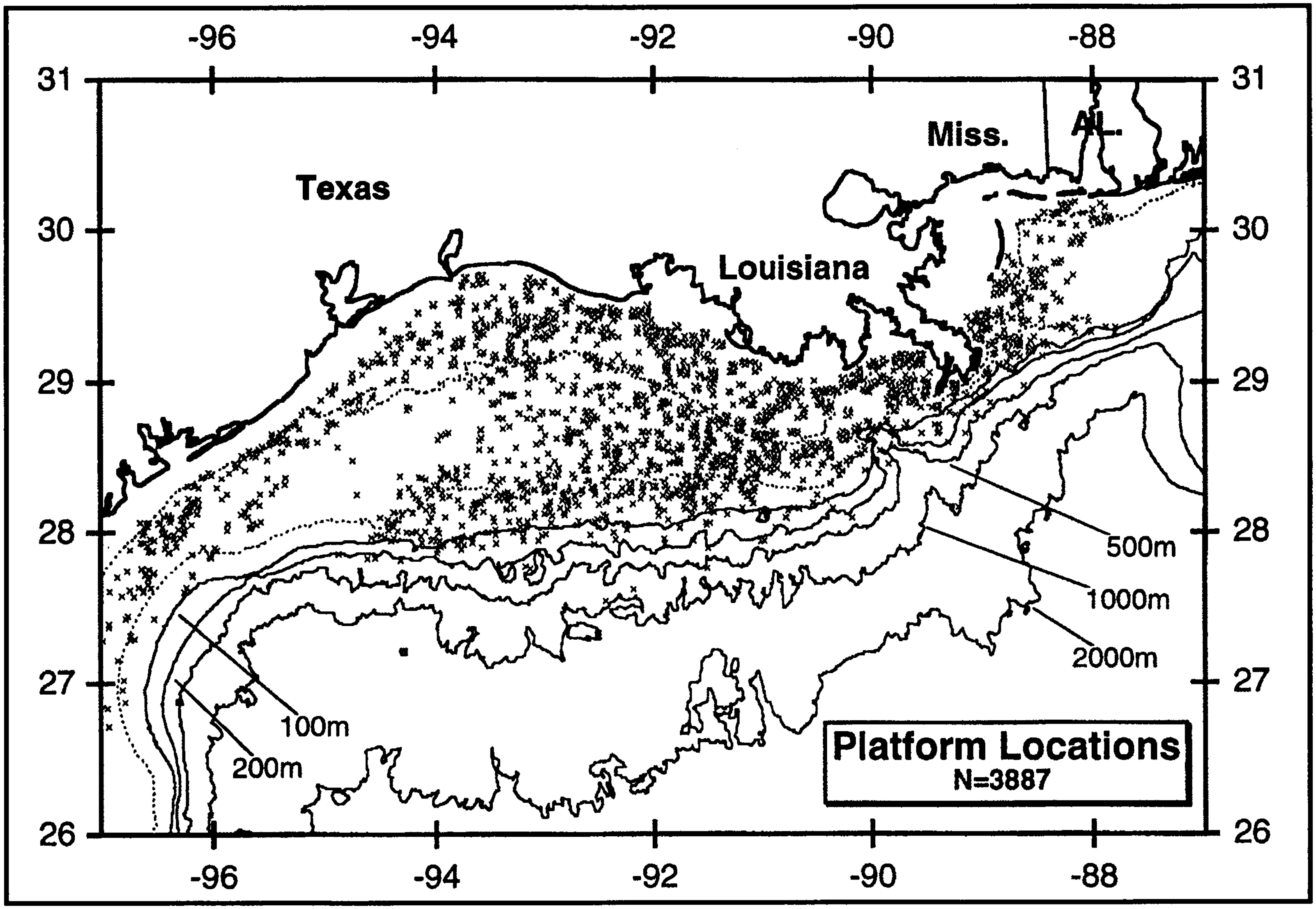

Figure 12. Locations of oil and gas structures on the shelf in the northern Gulf of Mexico OCS.

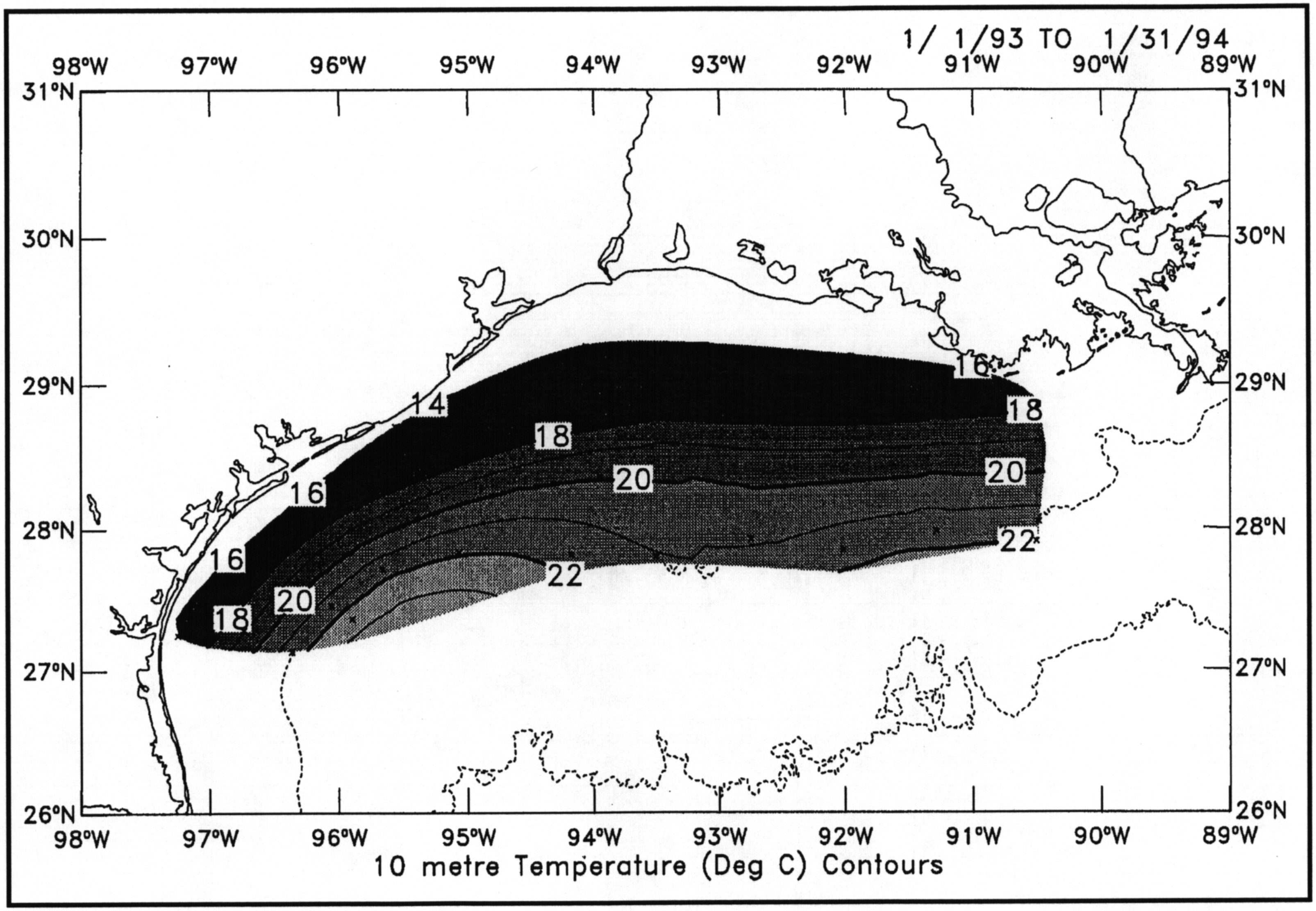

Figure 13. Contours of averaged January near-surface (10 m depth) temperatures measured by in-situ instruments during LATEX-A.

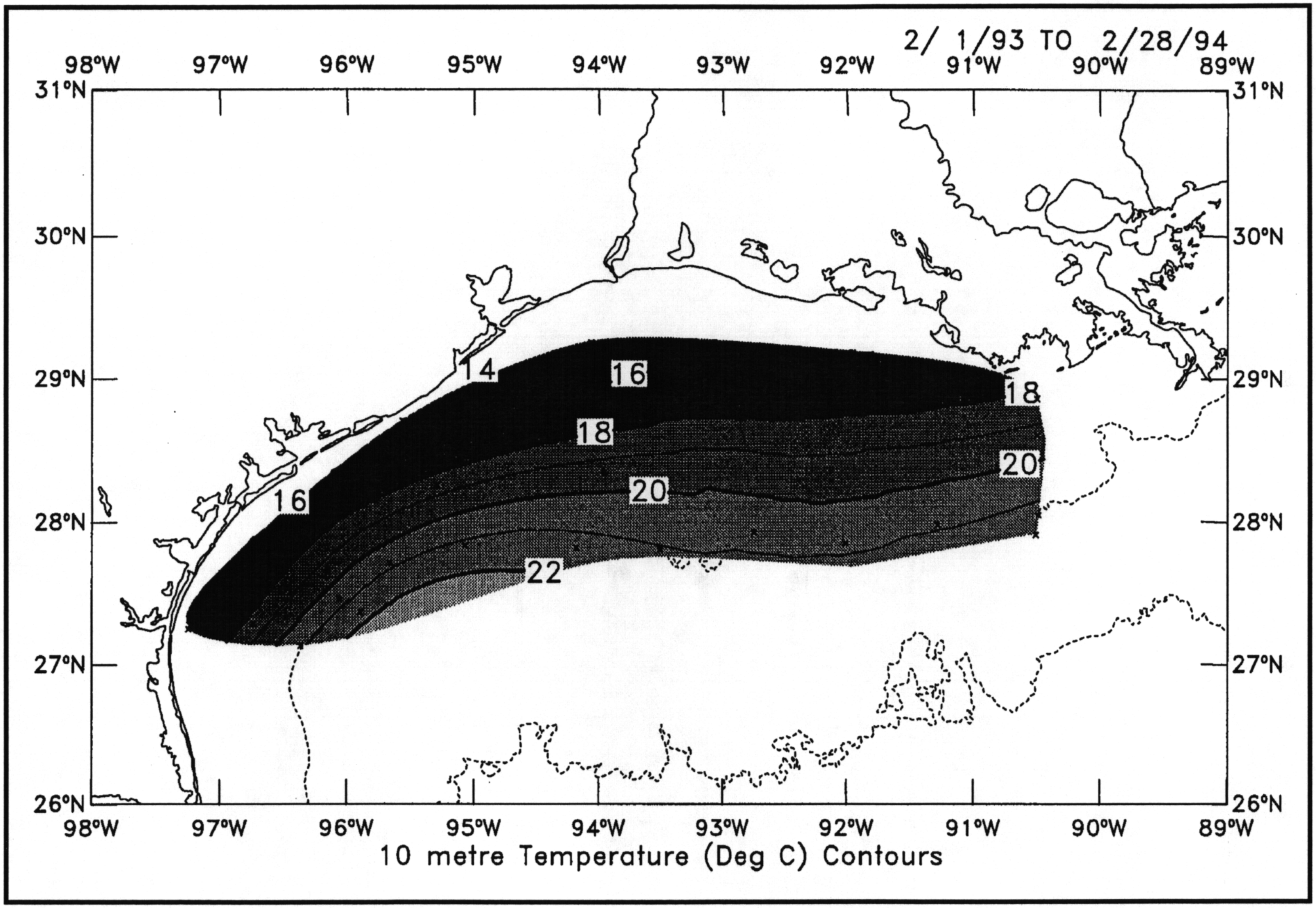

Figure 14. Contours of averaged February near-surface (10 m depth) temperatures measured by in-situ instruments during LATEX-A.

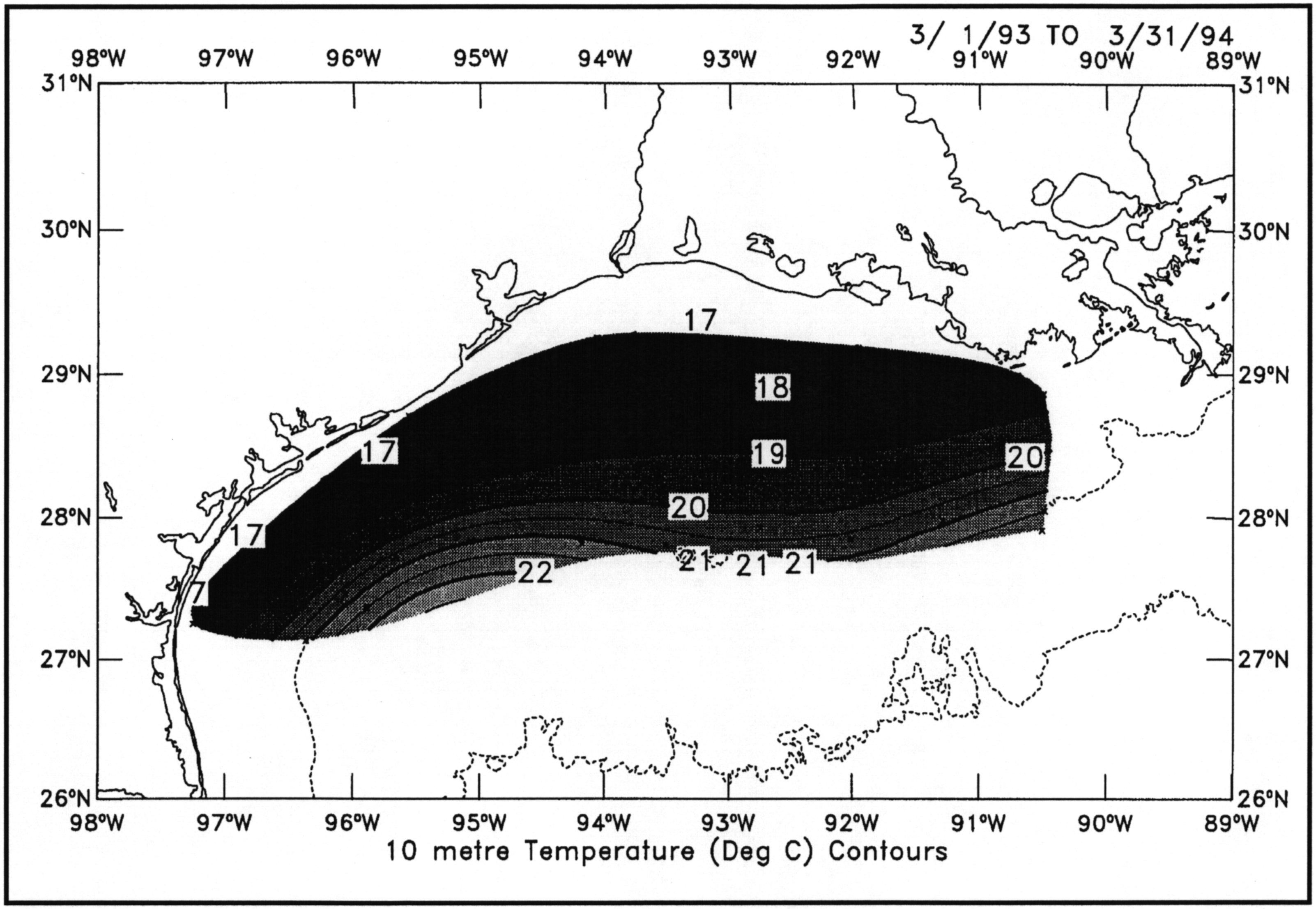

Figure 15. Contours of averaged March near-surface (10 m depth) temperatures measured by in-situ instruments during LATEX-A.

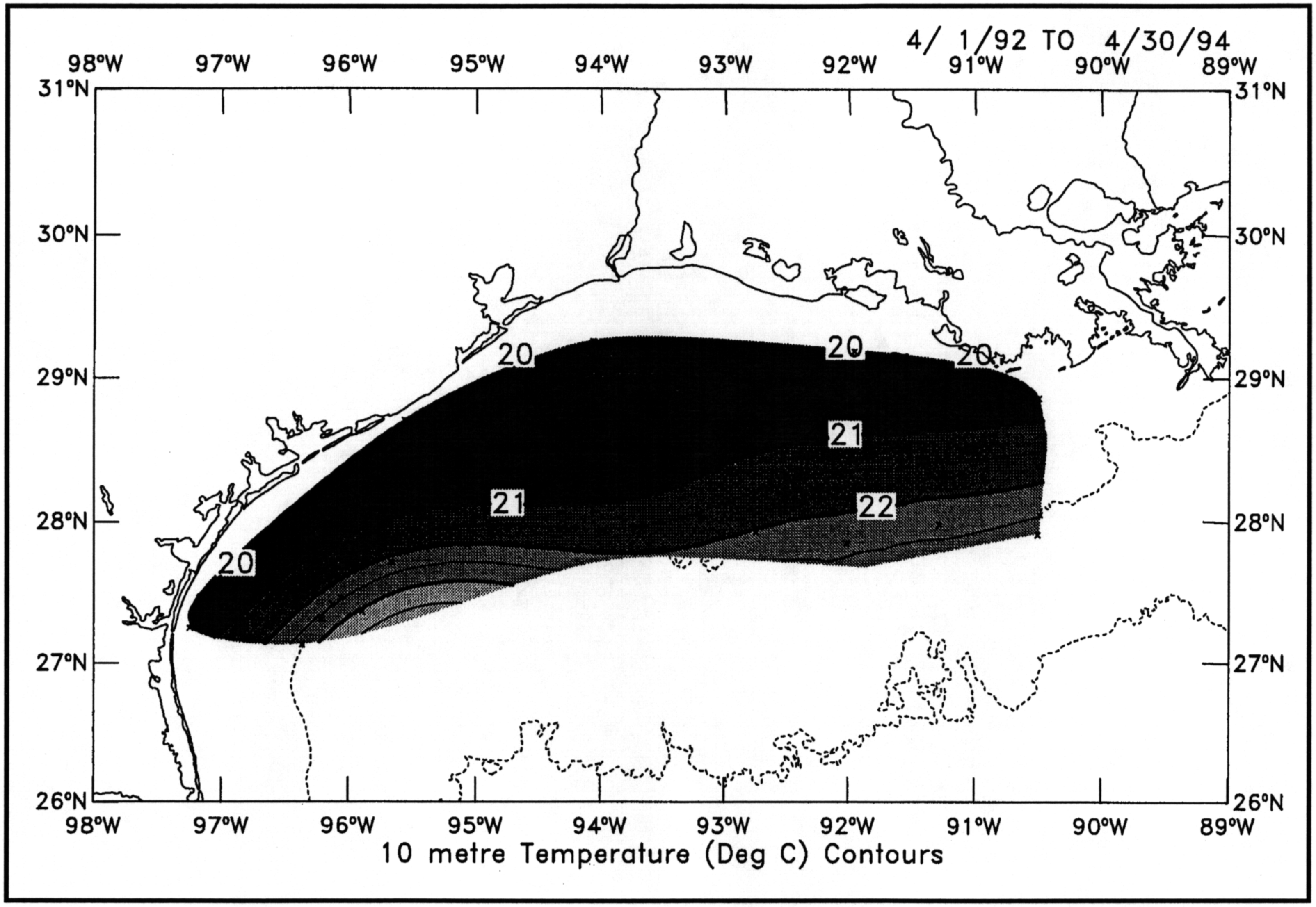

Figure 16. Contours of averaged April near-surface (10 m depth) temperatures measured by in-situ instruments during LATEX-A.

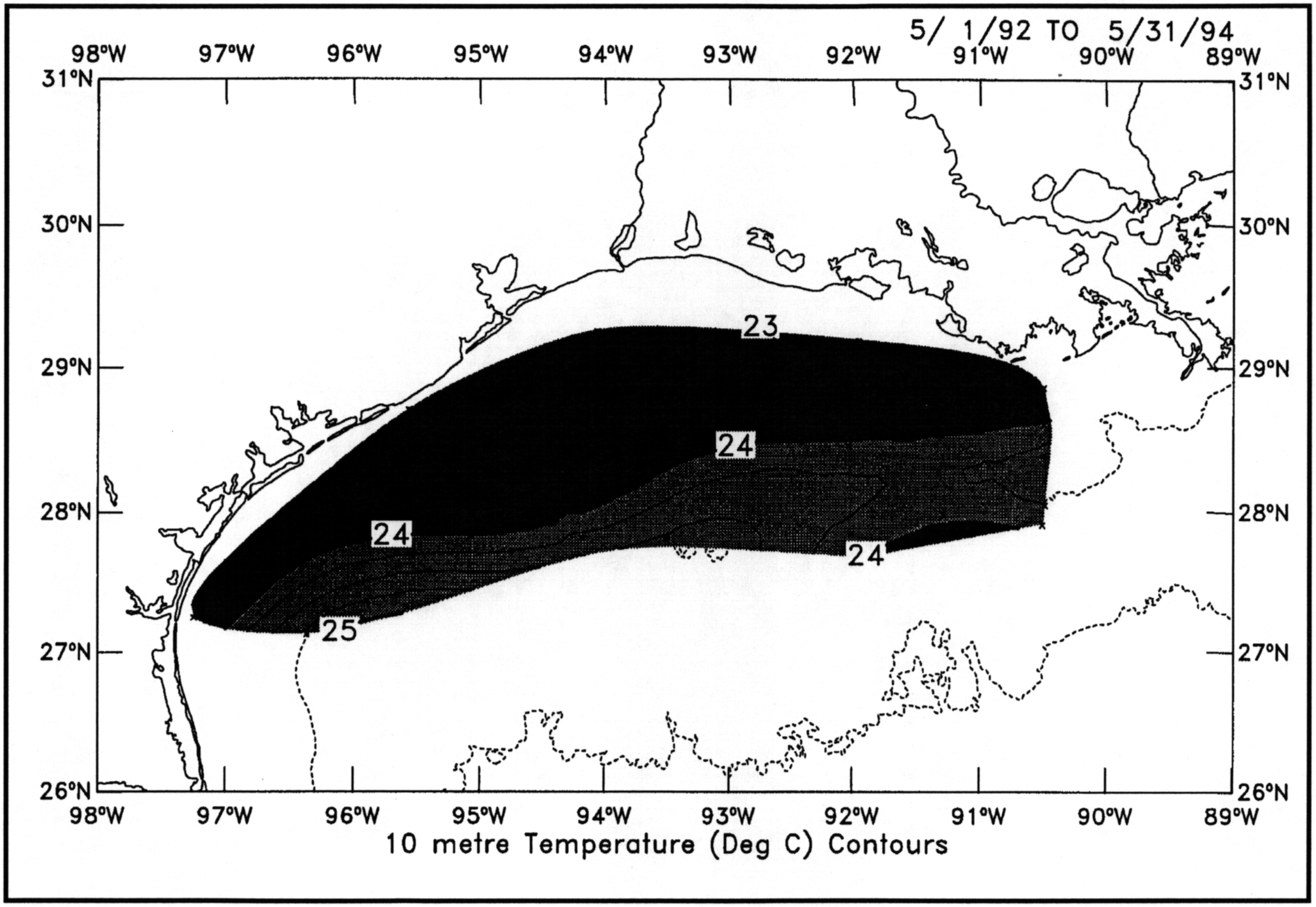

Figure 17. Contours of averaged May near-surface (10 m depth) temperatures measured by in-situ instruments during LATEX-A.

