OCS Study
MMS 99-0049

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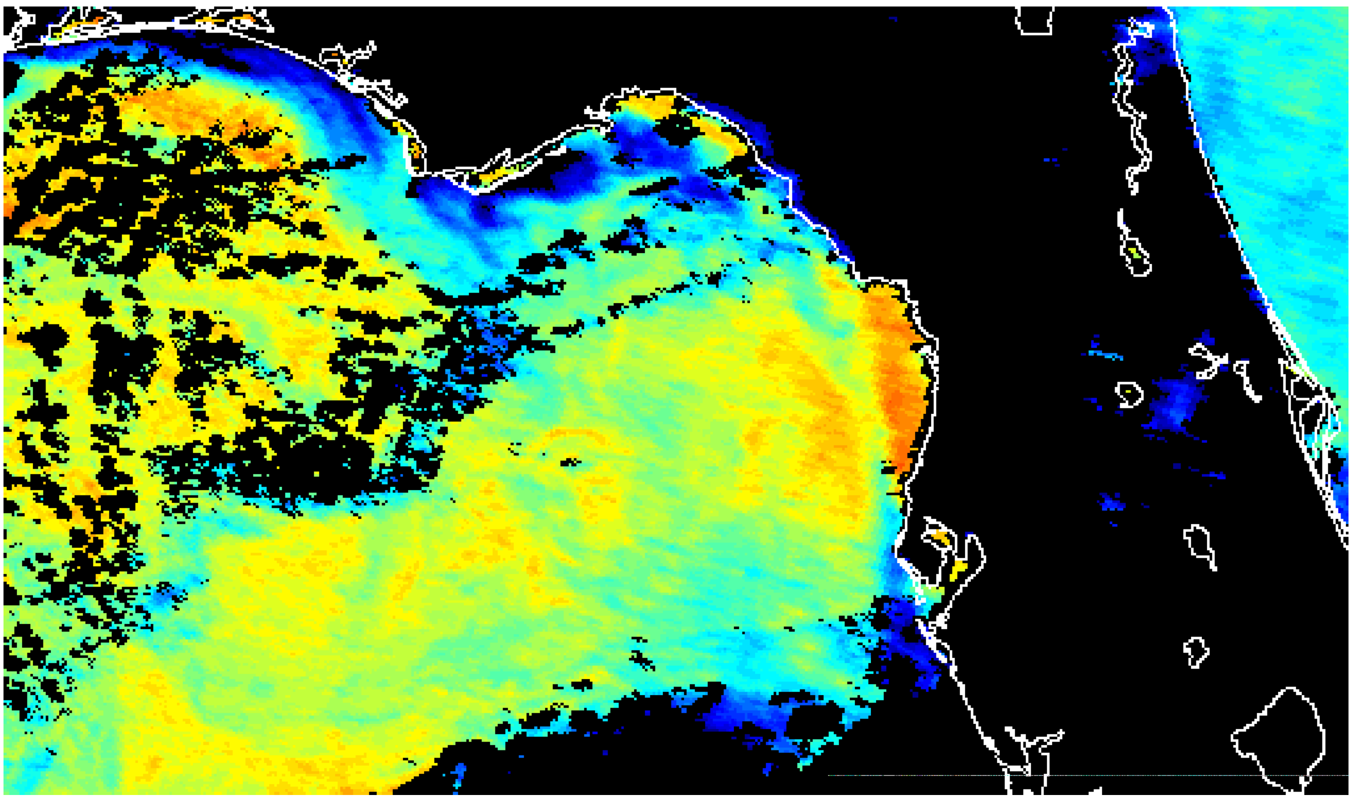
Final Report



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

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Coastal Upwelling and Mass Mortalities of Fishes and Invertebratesin the Northeastern Gulf of Mexico during Spring and Summer 1998

Final Report

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COVER

The cover, an AVHRR satellite image, shows a band of cool (blue color) upwelled water over the nearshore region of the northeastern Gulf of Mexico during May 24, 1998. Image courtesy of Dr. Frank Muller-Karger of University of South Florida, St. Petersburg, Florida.

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ABSTRACT

Climatic conditions associated with an El Niño event in summer of 1998 resulted in upwelling favorable winds, with higher than usual rainfall and river discharge of local rivers. This event was accompanied by unseasonably cooler water temperatures and elevated concentration of nutrients in the shelf of the northeastern Gulf of Mexico. Dense algal blooms were observed in response to upwelling and nutrient availability. Freshwater and the near-bottom cool dense waters created a highly stratified water column that suppressed vertical mixing and aeration of the bottom layer. Sinking dead algae and high biological oxygen demand, in combination with the stable water column led to near anoxic conditions over the mid-shelf bottom. Mass mortalities of fishes and invertebrates were observed in the region during this event, probably as a result of low oxygen. While certain climatic features were unusual, the area's prevailing oceanographic regime was neither unusual nor anomalous. Major long-term consequences of the upwelling event are expected to be relatively minor.

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Introduction

A widespread, protracted period of coastal upwelling occurred in the northeastern Gulf of Mexico (NEGOM) during spring and summer 1998. During this upwelling event, dense algal blooms and mass mortalities of fishes and invertebrates occurred from shore to depths of about 35 m in the central Florida Panhandle (Figure 1). This report presents a synthesis of available information and briefly summarizes climatic and oceanic conditions during the spring and summer 1998. We suggest possible causes and proximate biological consequences of upwelling in the NEGOM area.