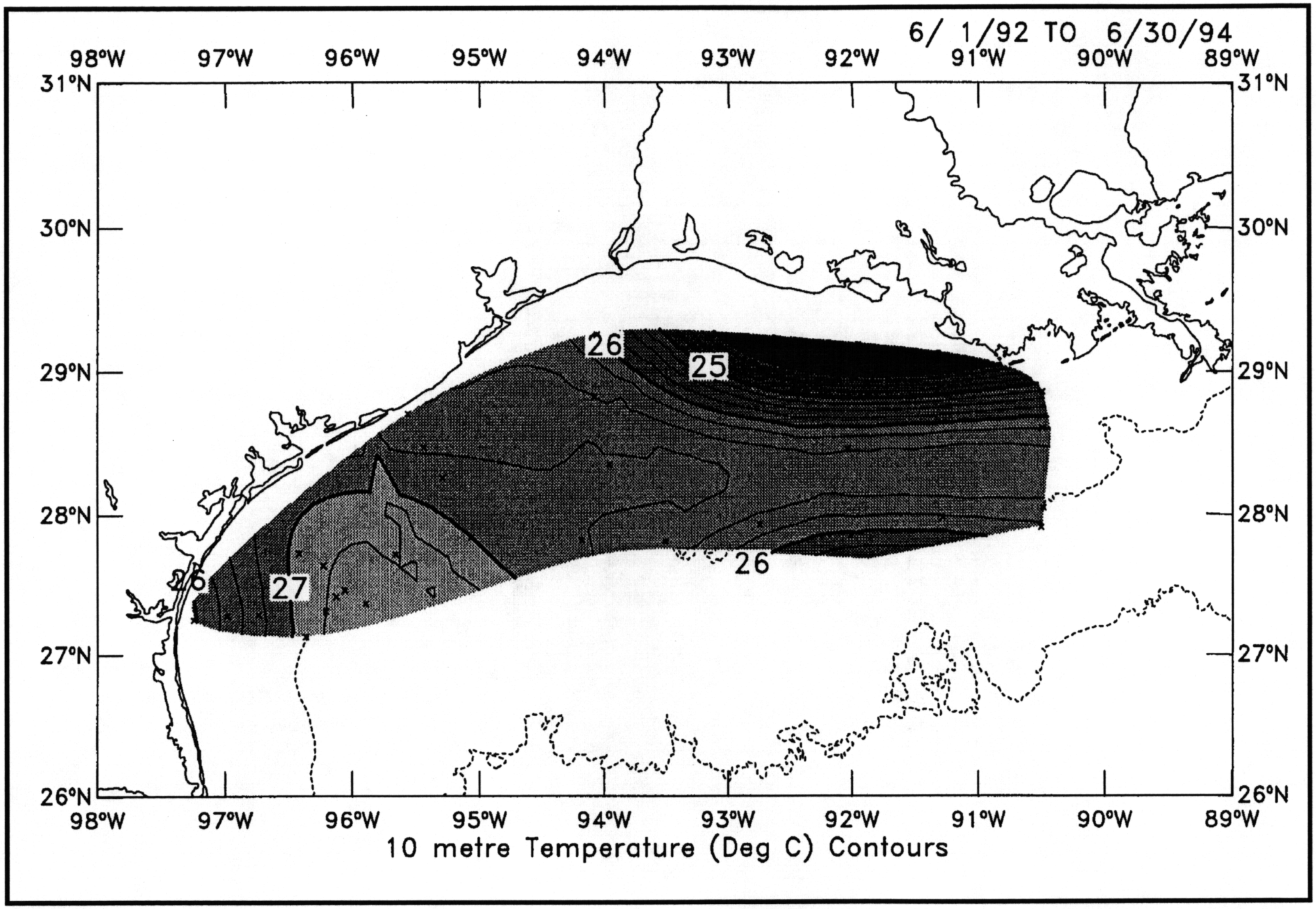

Figure 18. Contours of averaged June near-surface (10 m depth) temperatures measured by in-situ instruments during LATEX-A.

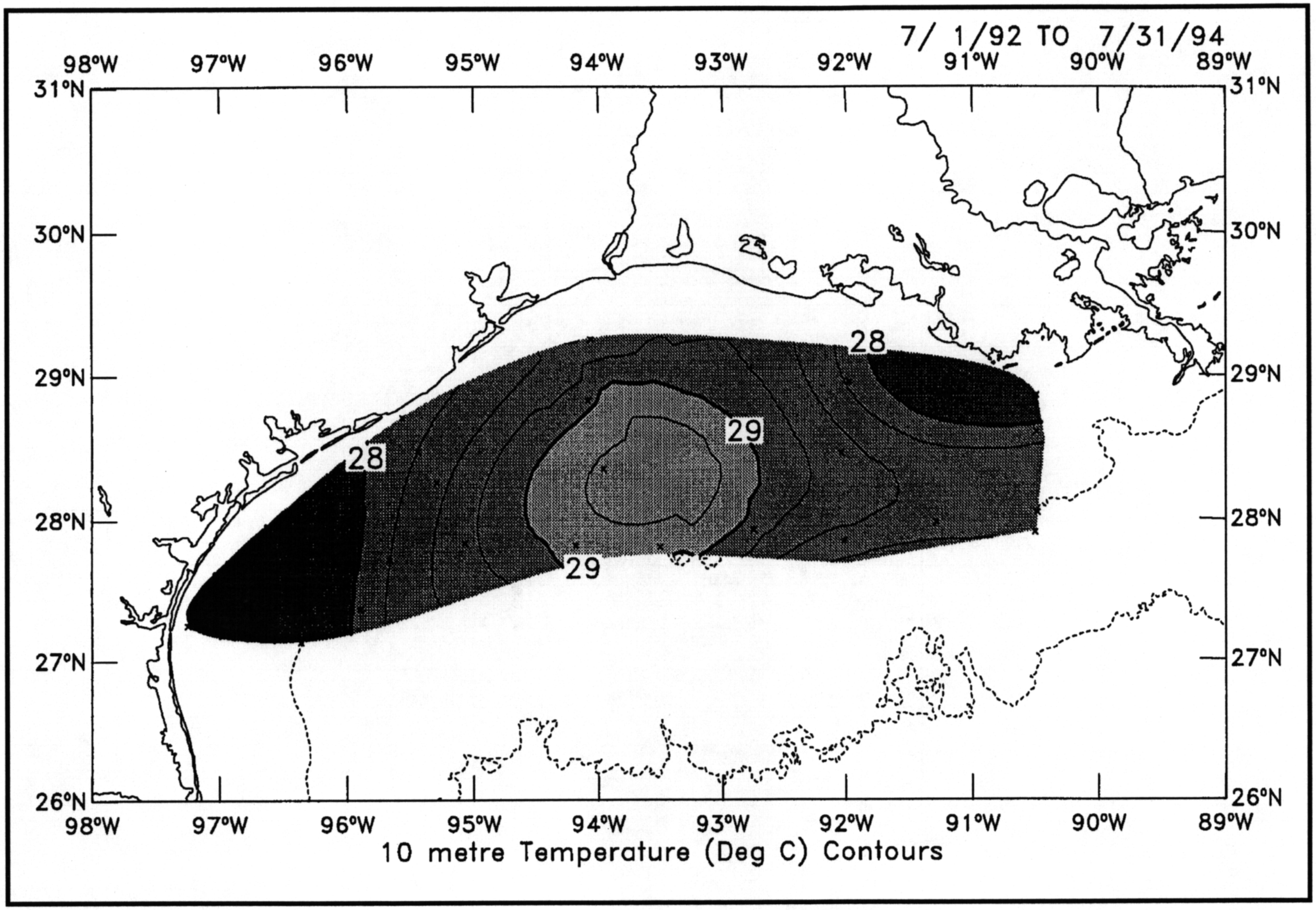

Figure 19. Contours of averaged July near-surface (10 m depth) temperatures measured by in-situ instruments during LATEX-A.

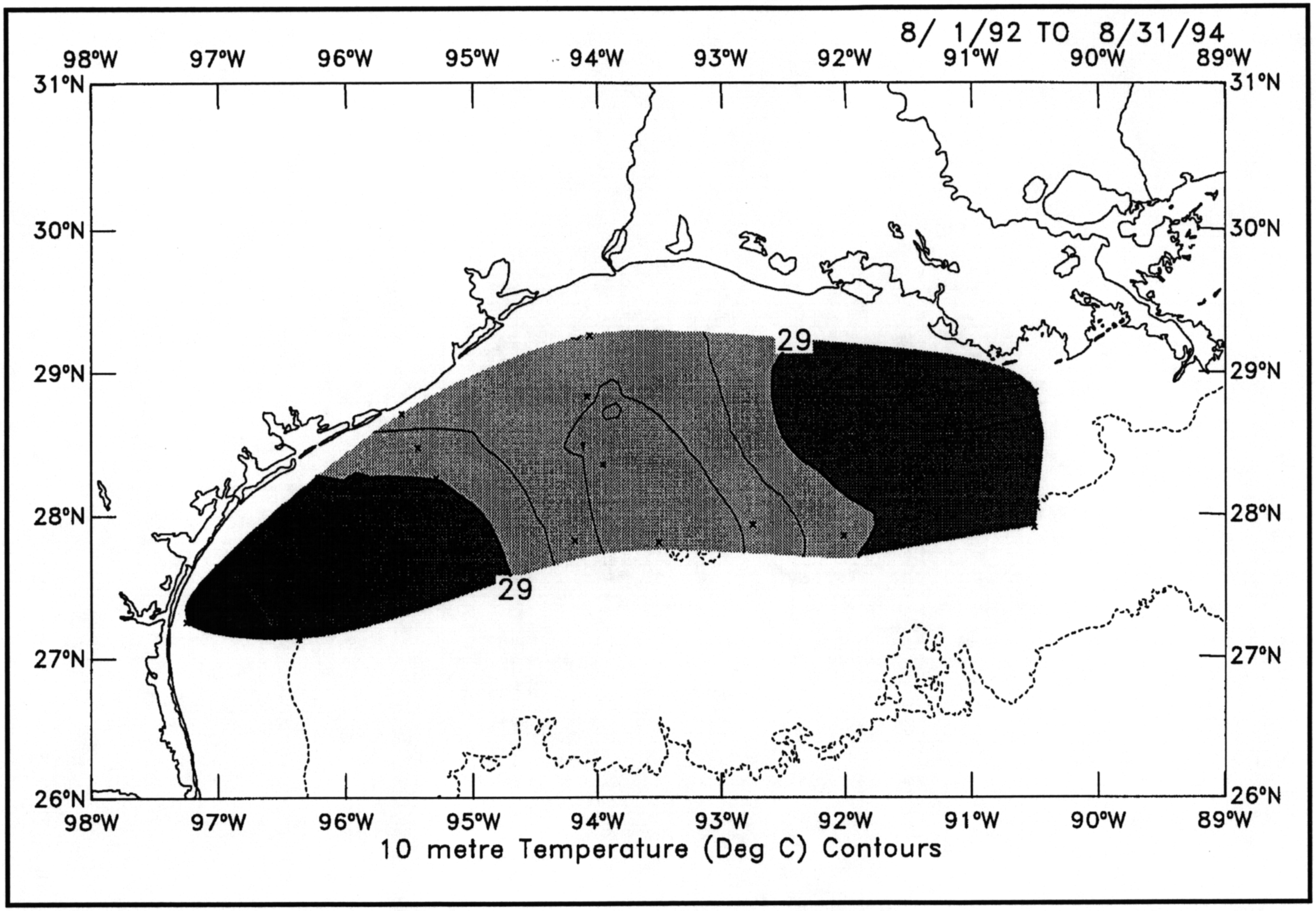

Figure 20. Contours of averaged August near-surface (10 m depth) temperatures measured by in-situ instruments during LATEX-A.

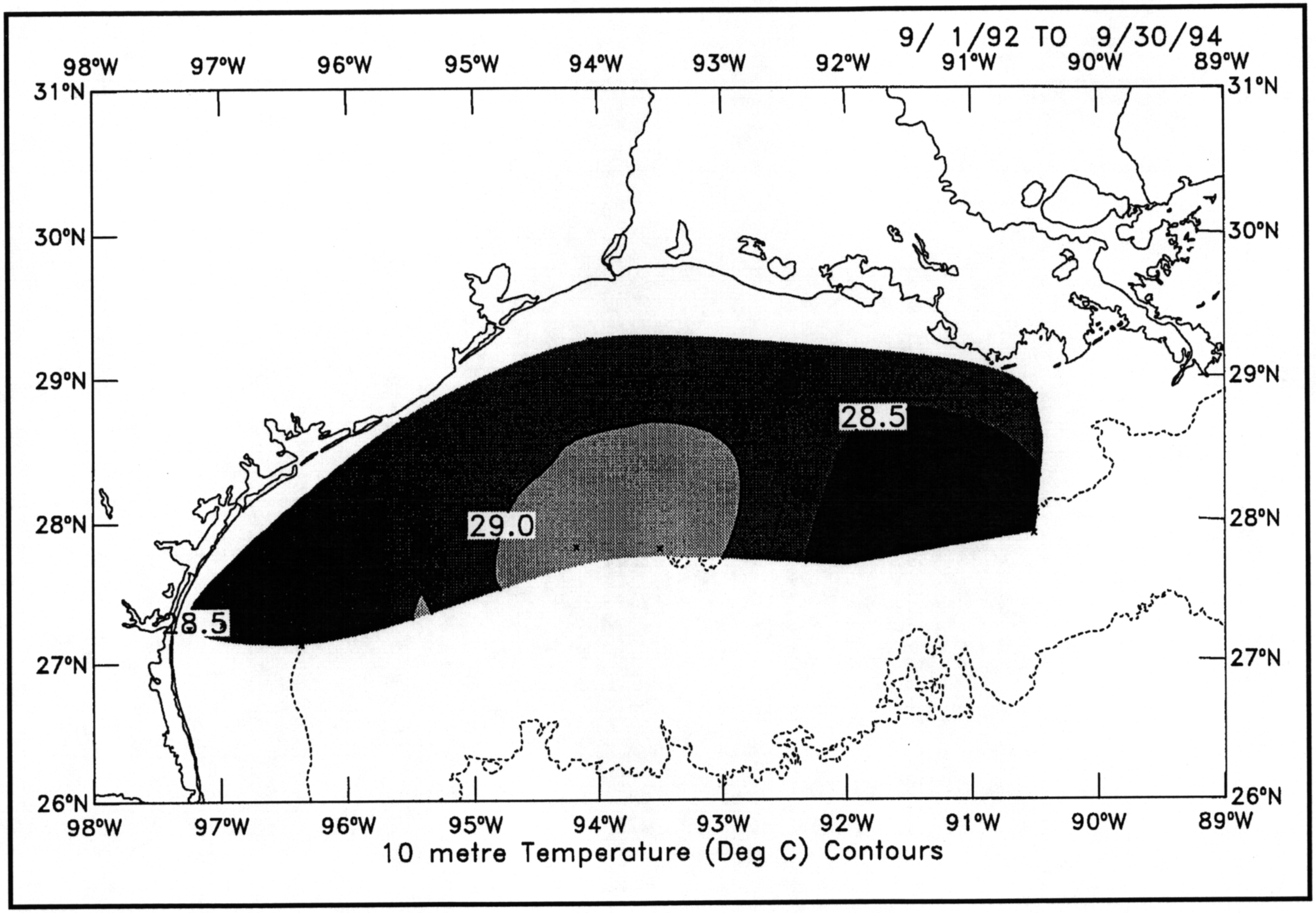

Figure 21. Contours of averaged September near-surface (10 m depth) temperatures measured by in-situ instruments during LATEX-A.

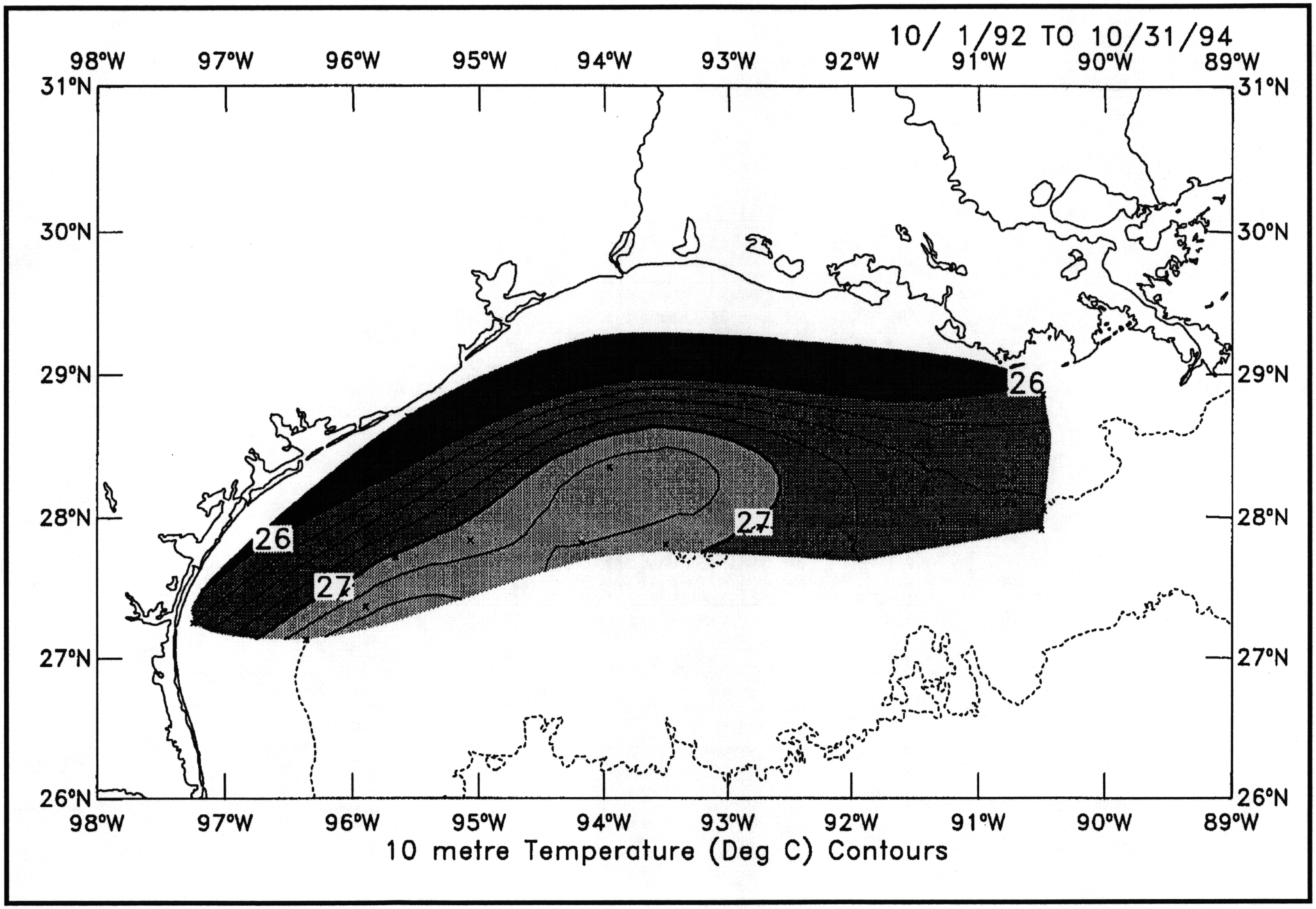

Figure 22. Contours of averaged October near-surface (10 m depth) temperatures measured by in-situ instruments during LATEX-A.