Figure 1. Area affected by the cold water event in the northeastern Gulf of Mexico. Stations A-1, C-1, D-1, and E-1 represent DeSoto Canyon moorings along the 100 m isobath.

Biological Observations

From mid to late May, commercial divers reported mass mortalities of fishes and invertebrates on wrecks and reefs at depths of 10-35 m (the limit of diver excursions) in a region approximately 20 km east and west of Panama City and 3-7 km offshore (Fitzhugh, pers. comm.) apparently coincident with upwelling. At about the same time fishers reported blue runners (*Caranx fusus* or *C. crysos*) and vermilion snappers (*Rhomboplites aurorubens*) floating on the surface offshore Panama City. According to commercial divers, fishers and professional biologists, the areal and depth distribution of dead marine animals closely approximated the distribution of cool water which moved on and offshore on the surface, or near the bottom. The presence of warm near-surface water over cool water created a strong thermocline reported to occur at depths of 3-12 m. Table 1 presents a time line of this and other biological events in the NEGOM which are discussed below.

On 8 June, following a period of offshore winds and nearshore upwelling (Nowlin et al., in press), a dense population of a cool water-tolerant filamentous red alga, *Heterosiphonia gibbesii* (Moncreiff, *fide* Shaffer, pers. comm.) was reported along and offshore Panama City beaches. Concentrations of *Heterosiphonia* appeared to move on- and offshore with cool water at irregular intervals, and reports of thick mats of algae in the water column and on the bottom continued until 12 July. After 12 July, concentrations of *Heterosiphonia* markedly decreased when the population died off or was cleared from the area by winds and currents, although algae continued to wash on beaches episodically the remainder of the summer. Accumulations of algae in St. Andrew Pass, on area beaches, and in coastal waters were usually associated with dead fish and invertebrates (Shaffer, pers. comm.).

On 25 June, large numbers of dead fishes and invertebrates were reported on reefs off Destin in water depths of 18-21 m. At a depth of about 12 m "colder than normal" (normal T ~25°C) water was encountered, and currents were reported to be eastward. On 1 July, National Marine Fisheries Service (NMFS) divers reported a strong thermocline at 4.5-7.5 m, in water 14 m deep in St. Andrew Pass. Visibility at the bottom was reduced to a few meters by floc and rafts of what appeared to be green algae. At the surface and at 7.5 m depth, respectively (the length of the Hydrolab cable), temperatures were 29.0 and 21.4° C; salinities were 32.8 and 35.3; and dissolved oxygen concentrations were 5.91 and 0.37 mg·L^{-1}. NMFS divers reported that all of the organisms seen below 6 m were dead except for crabs, which were moribund. Above the thermocline, fishes generally associated with deeper water or bottom habitats were seen (Table 2). At 14 m depth, bottom water temperature, salinity, and dissolved oxygen concentration were, respectively, 19° C, 35.3, and 0.37 mg·L^{-1}.
During low tides on 1-2 July, NMFS biologists observed distressed fish in St. Andrew State Recreation Area tidal pools; dead juvenile flounders, crabs and lethargic fishes inside the St. Andrew Pass jetties; and dead eels, burrfish, cowfish, crabs, starfish and sea cucumbers outside the pass, and on area beaches (Table 2). Water at the beaches was characterized as green and thick with algae. Mass mortalities did not recur (or were not reported) in the Panama City-Destin area during 3-6 July, and nearshore Gulf waters were reported to be clear and well mixed, with reduced algal densities. While fishkills were not reported during this four day period, large schools of lethargic fish (Spanish mackerel, "baitfish" and stingrays) were seen in the shallows at Destin Pass.

During the period 26 June-12 July, distressed, moribund and dead fishes and invertebrates were observed from the intertidal zone to about 30 m depth in the St. Andrew Bay-Destin region. Deepwater animals were observed at the surface offshore and in shallow water near shore during this period. Algal densities were observed to be much higher than usual. From 7-14 July, water temperatures at Panama City beaches varied between 18-20° C. Cool water and mass mortalities — similar in magnitude and species composition to those of 1-2 July, recurred in the Destin-Panama City area from 7-9 July, and fishers reported that highly stratified water, with currents setting to the east, extended 24 km offshore.

Table 1. Time line of events in the northeastern Gulf of Mexico from May to July, 1998.

Date	Observations	Location
May 15-31	Mass mortalities of fishes and invertebrates in 10-35 m. Blue runners and vermilion snapers floating in surface off Panama City	East of Panama City
June 8-12	Red alga (*Heterosiphonia*) bloom	Panama City-St. Andrew Pass
June 25	Dead fishes and invertebrates in 18-21 m	Off Destin
July 1	Strong thermocline (5-6 m) and dead organisms below it. Deepwater fishes above it.	St. Andrew Pass
July 1-2	Distressed fish reports	St. Andrew State Recreation Area
July 3-6	Lethargic fishes	Destin Pass
July 7-9	Mass mortalities of fishes	Destin-Panama City
July 10	Dead crabs; jellyfish and shrimp	Pensacola
	Small flounders, crabs, and rock shrimp swimming on surface.	New Pass
July 12	Crabs come ashore; cold water band 24-40 km long	Destin Ochlockonee River to Pensacola
July 20-22	Cool water band	Gulf Shores, Alabama
July 24	Event ends	

Table 2. Fishes and invertebrate groups reported by various observers to be either dead (D) or visibly distressed (S). No systematic collections were made, and the list is conservative. A question mark following a designation means that the most common group is supposed. Common names are used when identification of the species was not verified.

Fishes

Batrachoididae

Gulf toadfish, *Opsanus beta* (D/S)

Bothidae

bay whiff, *Citharichthys spilopterus* (D)

dusky flounder, *Syacium papillosum* (D)

fringed flounder, *Etropus crossotus* (D)

Gulf flounder, *Paralichthys* albigutta (D/S)

Carangidae

blue runner, *Caranx crysos* (D)

leatherjacket, *Oligoplites saurus* (D)

lookdown, *Selene vomer* (S)

round scad (cigarfish), *Decapterus punctatus* (D)

Carcharhinidae (?)

sharks (D)

Dasyatidae

stingray, *Dasyatis* sp. (S)

Diodontidae

striped burrfish, *Chilomycterus schoepfi* (D)

Haemulidae

white grunt, *Haemulon plumieri* (D)

French grunt, *Haemulon flavolineatum* (D)

pigfish, *Orthopristias chrysoptera* (D)

Labridae

pearly razorfish, *Hemipteronotus novacula* (D)

unidentified wrasses (D)

Lutjanidae

vermilion snapper, *Rhomboplites aurorubens* (D)

Narcinidae

lesser electric ray, *Narcine brasiliensis* (D/S)

Ogcocephalidae

batfish (D)

Ostraciidae

cowfish, *Lactophrys* sp. (D)

Ophichthidae (?)

eel (D)

Ophidiidae

bearded brotula, *Brotula barbata* (D)

Rajidae

skate, *Raja* sp. (D/S)

Scaridae

parrotfish (S)

Sciaenidae

red drum, *Sciaenops ocellatus* (S)

Scombridae

Spanish mackerel, *Scomberomorus maculatus* (S)

Scorpaenidae

scorpionfish (S)

Serranidae

Gulf black seabass, *Centropristis striata* (D/S)

gag grouper, *Mycteroperca microlepis* (D/S)

soapfish, *Rypticus* spp. (D)

Sparidae

pinfish, *Lagodon rhomboides* (D)

spottail pinfish, *Diplodus holbrooki* (D)

Sphyraenidae

northern sennet, *Sphyraena borealis* (D)

Uranoscopidae

southern stargazer, *Astroscopus y-graecum* (D)

Trichiuridae

snake mackerel, *Gempylus serpens* (S)

Invertebrates

Annelida

- polychaetes (D)

Arthropoda (Crustacea: Decapoda)

- shrimp, *Penaeus* sp. (D/S)
- pink shrimp (S)
- “deepwater” crabs (S)
- calico crab, *Hepatus epheliticus* (D/S)
- portunid crabs (D/S)

Chordata (Urochordata: Ascidiacea)

- sea squirts (D)

Cnidaria

- jellyfish (D)

Echinodermata

- sea urchins (D)
- starfish (D)
- sea cucumbers (D)

Mollusca

- Bivalvia: clams
- Cephalopoda: *Octopus*
- Gastropoda: snails; nudibranchs

Porifera

- sponges (D)

On 10 July, the water column was weakly stratified (21° C on the surface, and 19° C on the bottom at 12-13 m) in St. Andrew Pass, and strongly stratified 1.6 km offshore (25° C on the surface and 19° C at 12-13 m). Fishers reported that bottom currents were from west-to-east 16-64 km offshore. On 10 July, dead crabs, jellyfish and sharks washed up on Pensacola beaches, but correlation between the deaths of these organisms and upwelling is uncertain.

On 11-12 July, a diver reported surface conditions over the wreck *Elvira* located 6.4 km south of Destin in water 26 m deep, to be relatively warm (~ 24° C) with 12 m visibility. At about 9 m depth a strong thermocline was encountered and the water was turbid, with visibility reduced to about two meters. At a depth of about 14 m, water temperatures 'evened out' near 18° C, and visibility increased to about 8 m. Numerous fishes were seen at 24 m, but these appeared to be sluggish. Similar conditions were encountered at the wreck *Louise* in 17 m of water, but "everything was dead — crabs, snails, clams, grouper, batfish, everything..."

On 12 July, fishers reported thousands of small flounders, rock shrimp, 'regular shrimp' and crabs swimming on the surface in the New Pass area at St. Andrew Bay. At Destin, live, deepwater crabs were observed to be coming ashore in large numbers. Water temperatures during this time were reported to be about 6.5-8.5° C colder than surrounding water in a 24-40 km wide band of water extending from the Ochlockonee River to Pensacola. Cold water extended from a depth of 6 m beneath the surface to the bottom, and was reported to be "black and murky."