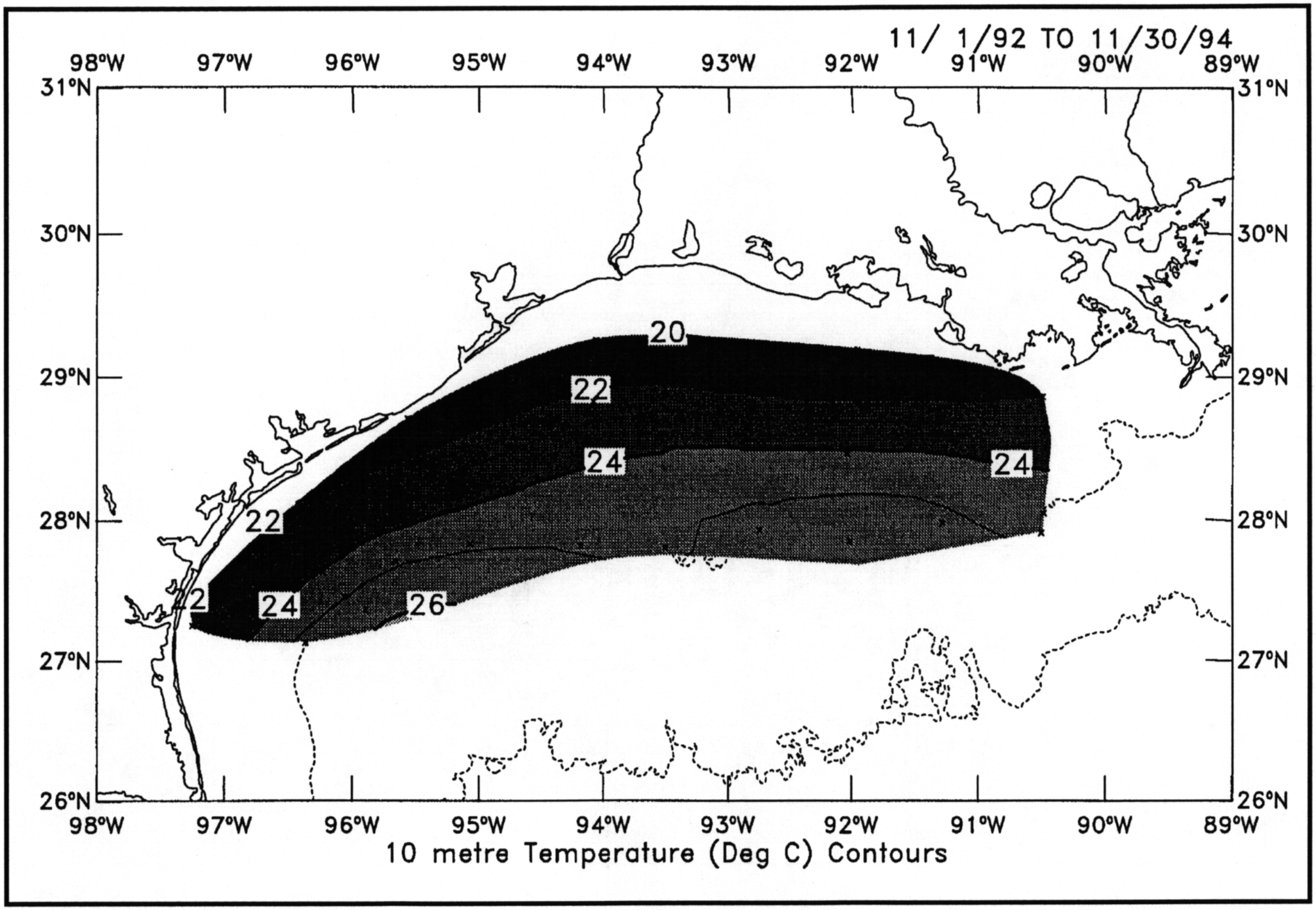

Figure 23. Contours of averaged November near-surface (10 m depth) temperatures measured by in-situ instruments during LATEX-A.

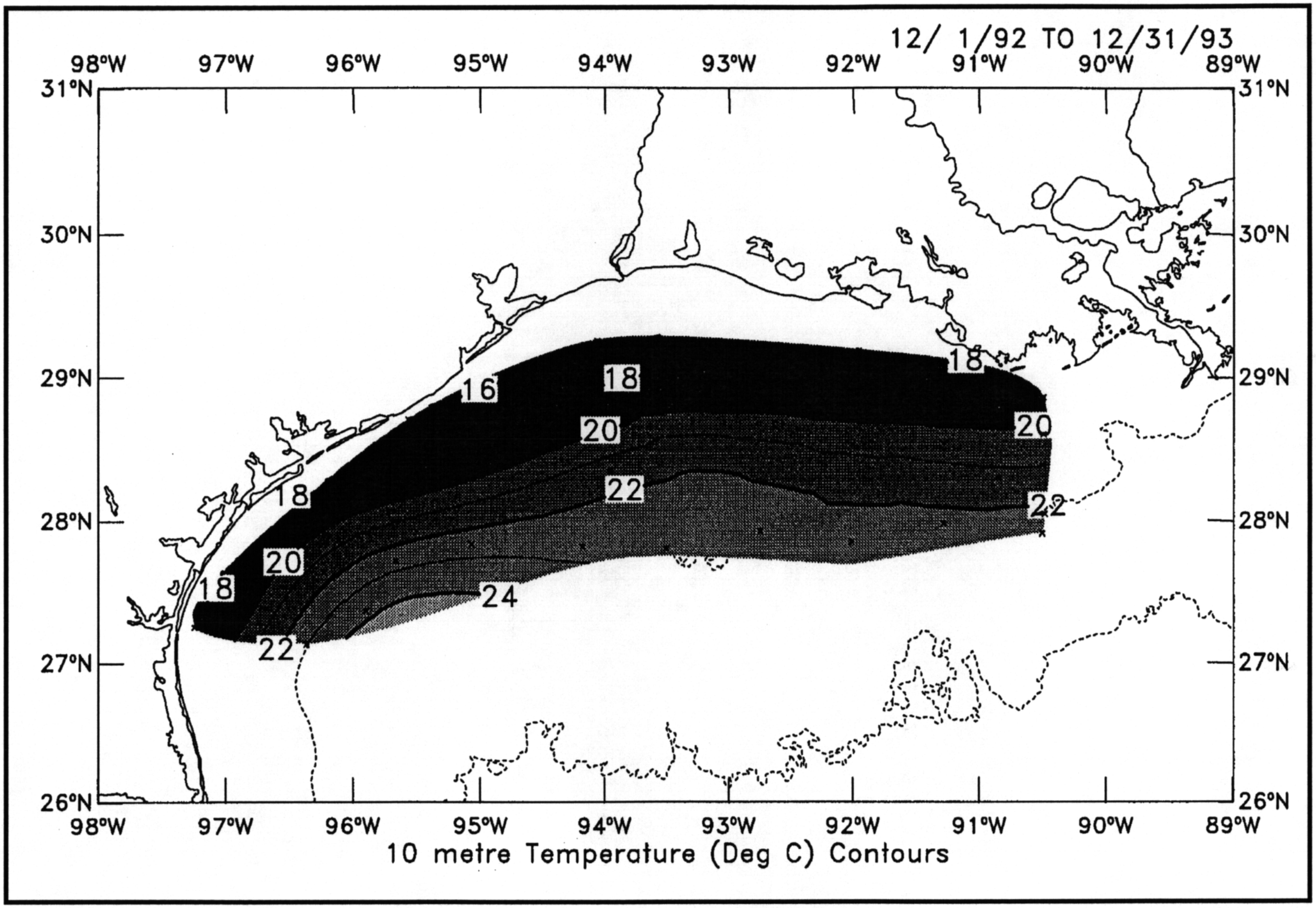

Figure 24. Contours of averaged December near-surface (10 m depth) temperatures measured by in-situ instruments during LATEX-A.

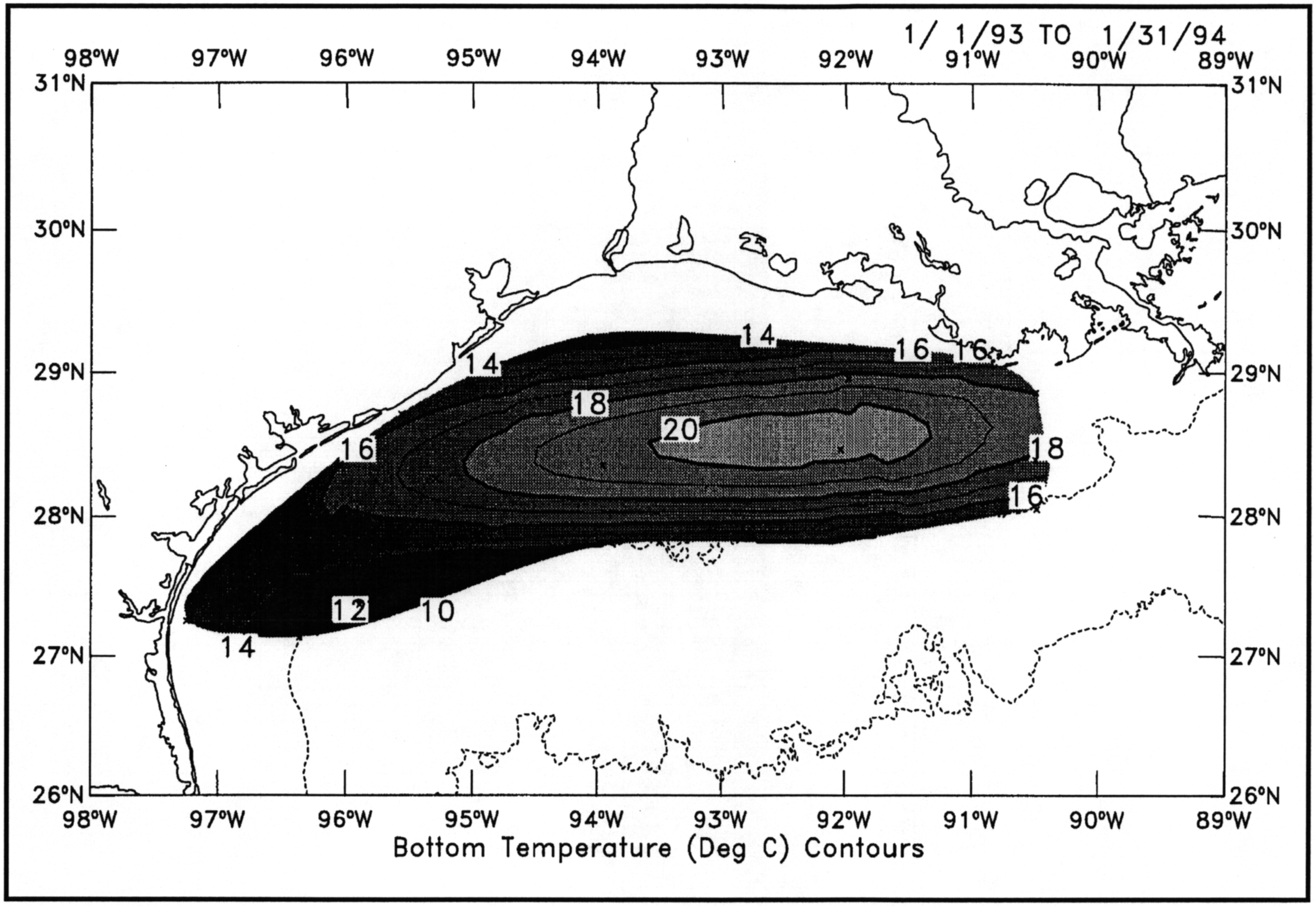

Figure 25. Contours of averaged January near-bottom temperatures measured by in-situ instruments during LATEX-A.

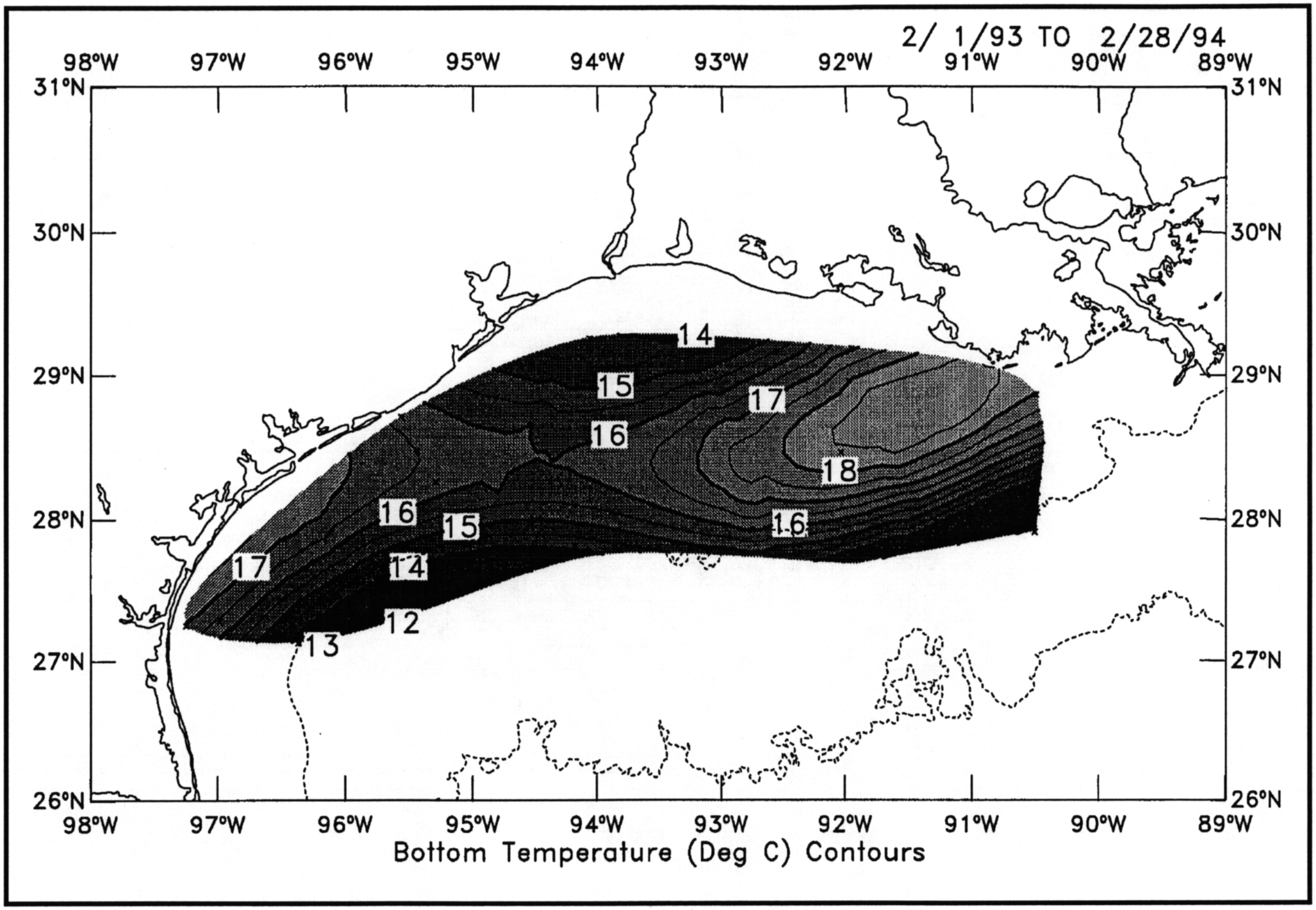

Figure 26. Contours of averaged February near-bottom temperatures measured by in-situ instruments during LATEX-A.

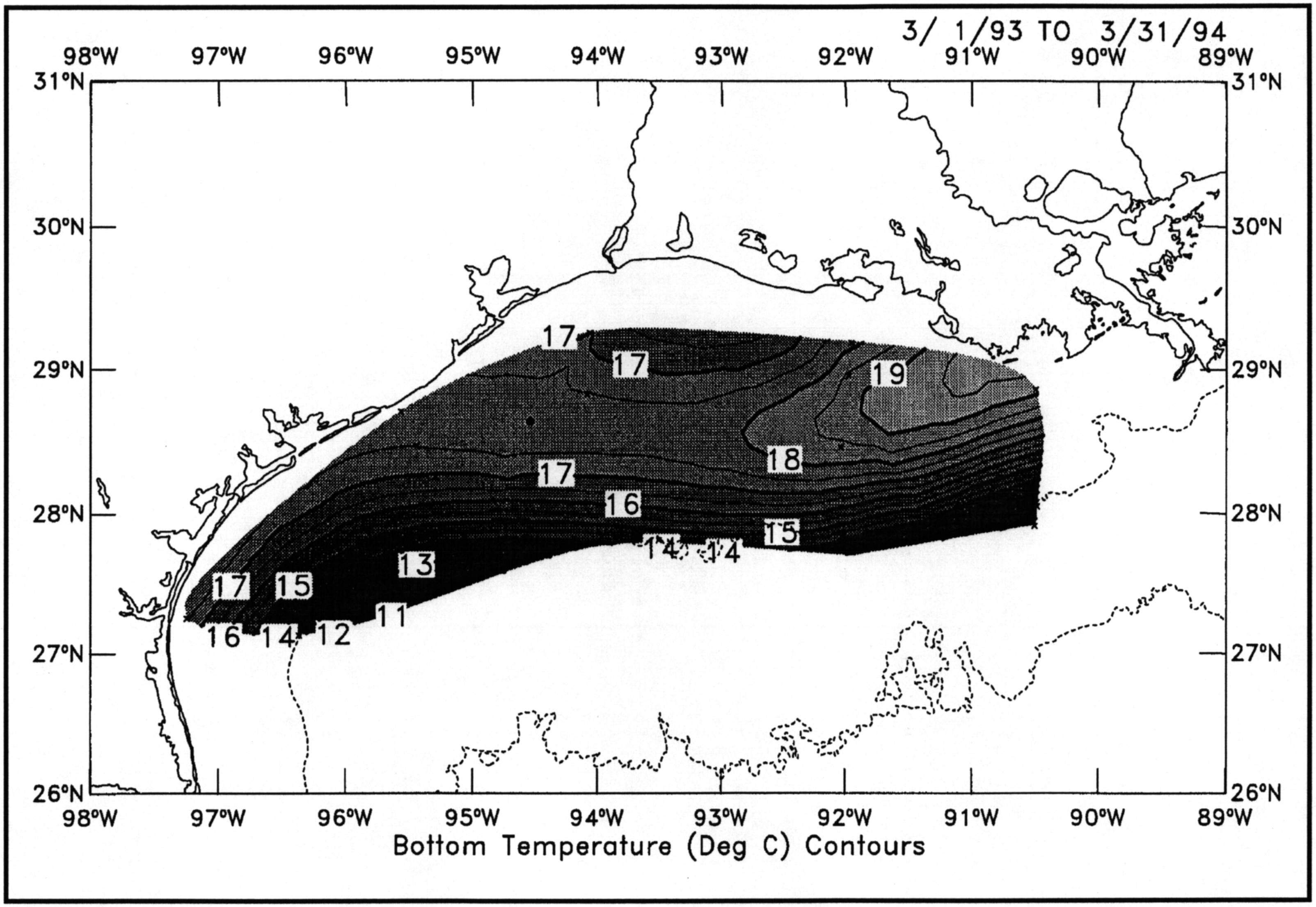

Figure 27. Contours of averaged March near-bottom temperatures measured by in-situ instruments during LATEX-A.

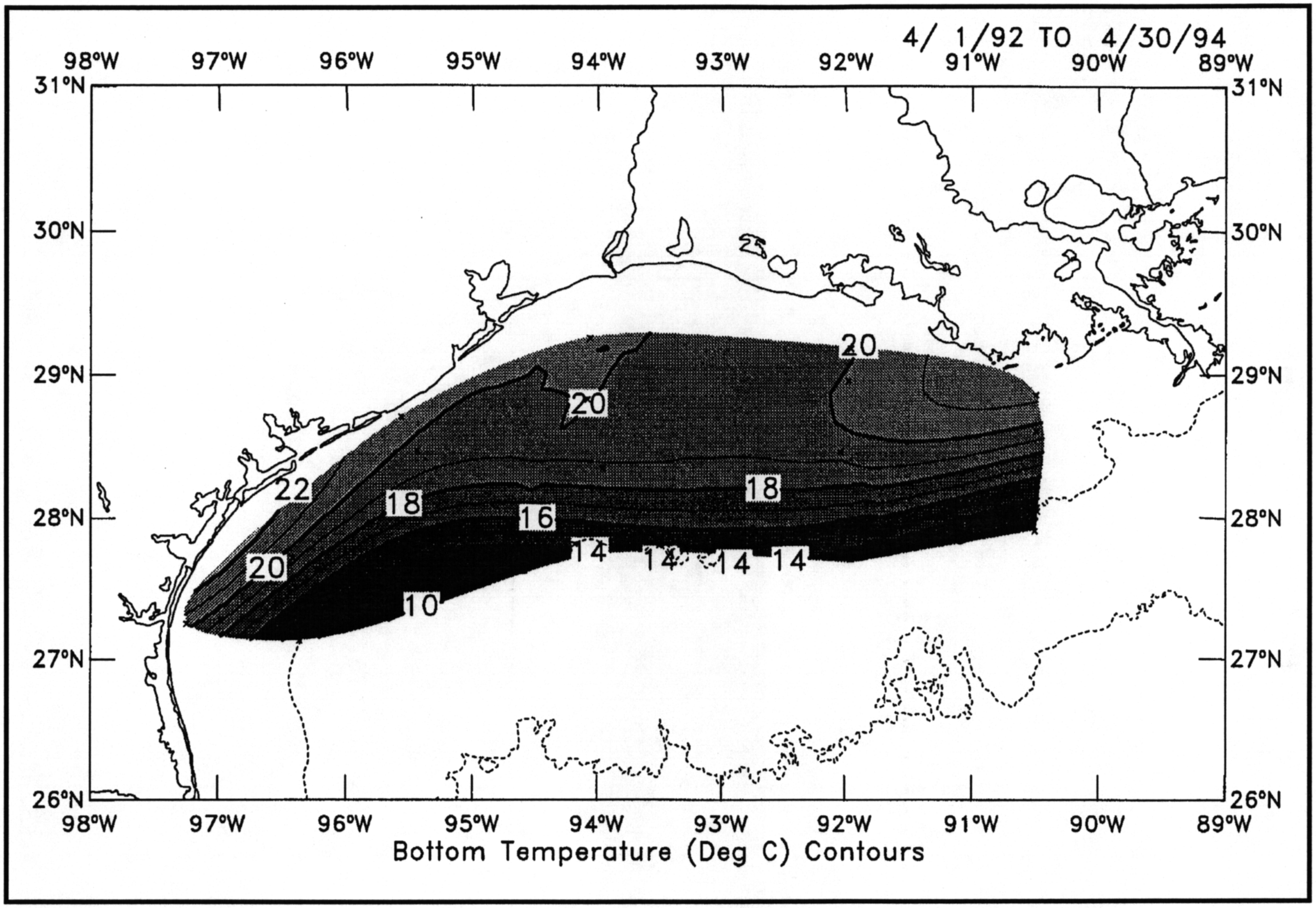

Figure 28. Contours of averaged April near-bottom temperatures measured by in-situ instruments during LATEX-A.