From 13-16 July, charter boat captains and divers reported cool water inshore and warmer water offshore, with dense algae extending 9-10 km offshore. Surf temperatures were 21.7° C at Panama City, and 25° C at Pensacola. On a line from 8 km south of Panama City to the St. Joe sea buoy, surface and bottom (15 m) temperatures were 29.0° C and 20.5° C, respectively (FDEP, pers. comm.). On 17 July a commercial diver reported that large milky clouds of unknown composition were seen about 9-10 km off Destin Pass, and that similar substances were observed in the pass on 4 July.

From 20-22 July, nearshore water became clearer, and surface temperatures increased to 27° C in the Panama City area. Satellite images indicated that cool water had moved to the west, and on 19 July, large numbers of lesser electric rays were observed in clear, cool water along a 1.6 km-long stretch of beach at Gulf Shores, Alabama (Vittor, pers. comm.). On 23 July, NMFS reported that the cold water event was dissipating and that water clarity was improving. Coastal winds in the Panama City-Pensacola area shifted to the southeast on 24 July, sea surface temperatures increased to 29° C, and fishers reported good catches of sharks, Spanish and king mackerel, grouper, snapper and redfish from Panama City to St. Joe Bay.

From information collected by NMFS biologists and marine scientists from other state and federal agencies (Fitzhugh et al., pers. comm.), mass mortalities on reefs appeared to be catastrophic. Offshore areas were apparently affected at different times, as cool water moved from east to west. For example, mortalities on reefs 20 km east of Panama City occurred in May, while reefs west of Destin, but not as far west as Pensacola, apparently experienced mortalities in June-mid July. Reports of dead fish floating on the surface offshore were received throughout the ten week period, while dead organisms washed up on beaches in the Panama City area were most frequently observed between 27 June and 12 July.

In addition to reports of dead animals, numerous observations were made of fishes and invertebrates exhibiting symptoms associated with low oxygen stress. Benthic species (e.g., shrimp, crabs, some fishes) were seen swimming on the surface; lethargic fishes were observed below the thermocline; and shrimp and crabs were reported to be "crawling out of the water" — similar to "jubilees" that occur periodically in Mobile Bay due to low dissolved oxygen concentrations.

Climatic Conditions

Unusual climatic conditions in the NEGOM from winter 1997 through mid-summer 1998 were attributable to complex interactions between a strong 1997-1998 El Niño-Southern Oscillation (ENSO) and a persistent negative phase North Pacific Oscillation (NP) teleconnection pattern (U.S. Department of Commerce, 1998a). According to the U.S. Department of Commerce (1998b), from January to February 1998 the southeastern U.S. experienced warm, stormy weather and heavy rainfall in advance of a pronounced, ENSO-related high pressure ridge that extended over the tropics and subtropics. Rainfall amounts increased as the ridge moved north. Large volumes of fresh water associated with floods in southern Alabama, Georgia and Florida entered the northeastern Gulf of Mexico from Mobile Bay to the Big Bend region of the Florida Panhandle during the second and third weeks of March (U.S. Department of Commerce, 1998b and c). During this time, runoff was above the long-term (14-70 years) average flow at most local rivers (Figure 2).

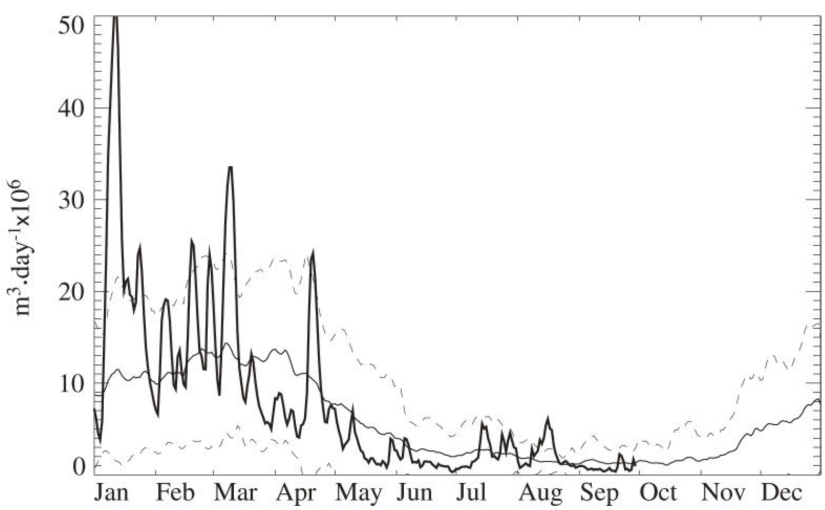

Figure 2. Tombigbee River discharge in 1998. Mean discharge (solid line) plus/minus one standard deviation (broken lines). From Nowlin et al. (1998).

Peak discharge volumes of the Mississippi River (30,583 $m^3 \cdot s^{-1}$) did not reach the Gulf until the third week of May, due to the northward reach of its much larger watershed (Miller, U.S. Army Corps of Engineers, pers. comm.). In late March, as the high pressure ridge moved northward into the south-central United States, warm, wet weather in the southeast was replaced by record-setting hot, dry conditions that persisted through late July, when the residual effects of the 1997-1998 El Niño on NEGOM climatic conditions dissipated (U.S. Department of Commerce, 1998b, c, and d). Coupled with atypical temperature and precipitation patterns, regional winds were also influenced by the ENSO-ridge system and, after its movement to the north, by a large atmospheric high pressure cell that dominated the Gulf of Mexico through most of July.

It is useful to compare descriptions of average (i.e., non-ENSO) winds in the NEGOM with those observed during spring-summer 1998. According to Blaha and Sturges (1981), winds are westward and relatively calm during spring, and without a dominant east-west component from May to July. Wolfe et al. (1988) and Tanner (1992) characterized prevailing spring-summer winds as northwestward or northeastward; and SAIC (1997) described late spring and summer winds as relatively calm and onshore, in agreement with Blaha and Sturges (1981).

Unlike these patterns, upper level and surface winds in the NEGOM were predominantly eastward and northeastward under the influence of the northern arm of a large atmospheric high pressure cell during spring-summer 1998 (Purdue University, 1998). Nowlin et al. (in press) described regional surface winds from April to August 1998 as generally eastward and onshore, with a strong offshore wind event at the end of the first week in June (Figure 3). Sturges (pers. comm.) found that the alongshore mean winds were predominantly eastward from January through mid-July, except for a month-long period of weak westward flow from mid-March through mid-April. Price (pers. comm.) analyzed NEGOM surface winds and demonstrated that May-June 1998 winds were more northeastward and eastward than in May-June 1997.

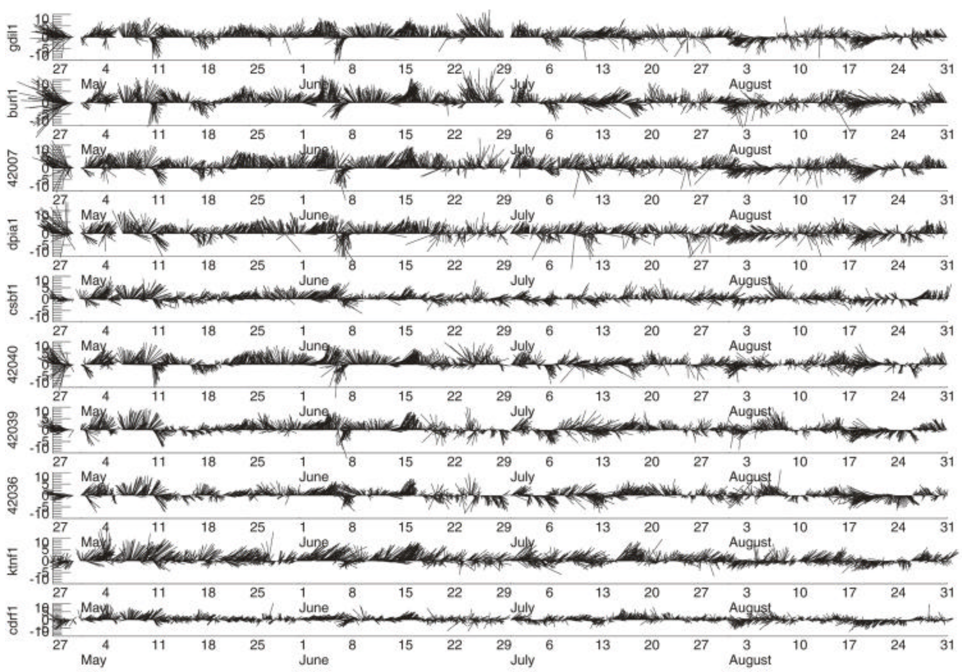

Figure 3. Wind vectors from stations around the northeastern Gulf of Mexico from May to August 1998. From Nowlin et al. (1998).

Oceanography

Information presented here was extracted from the results of an extensive investigation of hydrographic conditions and their evolution in the NEGOM from early April to early August 1998 (Nowlin et al., in press). A complete dataset and detailed analyses are found in Nowlin et al. (1998).

In a search for evidence of upwelling prior to cruise N2 in May, Nowlin et al. (1998) examined a time series of near-bottom temperature records from four moorings located near the 100 m isobath in the NEGOM (Figure 1). From west to east, mooring locations A-E were located, respectively, southeast of the Chandeleur Islands, south of Pensacola Bay, southwest of Choctawhatchee Bay, and southwest of