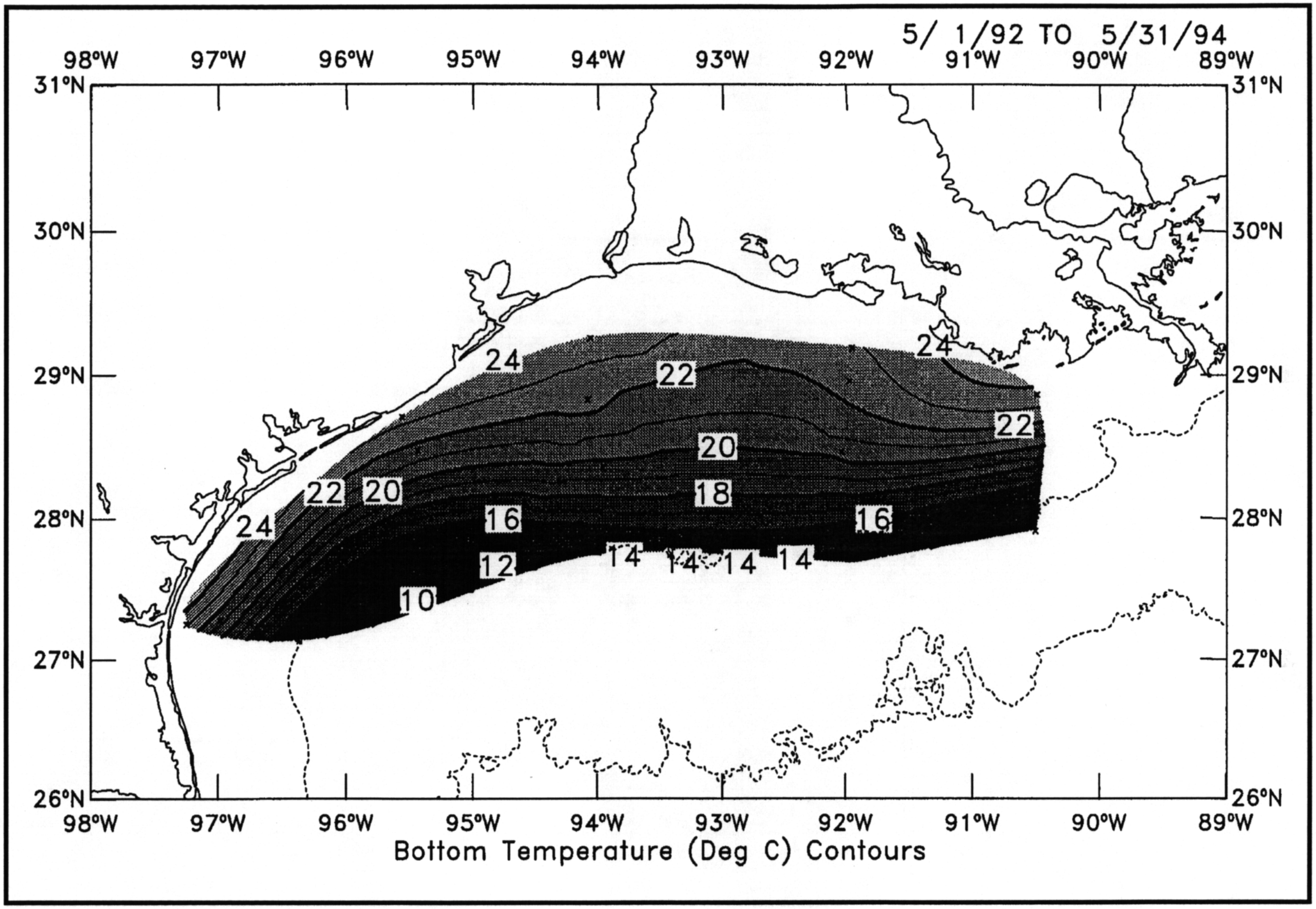

Figure 29. Contours of averaged May near-bottom temperatures measured by in-situ instruments during LATEX-A.

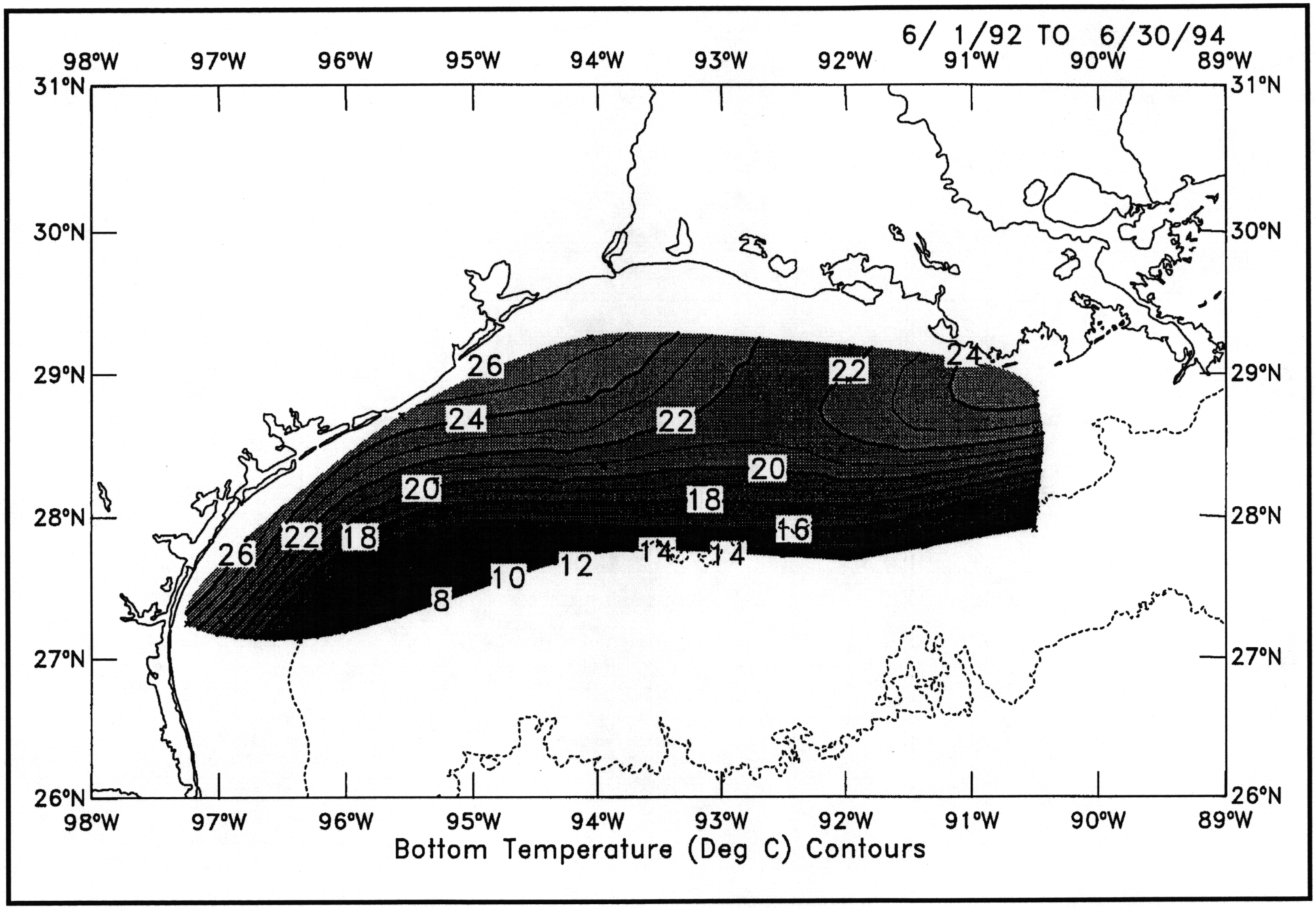

Figure 30. Contours of averaged June near-bottom temperatures measured by in-situ instruments during LATEX-A.

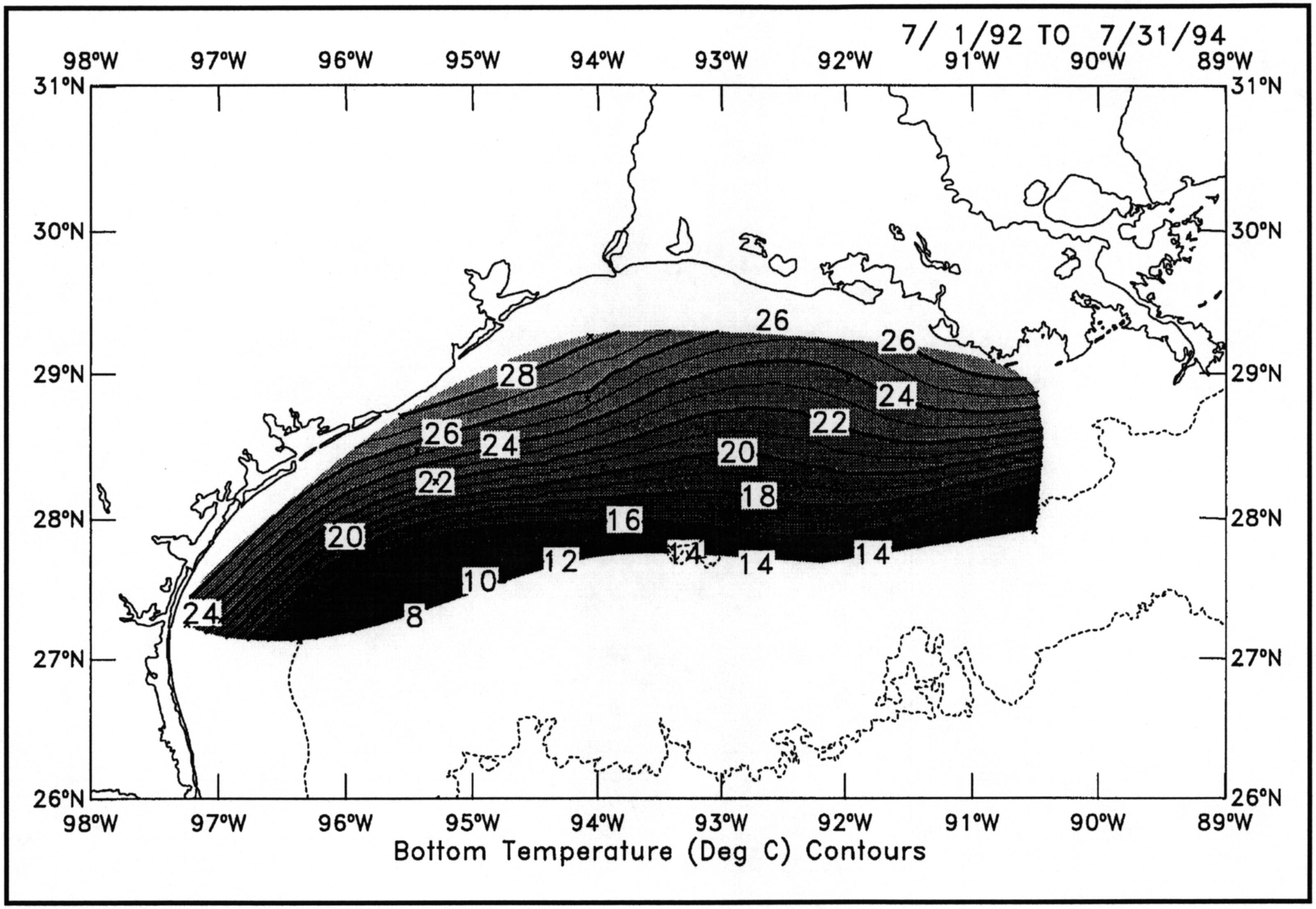

Figure 31. Contours of averaged July near-bottom temperatures measured by in-situ instruments during LATEX-A.

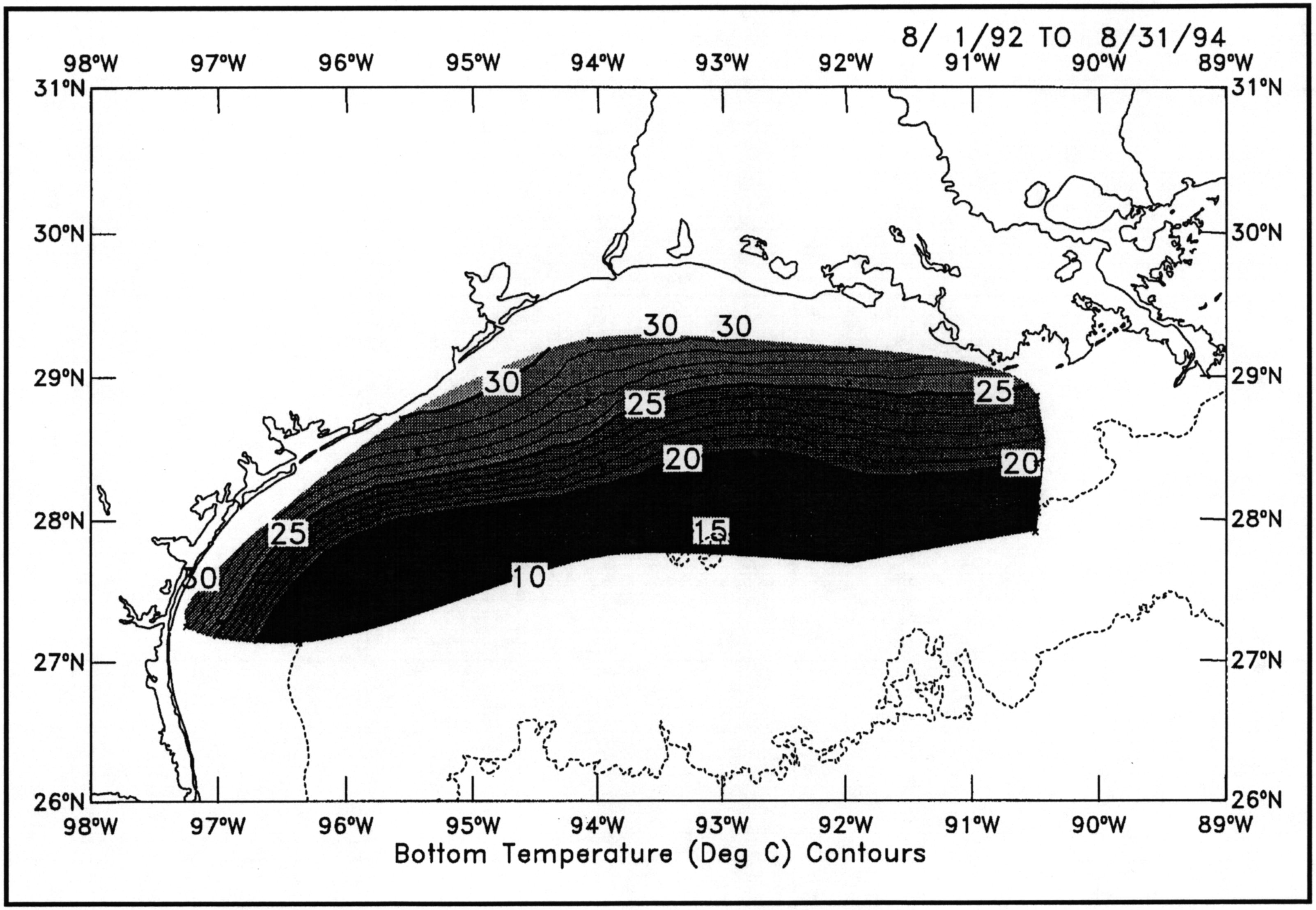

Figure 32. Contours of averaged August near-bottom temperatures measured by in-situ instruments during LATEX-A.

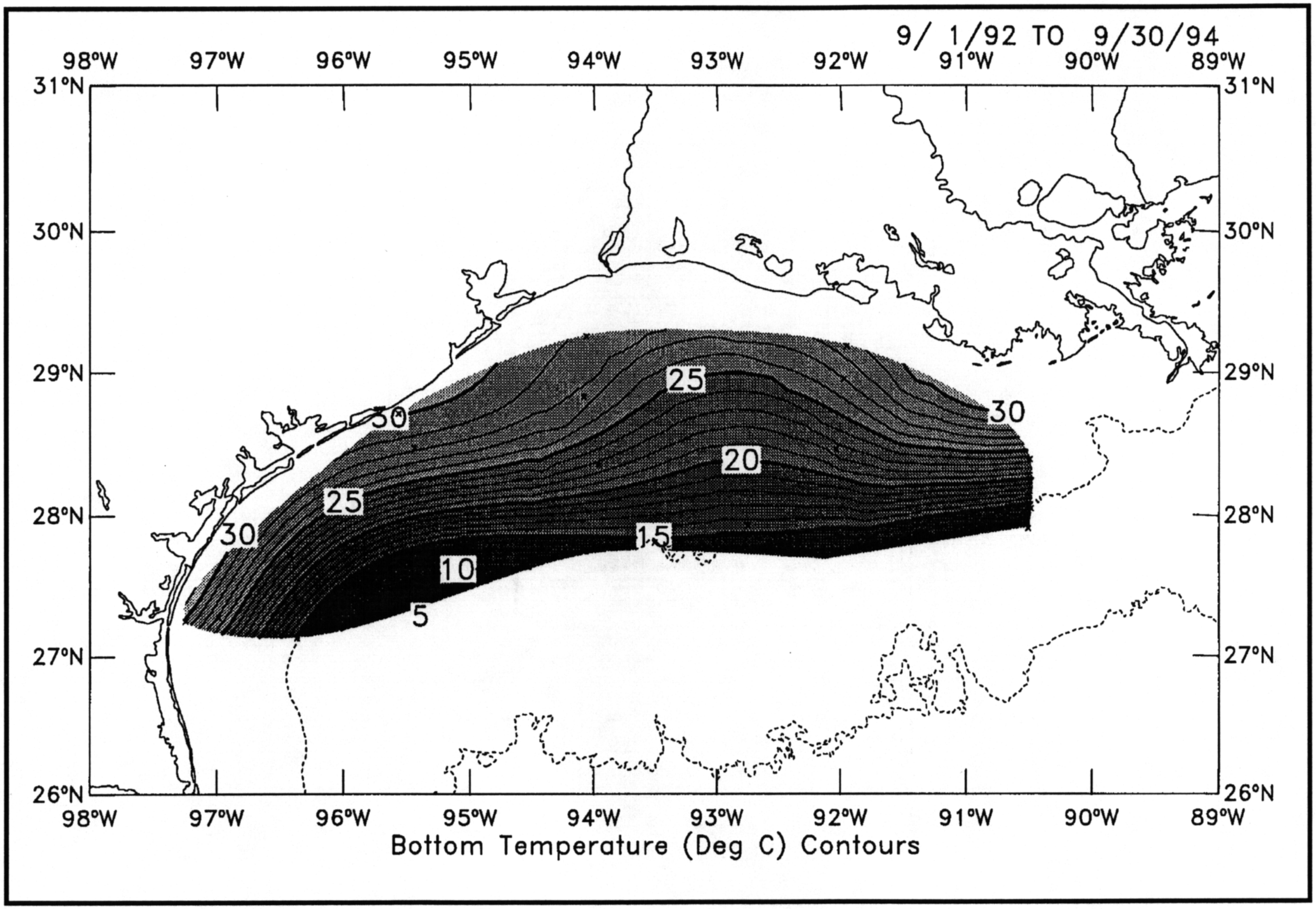

Figure 33. Contours of averaged September near-bottom temperatures measured by in-situ instruments during LATEX-A.