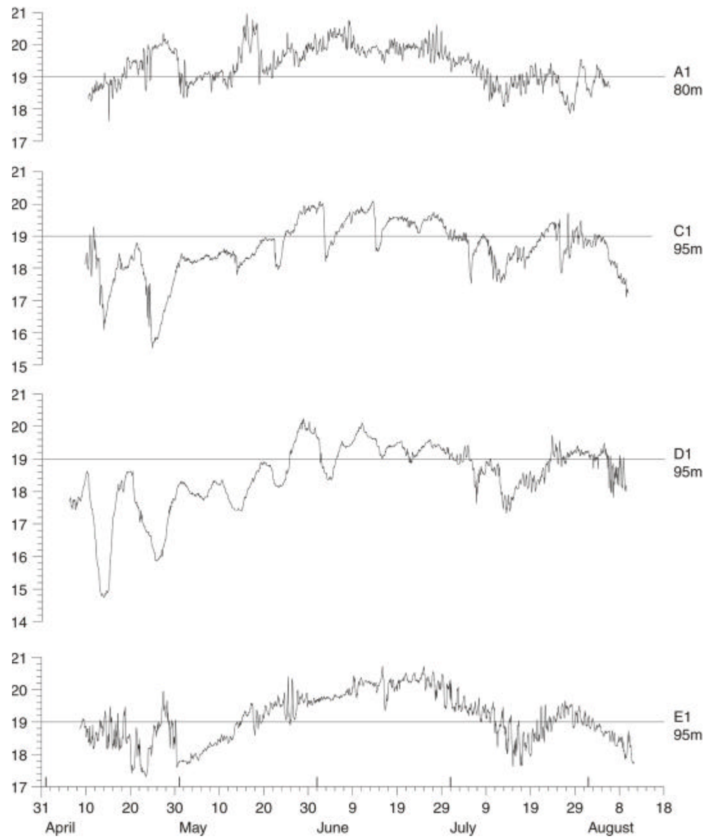

Figure 4. Near bottom temperature times series from the DeSoto Canyon stations. From Nowlin et al. (1998).

St. Andrew Bay, at the head of DeSoto Canyon (SAIC, 1998). Temperature records indicated that two pulses of cool bottom water in April at moorings C and D were followed some ten days later by a cool water intrusion at mooring E. There was no evidence of cool water at 100 m depths at mooring A during March or April. Cool water at moorings C, D, and E in April apparently "set the stage" for more extensive onwelling observed during cruise N2 in May.

The sea surface height anomaly (SSHA) field from April-August indicated the presence of a small anticyclone over DeSoto Canyon on 15 April. By 29 April, this feature had strengthened, and by 13 May had coalesced with a second anticyclone that translated northwest from its earlier position west of Tampa (Figure 5). By 15 July the anticyclone over DeSoto Canyon strengthed to a dynamic height > 20 cm, assumed an east-west orientation and by 22 July connected with a larger anticyclone to the south. After 22 July (at about the time when upwelling, mortalities and algal blooms off Panama City stopped), connections between the northern and southern anticyclones weakened and diminished in size. On 19 August a single anticyclone was located near the head of DeSoto Canyon.

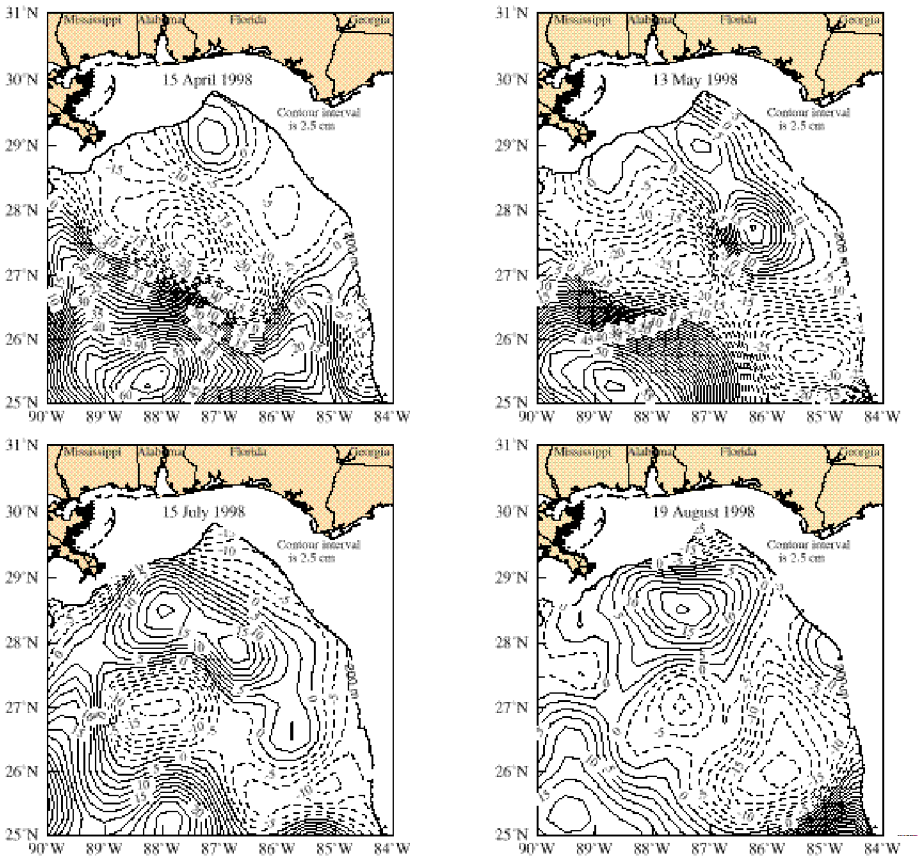

Figure 5. Sea surface height on the northeast Gulf of Mexico from April to August 1998. From Nowlin et al. (1998).

Acoustic Doppler current profiler (ADCP) measurements during cruise N2 confirmed SSHA observations, and established that currents associated with the anticyclone located over DeSoto Canyon (Figure 6), were along-isobath on the northern edge of the canyon at speeds of 10-25 cm·s^{-1}. The flow of deep water was shoreward along the sides of the canyon and in the bottom Ekman layer. Cool water penetrated closest to shore near the head of the canyon.

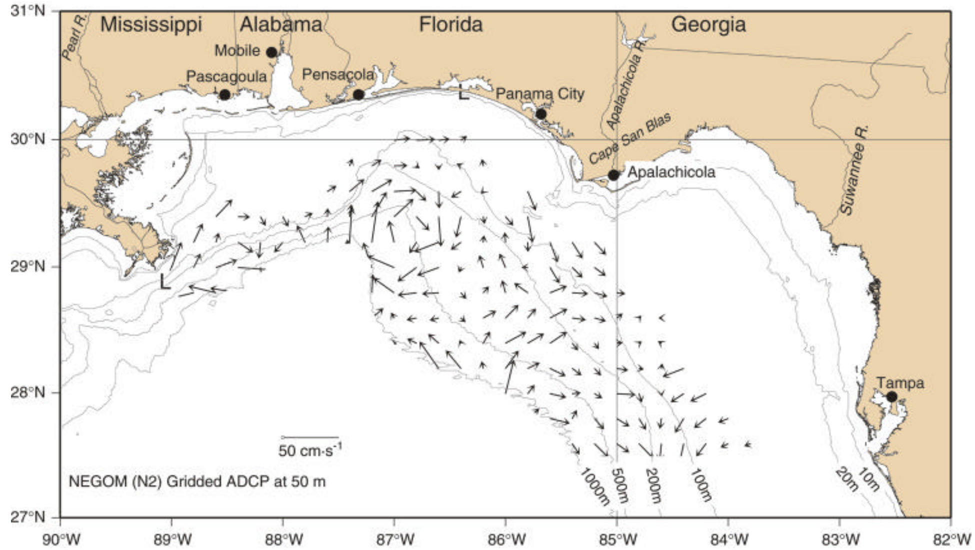

Figure 6. Acoustic Doppler Current Profiler vectors at 50 m from May 5-16, 1998. From Nowlin et al. (1998).

While cool water was not observed over SAIC's 100 m isobath moorings A or B in April, clear evidence was found that onshore, near-bottom flow reached the 10 m isobath at most stations west of Cape San Blas prior to the N2 cruise in May (see Nowlin et al., in press). Bottom water did not penetrate to these shallow depths at stations southeast of Cape San Blas. It is of interest to note that the presence of cool bottom water on the innershelf west of Cape San Blas occurred as much as a month before the first reports of mass mortalities in the region, and prior to the time AVHRR imagery detected cool water on the surface. Warm temperatures in spring, enhanced by fresh water from local river sources on the surface and cool water near the bottom resulted in a stable water column with the strongest pycnocline west of Cape San Blas and east of Mobile Bay — in the region generally corresponding to the distribution of depressed dissolved oxygen concentrations (Figure 7).

Nowlin et al. (in press) observed that the distribution of fresh surface water in May occurred inshore on N2 transect lines 1 and 2 west of Mobile Bay (Fig. 1 in Nowlin et al., in press), and offshore on transects 3-7, in the region south southeast of Mobile Bay to southwest of Cape San Blas. Local rivers were suggested to be the source of fresh water observed at western, inshore stations, while the presence of fresh water on the surface offshore, "could have been caused by surface water moving offshore due to nearshore upwelling or by advection from the west due to the anticyclonic circulation over DeSoto Canyon." (Nowlin et al., in press). In early

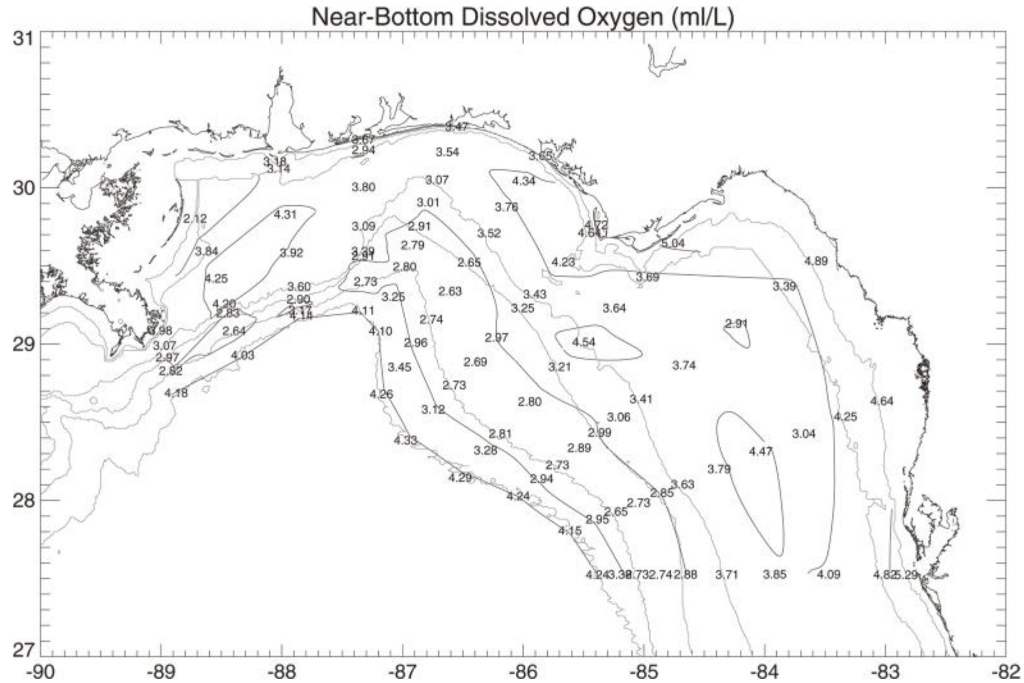

Figure 7. Near-bottom dissolved oxygen from May 5-16, 1998. From Nowlin et al. (1998).