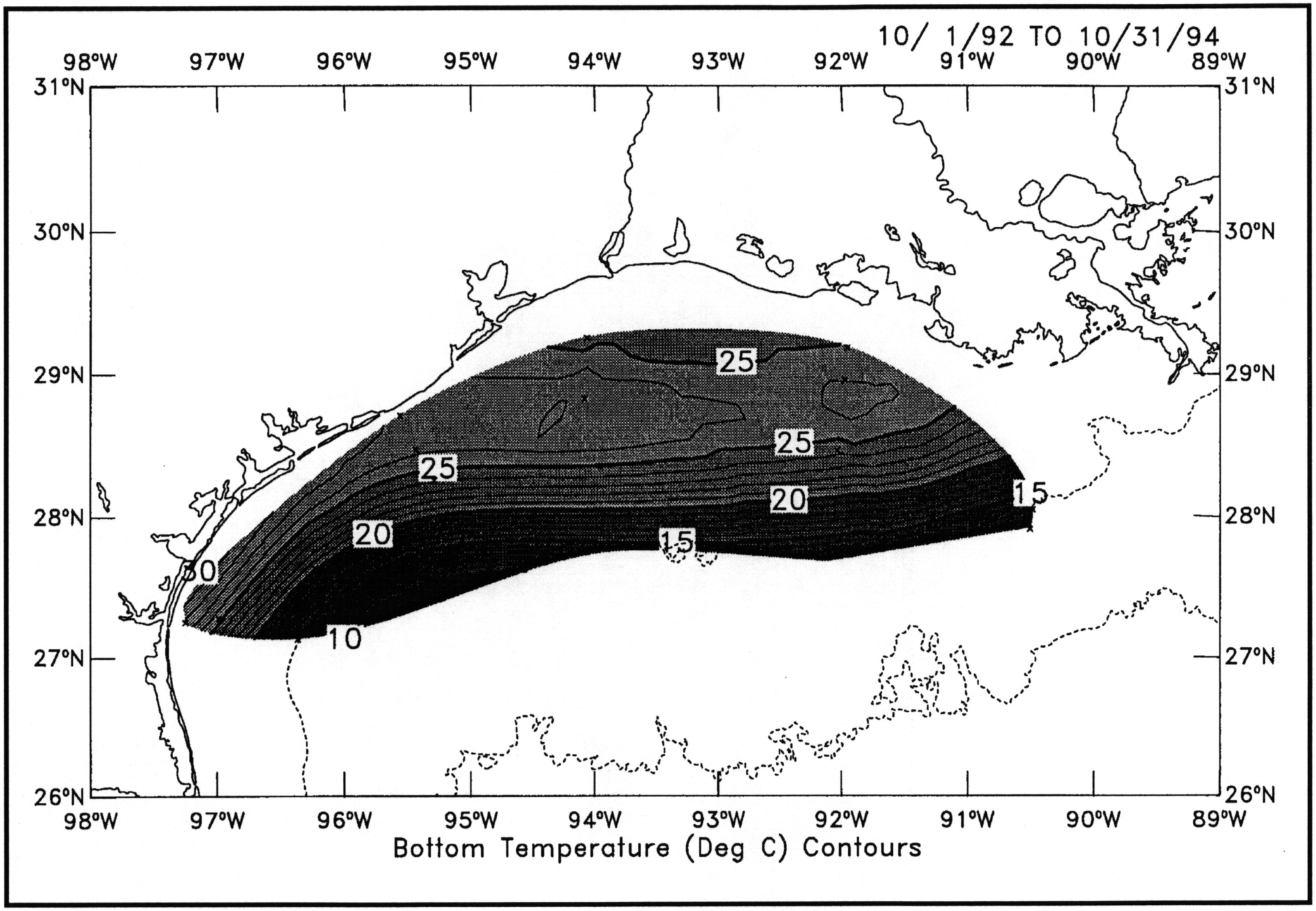

Figure 34. Contours of averaged October near-bottom temperatures measured by in-situ instruments during LATEX-A.

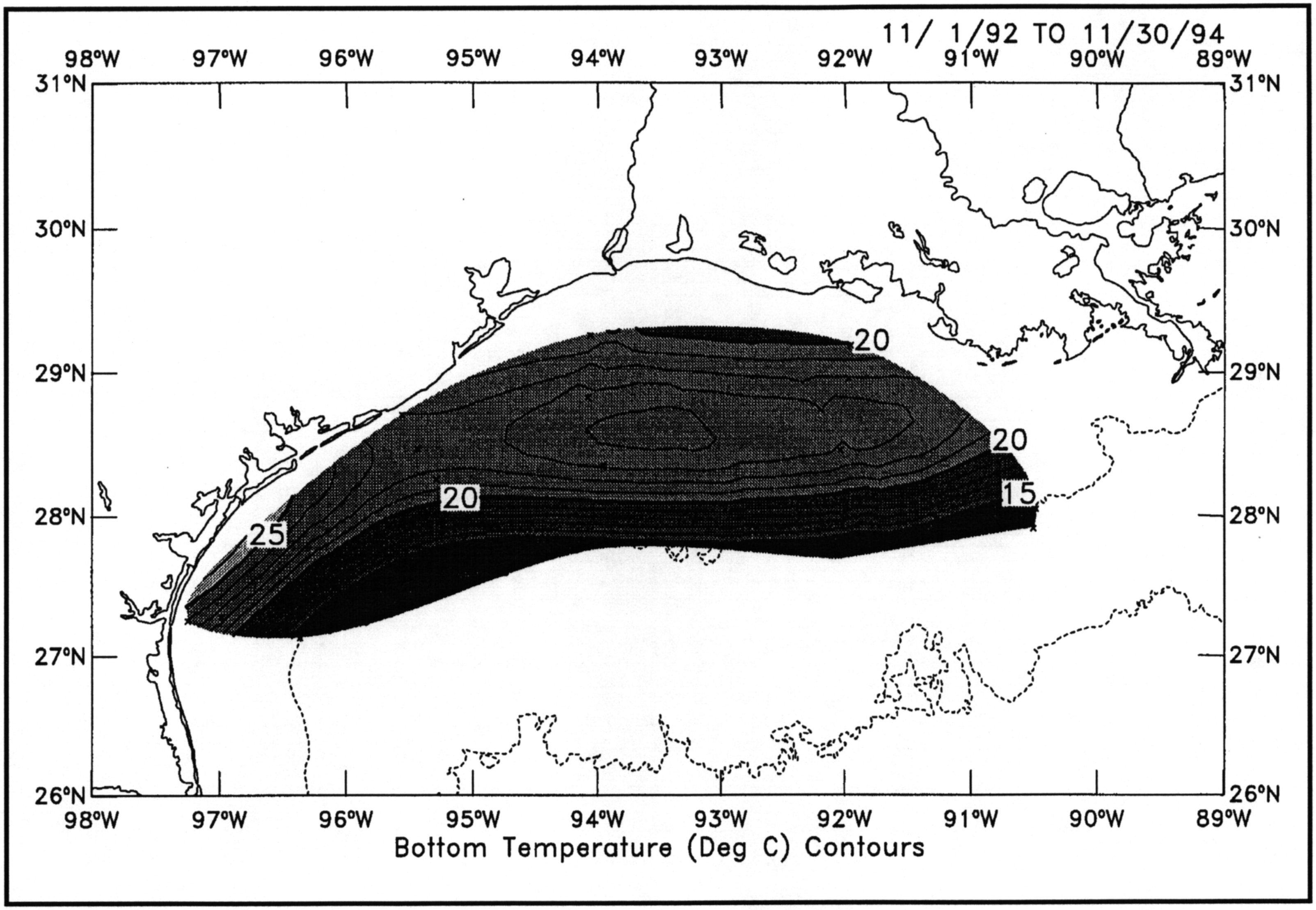

Figure 35. Contours of averaged November near-bottom temperatures measured by in-situ instruments during LATEX-A.

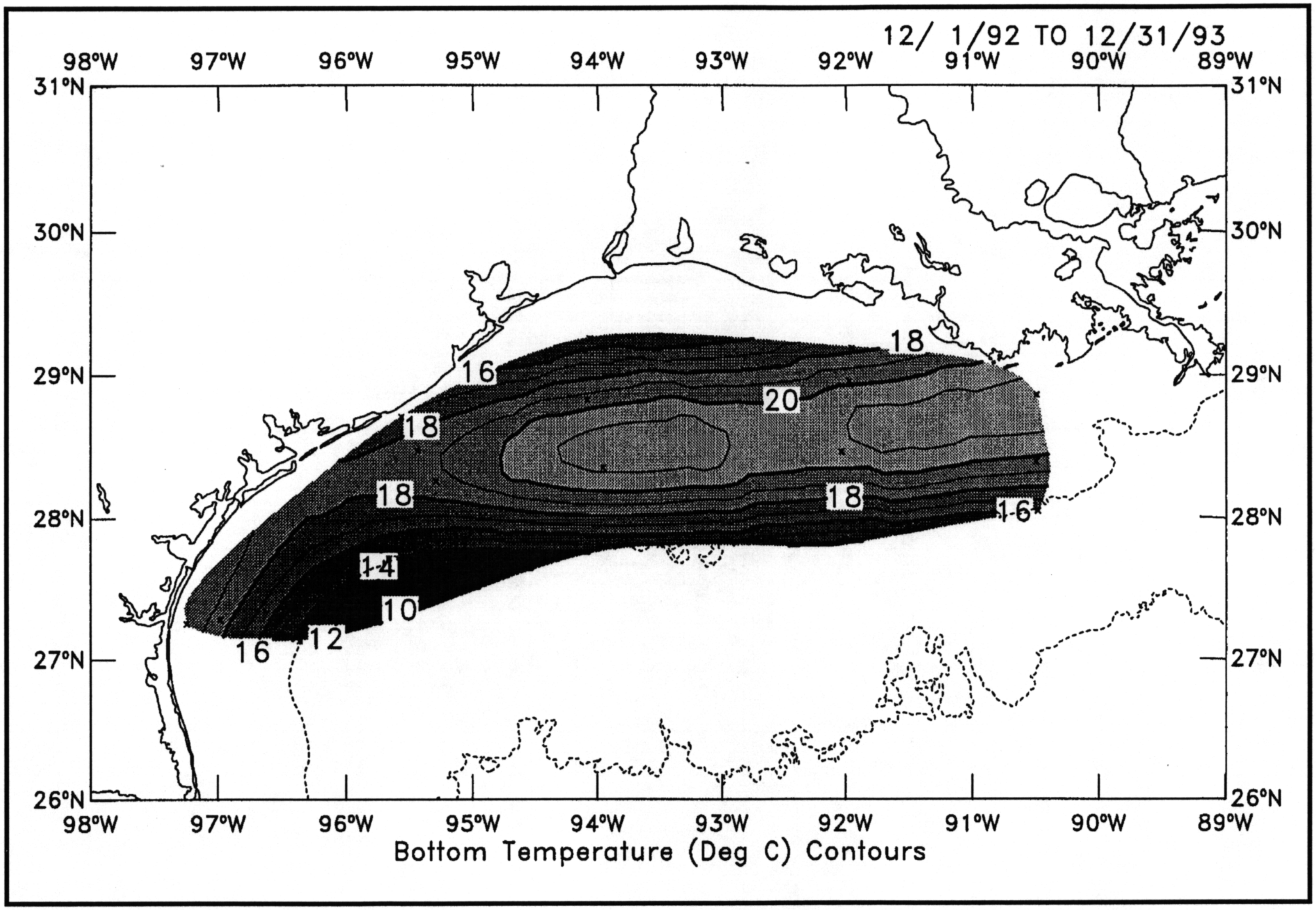

Figure 36. Contours of averaged December near-bottom temperatures measured by in-situ instruments during LATEX-A.

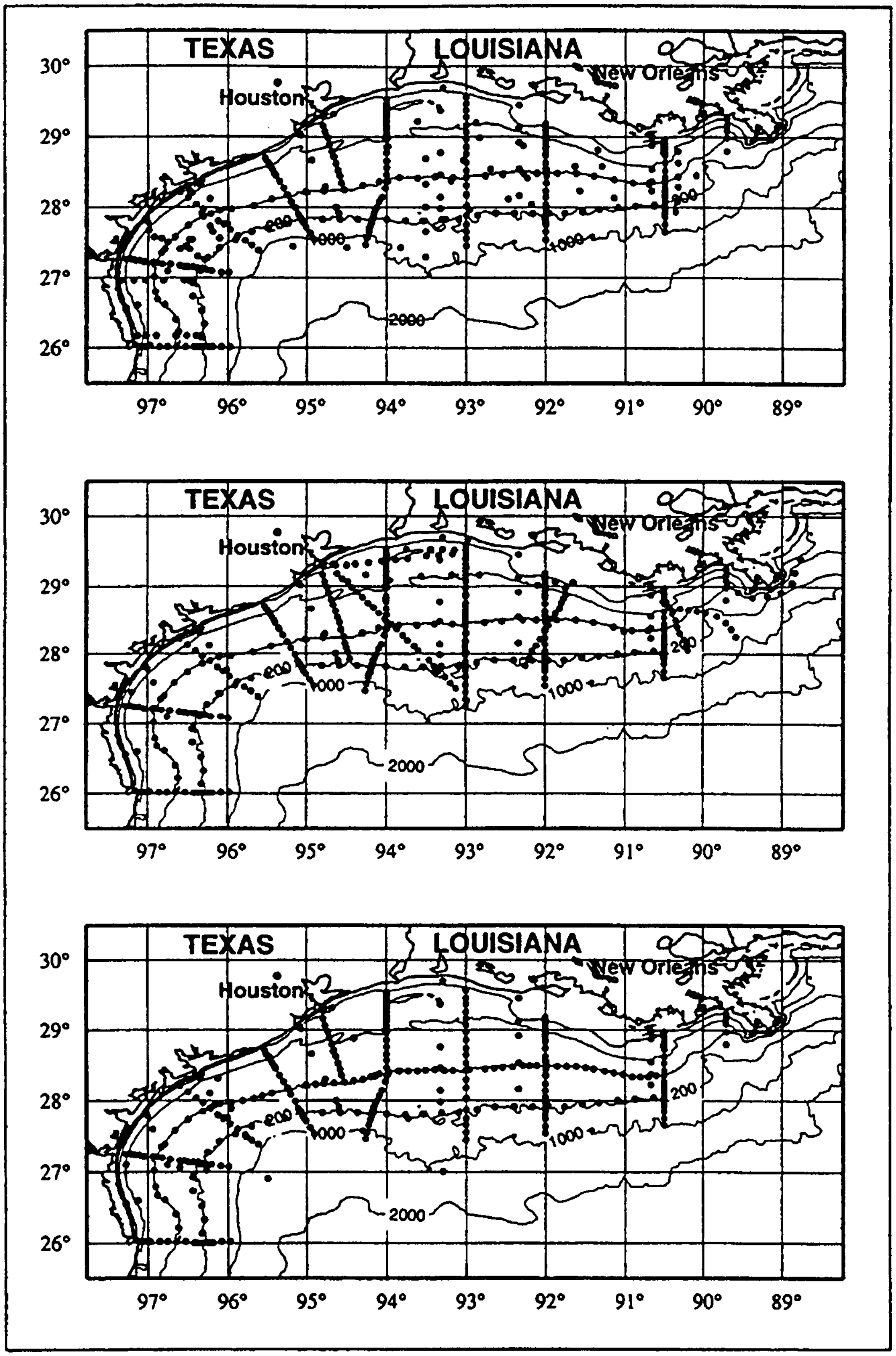

Figure 37. Composite of hydrographic station locations used to compute average temperatures and salinities for: ten spring cruises (top panel), nine summer cruises (middle panel), and six fall cruises (bottom panel).

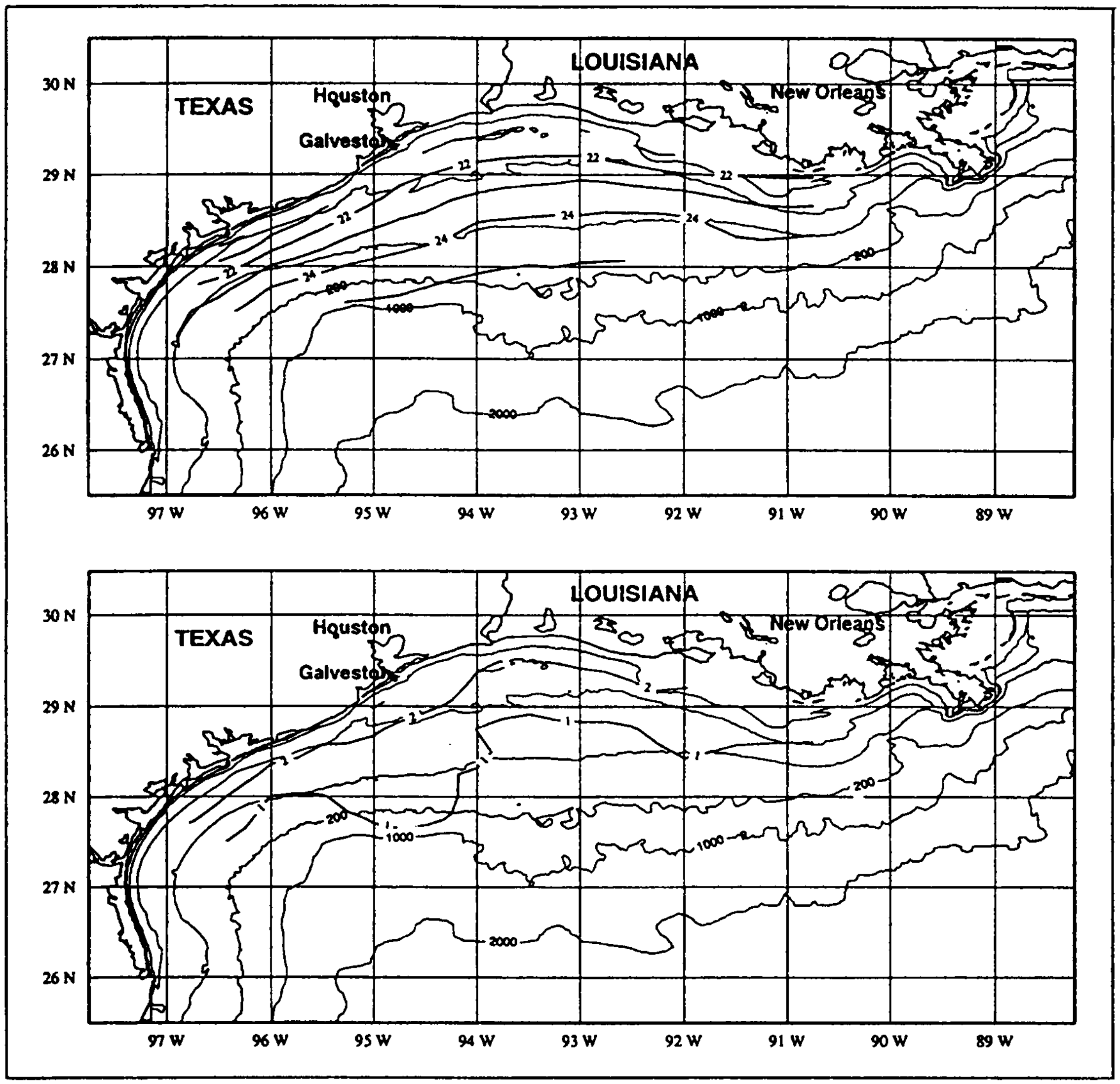

Figure 38. Average sea surface temperature (top) and its standard deviation (bottom) for fall (November) cruises. Contours in °C. (from LATEX-A 1997).

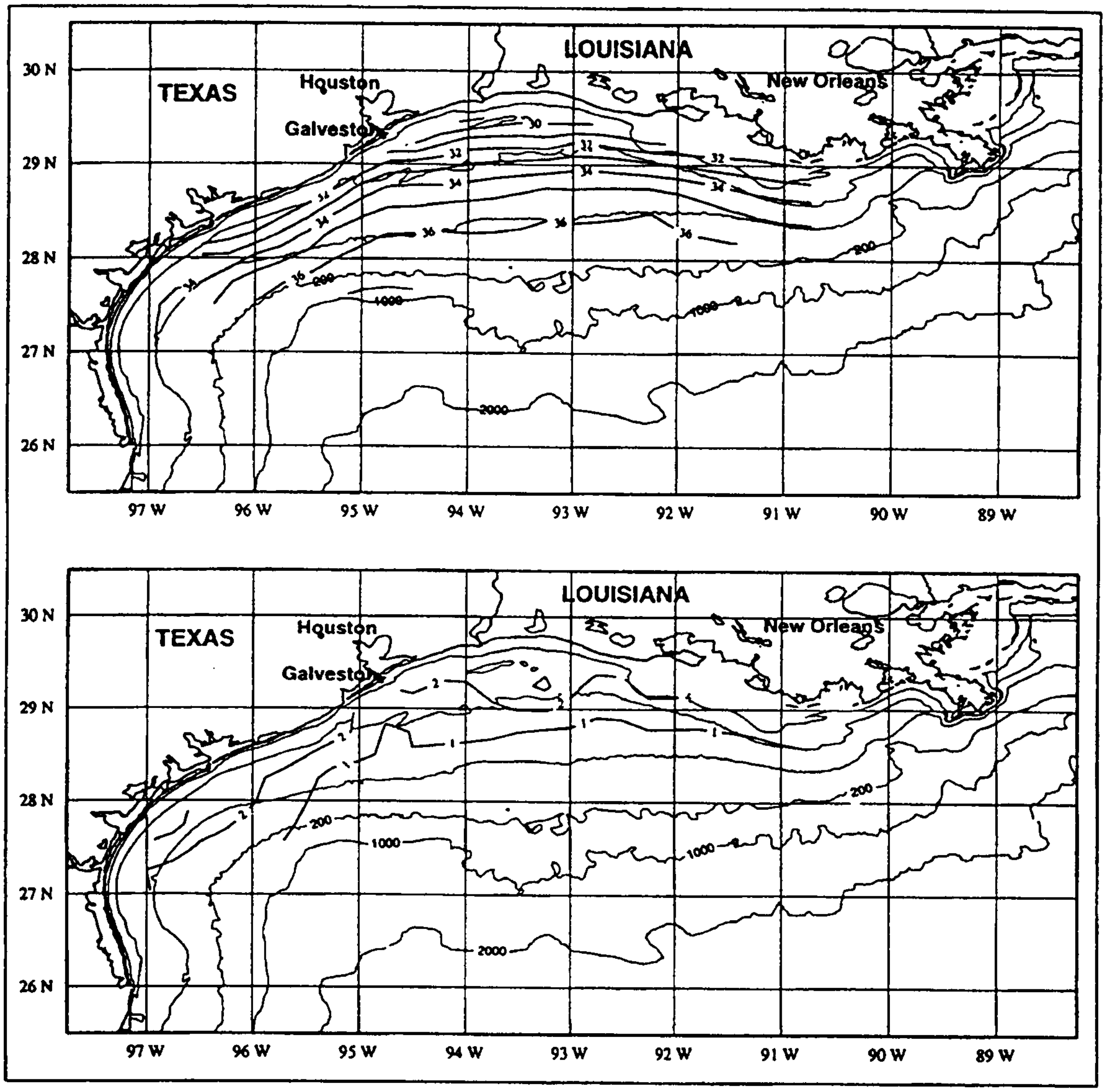

Figure 39. Average sea surface salinity (top) and its standard deviation (bottom) for fall (November) cruises. Contours in ppt. (from LATEX-A 1997).

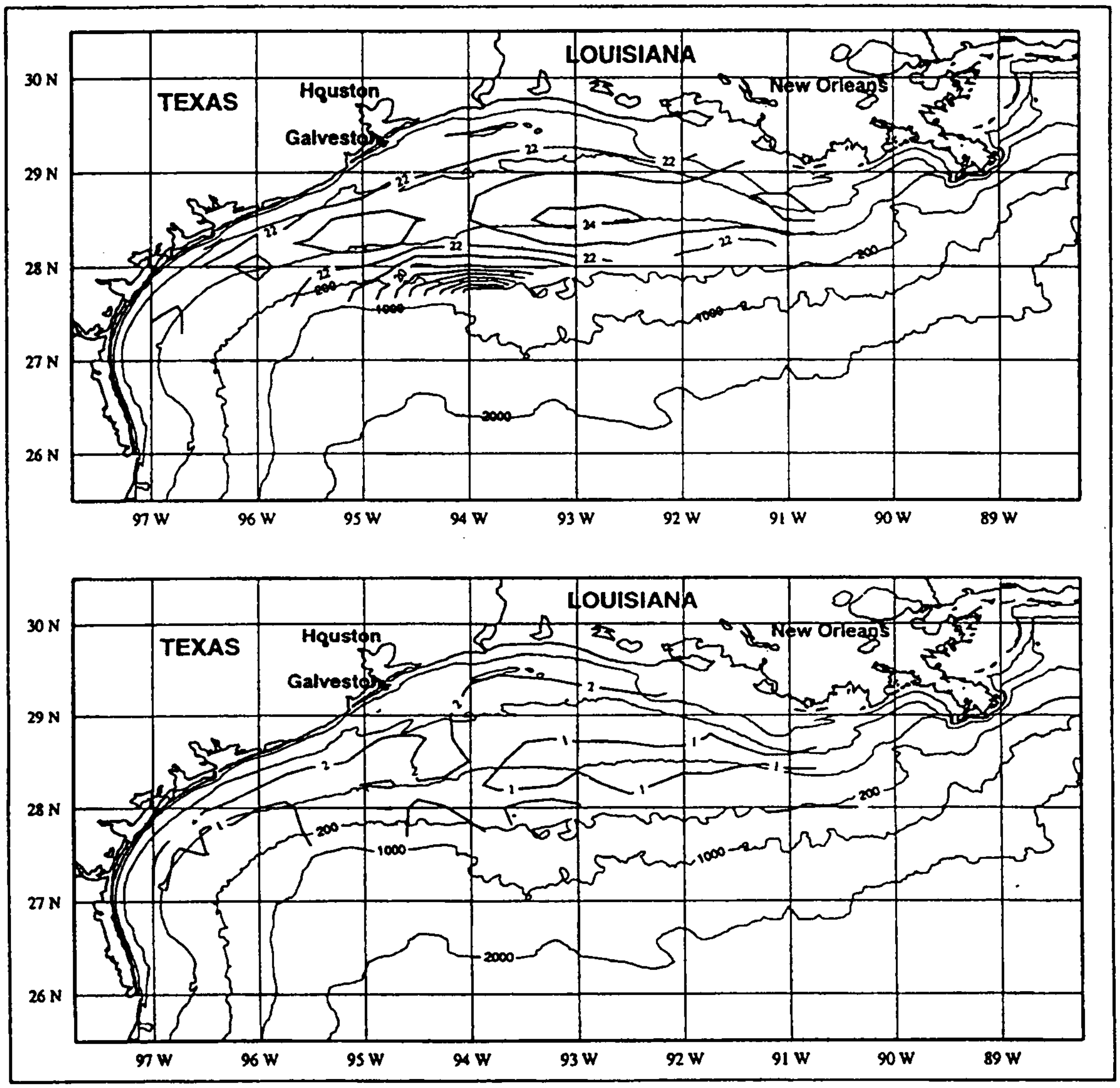

Figure 40. Average bottom temperature (top) and its standard deviation (bottom) for fall (November) cruises. Contours in °C. (from LATEX-A 1997).

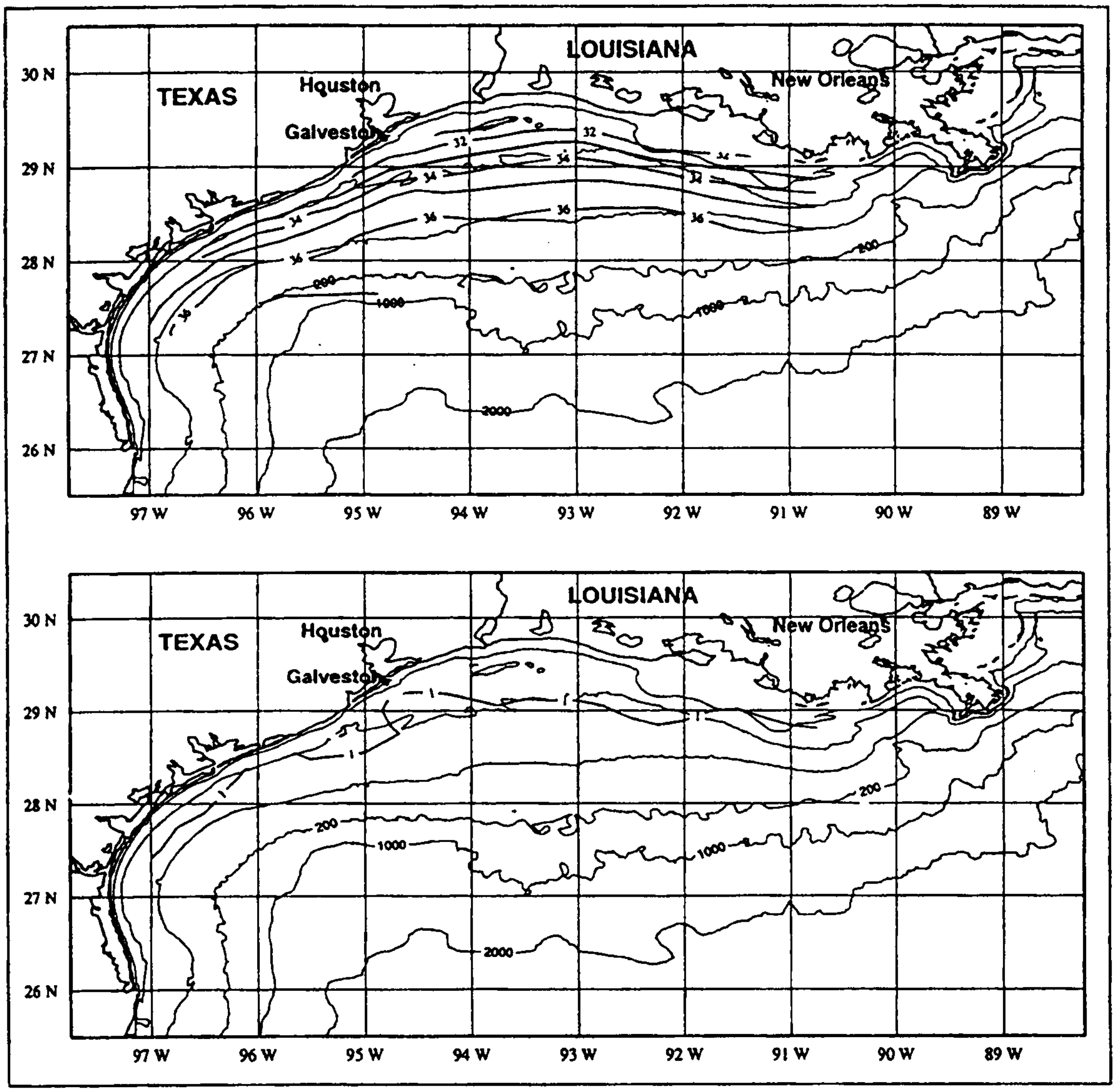

Figure 41. Average bottom salinity (top) and its standard deviation (bottom) for fall (November) cruises. Contours in ppt. (from LATEX-A 1997).

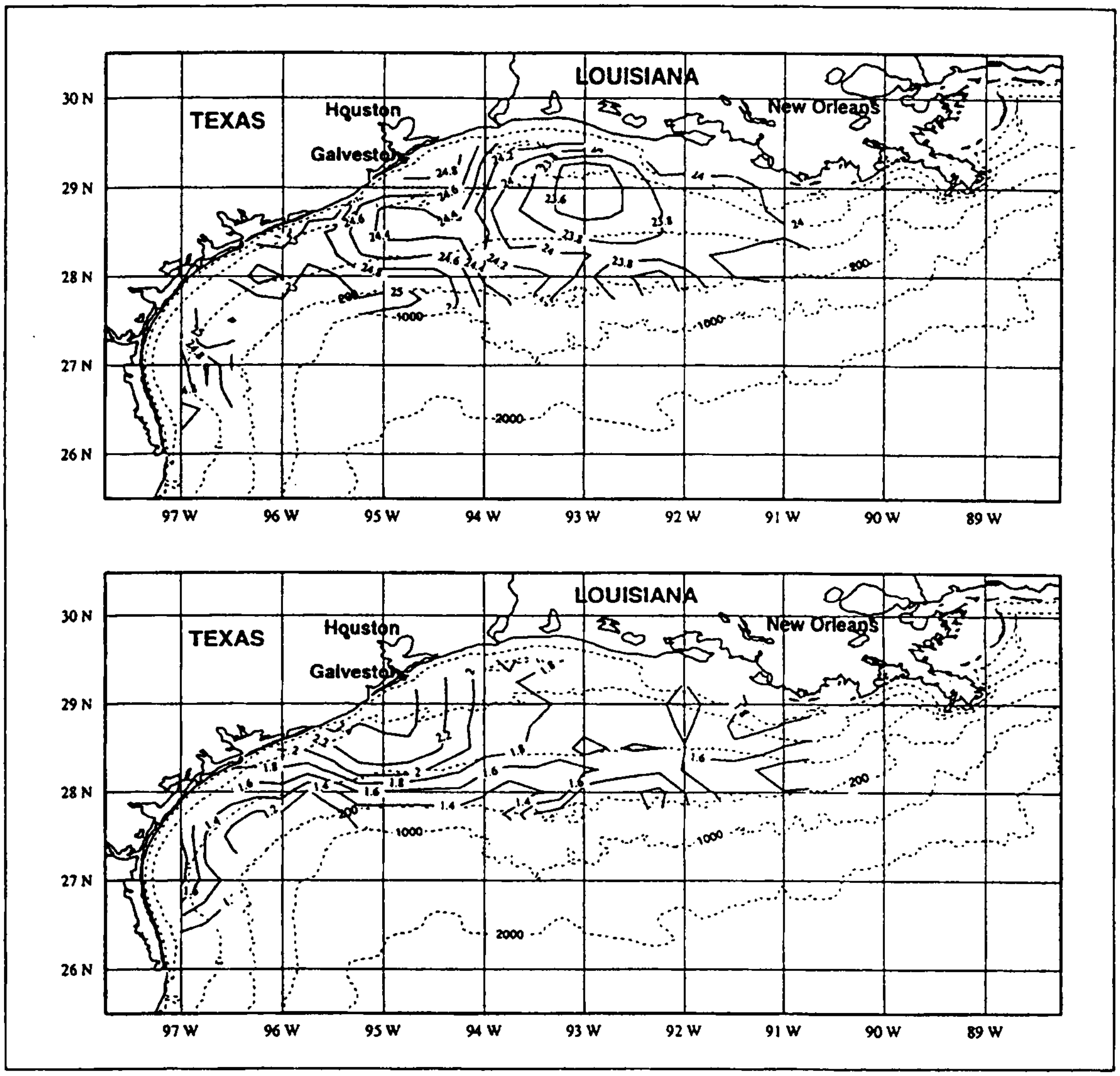

Figure 42. Average sea surface temperature (top) and its standard deviation (bottom) for spring (May) cruises. Contours in °C. (from LATEX-A 1997).

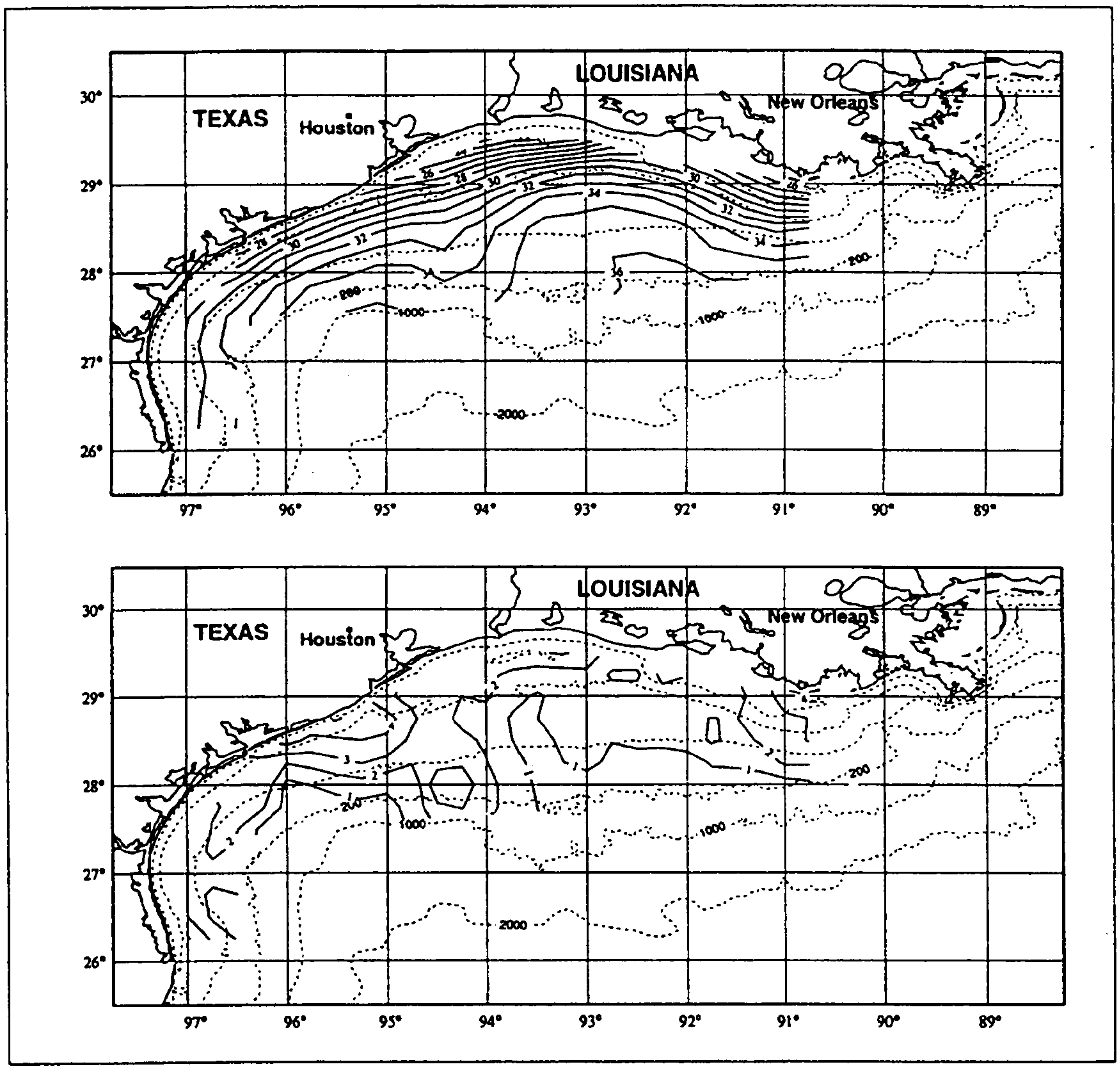

Figure 43. Average sea surface salinity (top) and its standard deviation (bottom) for spring (May) cruises. Contours in ppt. (from LATEX-A 1997).

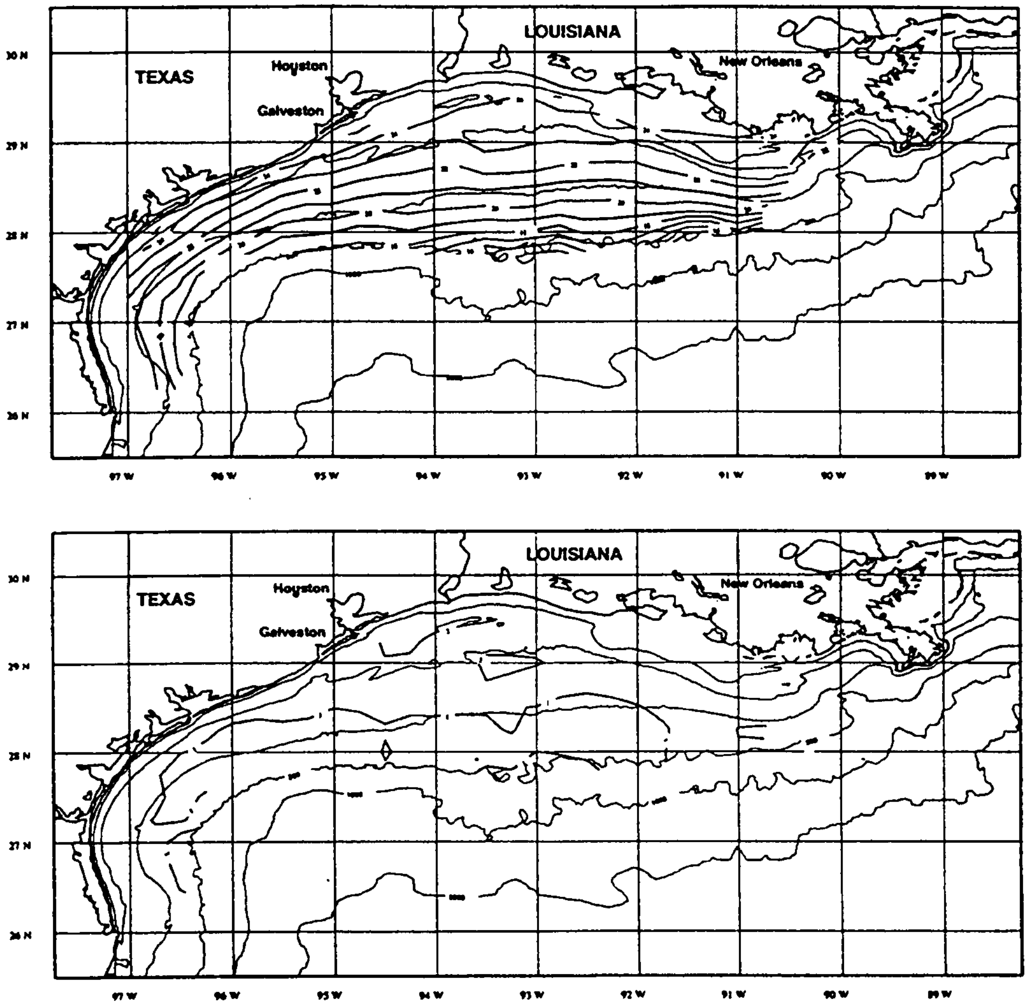

Figure 44. Average bottom temperature (top) and its standard deviation (bottom) for spring (May) cruises. Contours in °C. (from LATEX-A 1997).

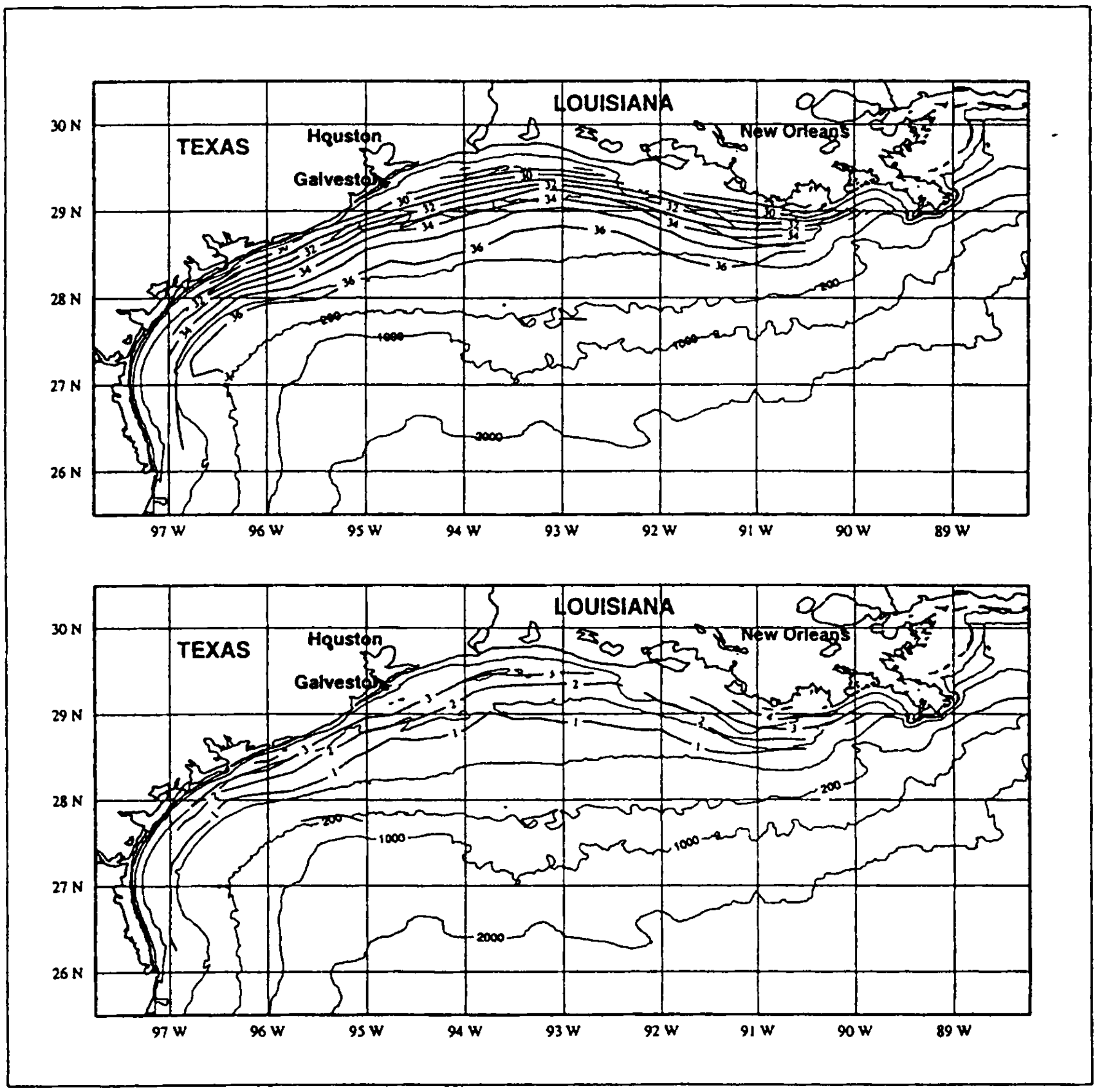

Figure 45. Average sea surface salinity (top) and its standard deviation (bottom) for spring (May) cruises. Contours in ppt. (from LATEX-A 1997).

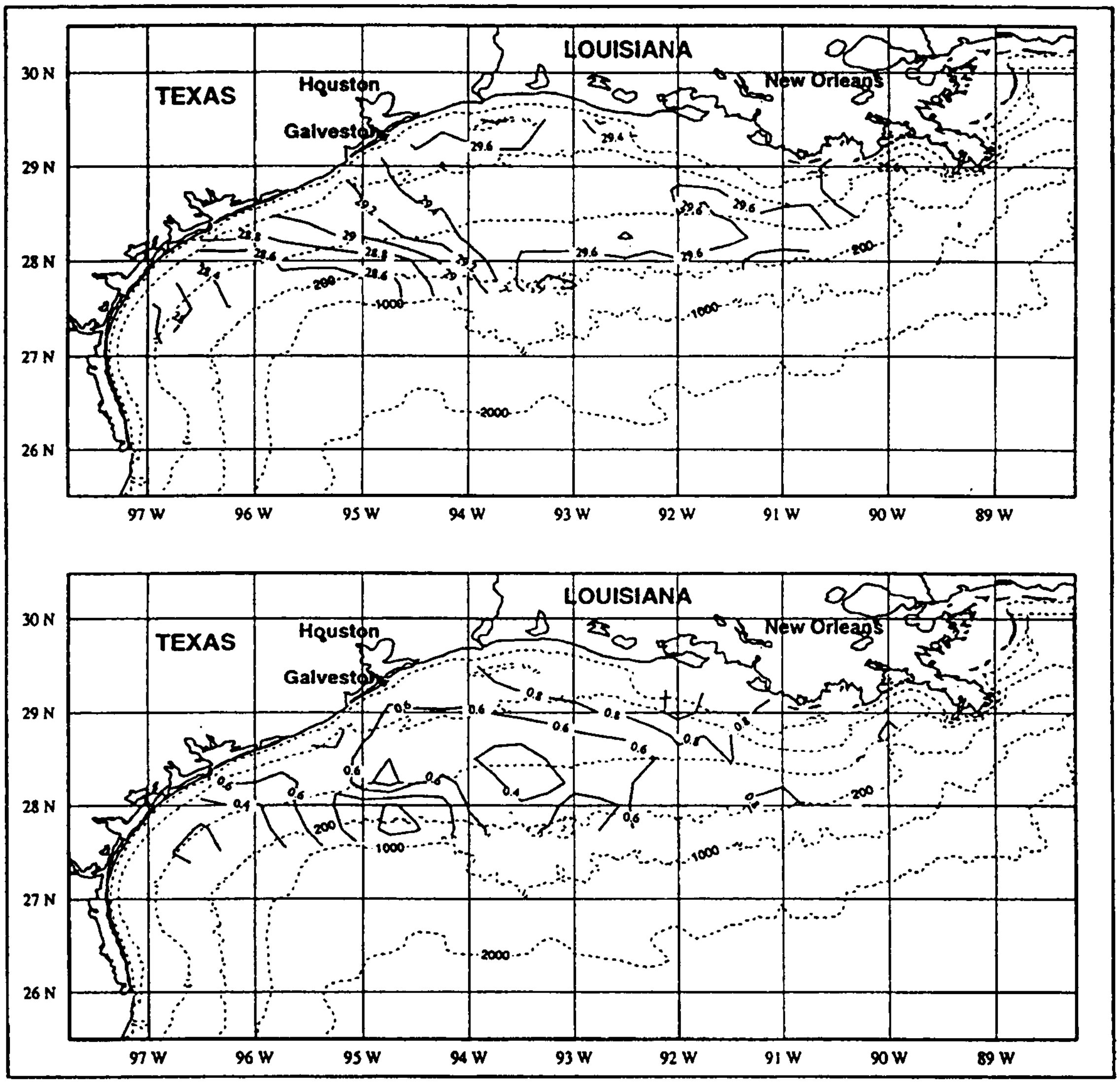

Figure 46. Average sea surface temperature (top) and its standard deviation (bottom) for summer (July/August) cruises. Contours in °C. (from LATEX-A 1997).

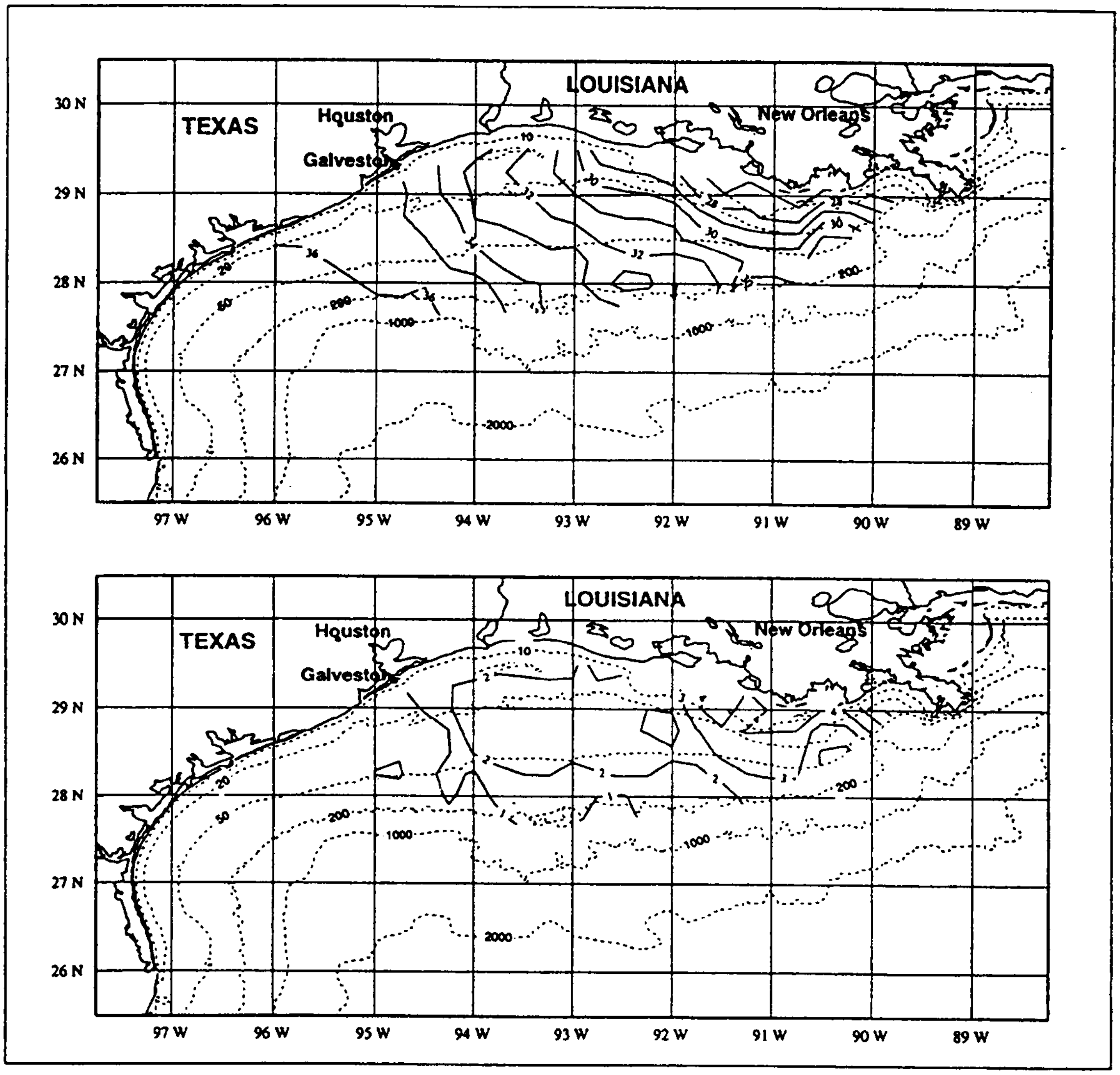

Figure 47. Average sea surface salinity (top) and its standard deviation (bottom) for summer (July/August) cruises. Contours in ppt. (from LATEX-A 1997).

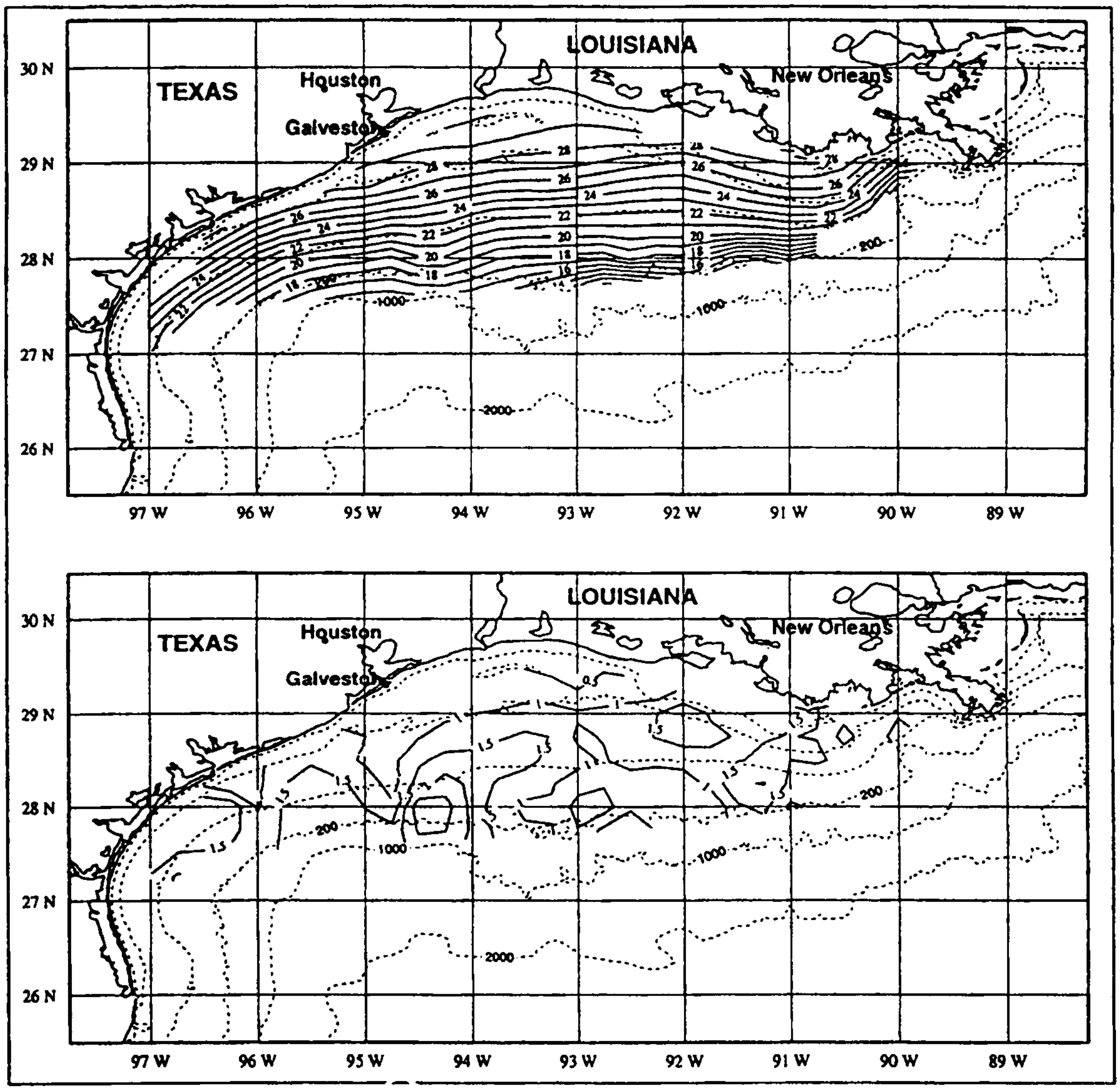

Figure 48. Average bottom temperature (top) and its standard deviation (bottom) for summer (July/August) cruises. Contours in °C. (from LATEX-A 1997).

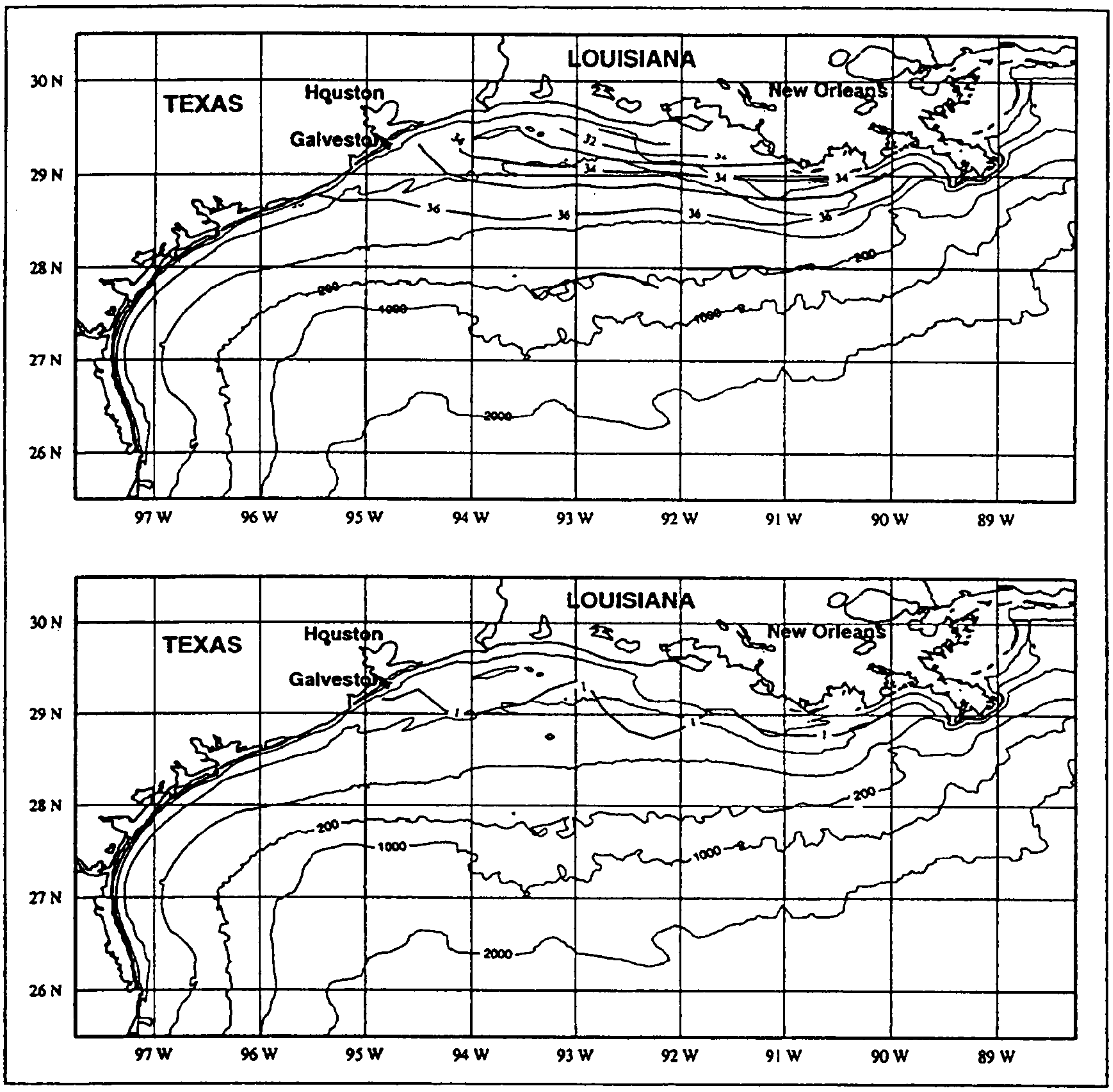

Figure 49. Average bottom salinity (top) and its standard deviation (bottom) for summer (July/August) cruises. Contours in ppt. (from LATEX-A 1997).

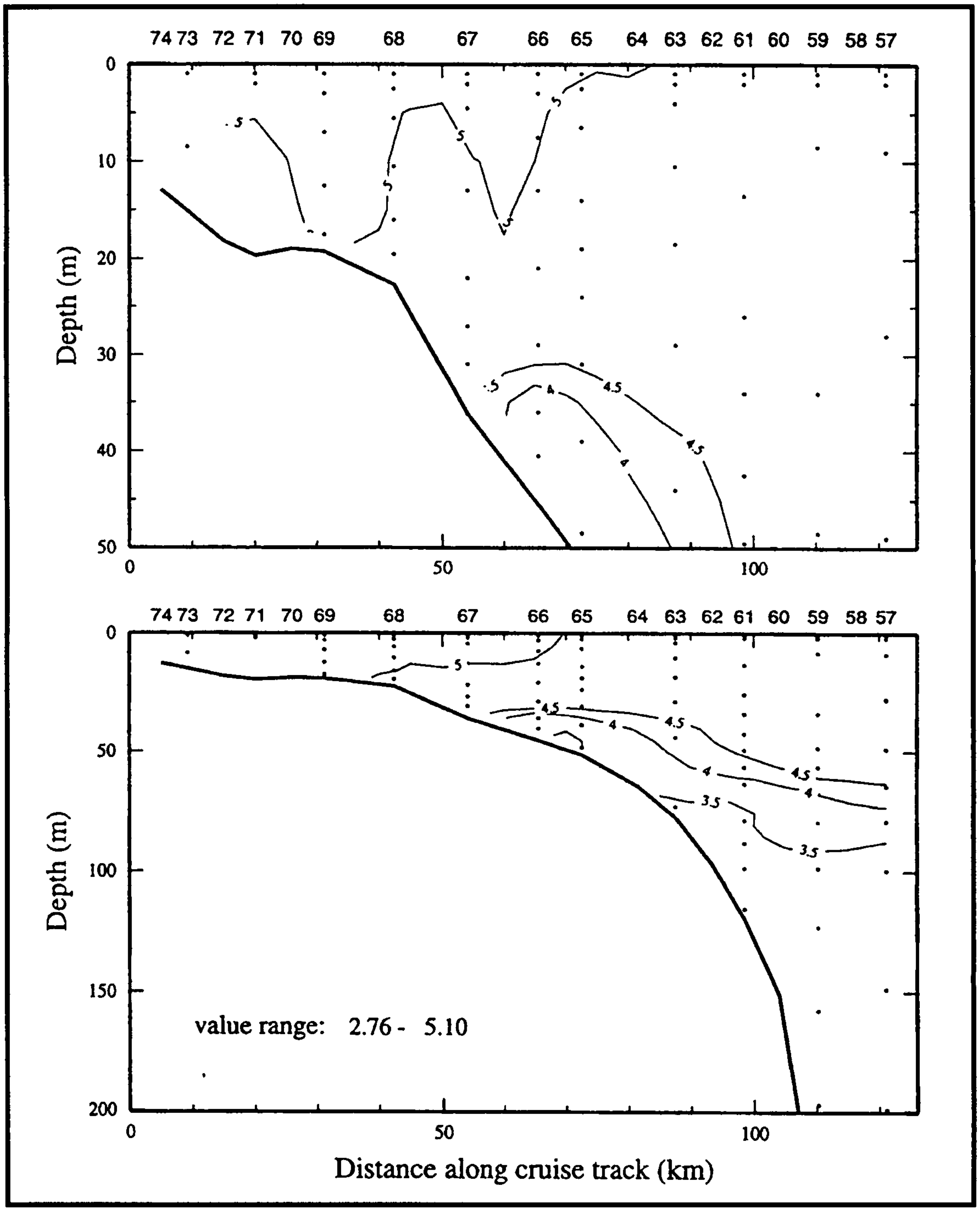

Figure 50. Contours of dissolved oxygen concentrations (ml/l) along a cross-shelf transect offshore of Terrebonne Bay, La., in fall 1992, showing the absence of hypoxic conditions over the shelf. Low values (2.76 ml/l) occurred offshore past the shelf break.

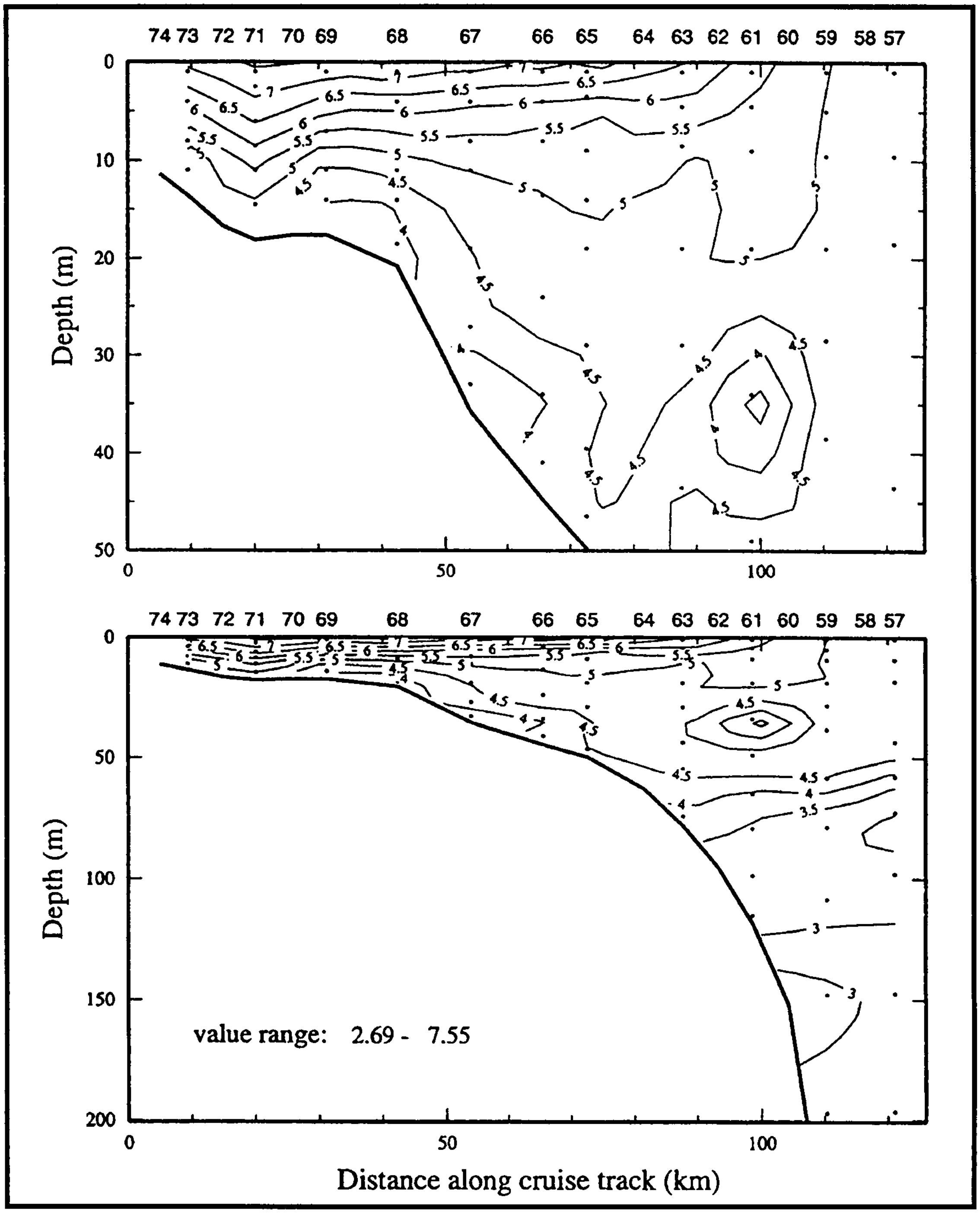

Figure 51. Contours of dissolved oxygen concentrations (ml/l) along a cross-shelf transect offshore of Terrebonne Bay, La., in winter (February 1993). High DO values occurred across the shelf. Lowest DO concentrations found just seaward of the shelf break.

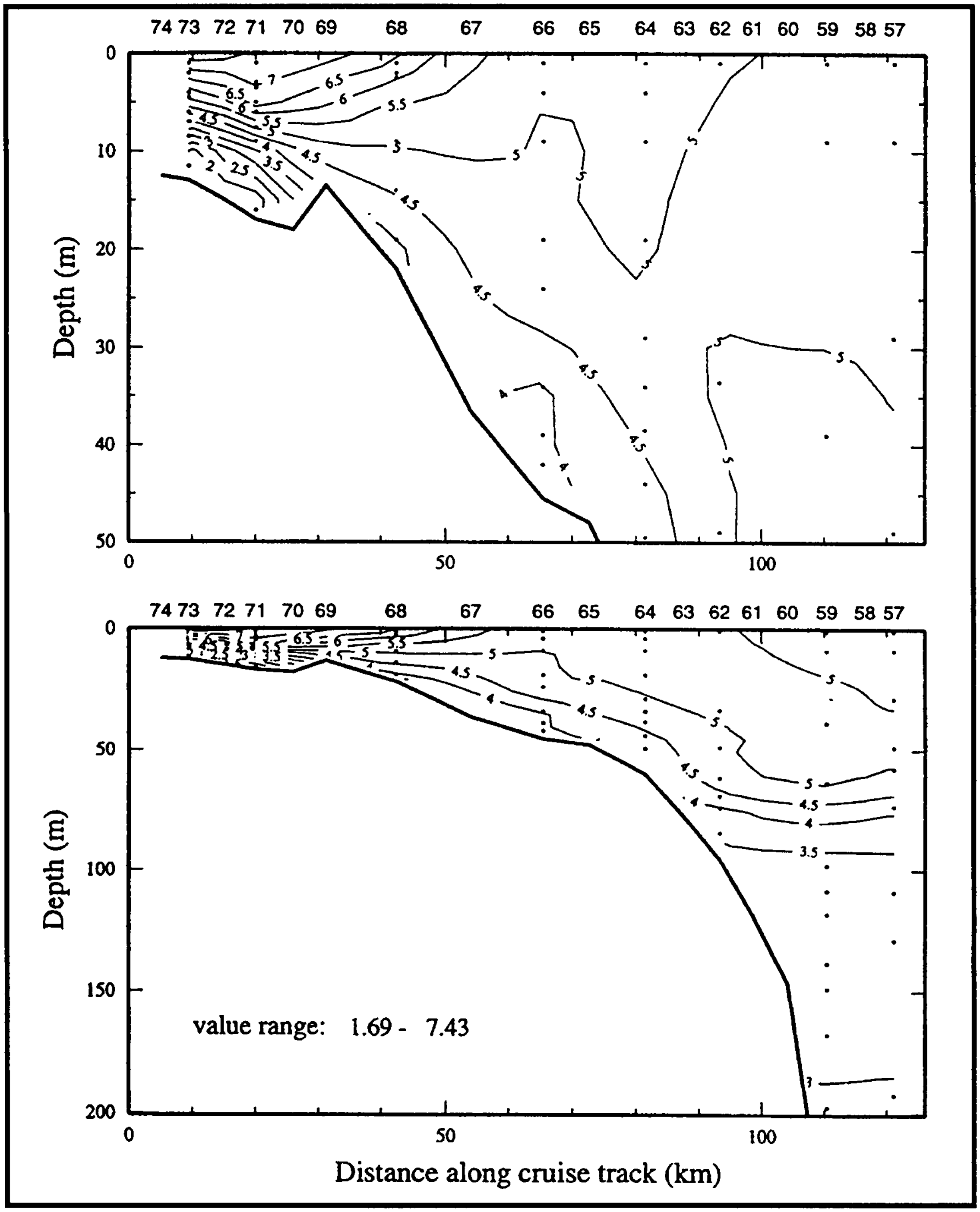

Figure 52. Contours of dissolved oxygen concentrations (ml/l) along a cross-shelf transect offshore of Terrebonne Bay, La., in spring (April/May 1992). Low concentrations occurred over a relatively narrow inner shelf band with highest values near the surface.

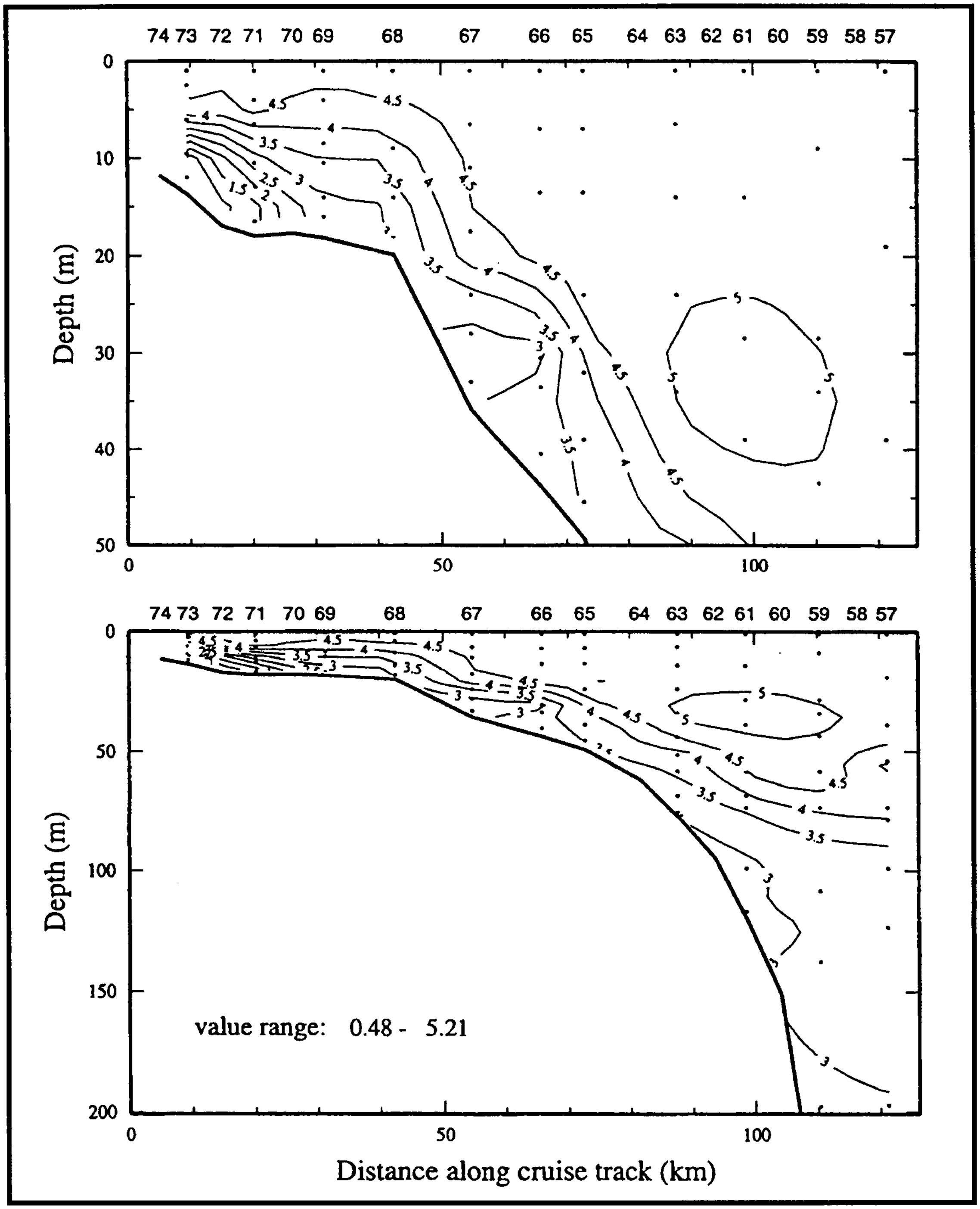

Figure 53. Contours of dissolved oxygen concentrations (ml/l) along a cross-shelf transect offshore of Terrebonne Bay, La., in summer (July/August 1992). Low concentrations occurred across much of the shelf near the bottom. Anoxic conditions (<1 ml/l) occurred at the bottom on the inner shelf.

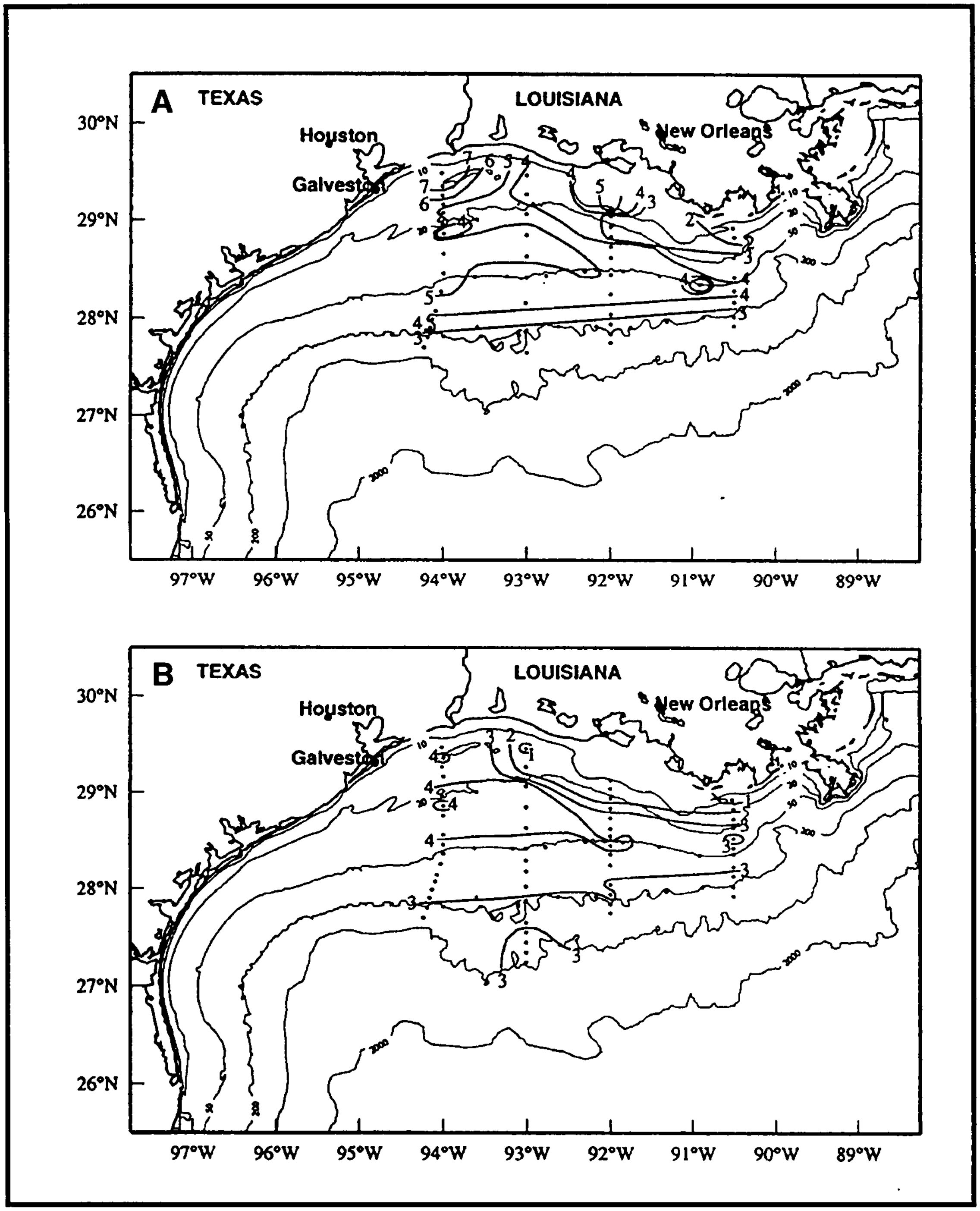

Figure 54. Horizontal contours of bottom dissolved oxygen concentrations (ml/l) in: (A) spring (April/May 1992; top panel) and (B) summer (July/August 1992; bottom panel).

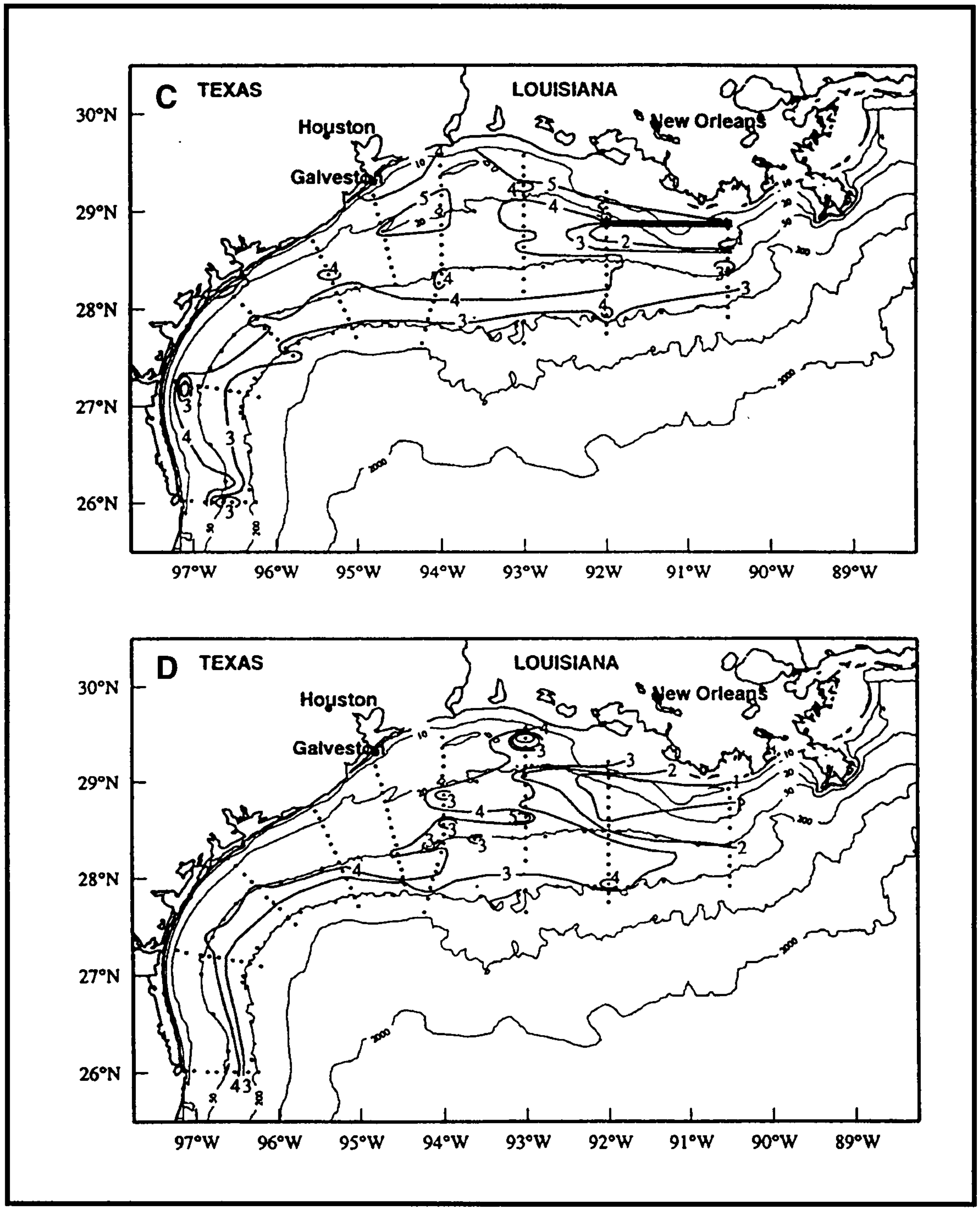

Figure 55. Horizontal contours of bottom dissolved oxygen concentrations (ml/l) in: (C) spring (April/May 1993; top panel) and (D) summer (July/August 1993; bottom panel).

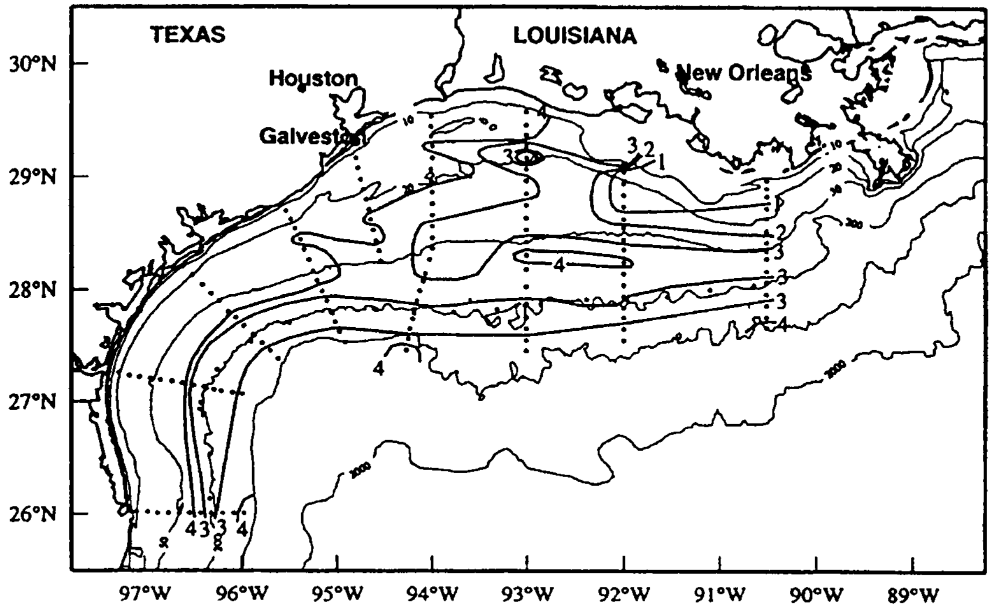

Figure 56. Horizontal contours of bottom dissolved oxygen concentrations (ml/l) in: summer (July/August 1994).

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U.S. Geological Survey
Biological Resources Division

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 responsibility includes fostering the sound use of our lands 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 enjoyment of live 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.

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