June, a cool event lasting several weeks was observed at meteorological stations located in Mississippi Sound and at Dauphin Island. The presence of cool water (temperature decline of ~5°C) observed at these locations by Nowlin et al. (1998) occurred soon after peak discharges from the Mississippi River, as noted earlier. The maximum eastward extent of the Mississippi River plume occurs during eastward winds (Walker, 1994), suggesting that the source of cool water observed in June may also have had a riverine source.

Nowlin et al. (in press) reported transmissivity at 660 nm wavelength was at least 80 to greater than 90% in nearshore bottom water from Pensacola to Tampa — evidence that offshore water, low in chlorophyll, upwelled onto the shallow shelf east of Mobile Bay. West of transect line 4, off Pensacola, percent light transmission decreased inshore and toward the surface.

According to Nowlin et al. (in press), nutrient concentrations appeared to be elevated at inner and midshelf locations where cooler upwelled water was observed. High nitrate concentrations were associated with depressed oxygen concentrations at these locations.

Discussion

The seasonal evolution of environmental features in northern portions of the NEGOM from spring through mid-summer are, with some variation in timing, due to interannual variation in climate and ocean conditions, predictable sequelae of the sun's poleward progression. In late spring, air and sea surface temperatures begin a warming trend that continues through mid- to late August. A pycnocline develops and strengthens with increasing surface temperatures and winter-spring discharges of fresh water from rivers and estuaries. By early summer, water below the pycnocline is isolated from the mixed layer, and oxygen replenishment occurs largely by diffusion as turbulent mixing decreases with the late spring-summer reduction of frontal passages and strong winds. This sequence of events is similar to that associated with hypoxia in the Louisiana shelf (Wiseman et al., 1994). Prevailing spring and summer winds in coastal regions of the NEGOM are northerly, easterly, southerly or nearly calm (Blaha and Sturges, 1981; SAIC, 1997), depending on the period of record and distribution of stations selected for analysis. Prevailing westerly winds (i.e., to the east), as observed through most of the period from January through late July 1998, are uncommon in the NEGOM.

In addition to unusual winds, precipitation patterns during the first seven months of 1998 were atypical with respect to the 104 year period of record. Above average volumes of fresh water entered east-central portions of the NEGOM throughout winter, and a large, days-long "pulse" of fresh water from heavy rains in coastal watersheds reached this region of the Gulf in mid-March. It is likely that nutrient loading in shelf waters increased during the period of high river runoff and estuarine flushing. Rainfall ended after mid-March, and unusually warm, dry weather dominated eastern portions of the NEGOM until late July. With increasing temperatures, the cessation of storms and greatly diminished discharges of fresh water, a strong pycnocline may have developed in NEGOM shelf waters in late March or April, a month or more earlier than the seasonal norm.

Unusual climatic conditions were temporally correlated with, but probably causally unrelated to anticyclonic ocean features in the NEGOM described by Nowlin et al. (in press). As described by these authors, clockwise circulation and cool water upwelling were forced by an anticyclone located over DeSoto Canyon during the period of interest from April through July 1998. Nowlin et al. (in press) demonstrated that widespread upwelling occurred prior to their 5-16 May cruise, with the penetration of cool, near-bottom water to, or possibly inshore of the 10 m isobath on much of the shelf between Mississippi Sound and Cape San Blas. The maximum penetration of cool bottom water during the first half of May and in mid-July occurred near the head of the DeSoto Canyon. Reports of unusually cool water nearshore and observations of distressed or dead marine organisms suggest that pulses of cool water also penetrated to innershelf depths after mid-May, in June and in early July.

Nowlin et al. (in press) presented clear evidence of upwelling prior to early May, however AVHRR satellite images of sea surface temperatures indicate that upwelled water did not reach the surface in nearshore shelf waters until about 11-12 May, after which it was detected (with considerable temporal and areal variation), between Mississippi Sound and the southern Big Bend region through 18-20 July. Remote sensing (Muller-Karger, in press) supported by observations of commercial divers suggests that upwelling was strong and persistent west of Cape San Blas and east of Pensacola Bay, generally corresponding to the region where mass mortalities occurred and ecological impacts were most pronounced. Ecological conditions were less affected east and west of what appears to have been the central, or core upwelling area.

Strong innershelf upwelling occurred prior to cruise N2 in May, several weeks before mass mortalities were first reported. Because cause and effect between upwelling and mass mortalities are uncertain, speculative and non-mutually exclusive explanations for the weeks-long lag between upwelling and mass mortalities are offered, with implicit caveats. First, it is possible that dissolved oxygen concentrations in upwelled DeSoto Canyon water were higher in April and mid-May than during the last two weeks of May. Dense concentrations of the tropical, cool water-tolerant alga, *Heterosiphonia* cf. *gibbesii* (see Pakker et al., 1995) were not observed until late May-early June, within the time frame of mass mortality events on reefs off Panama City. The source of *Heterosiphonia* is not known, but a propagule of some size may have been transported onto the shelf by anticyclonic currents described earlier. According to Nowlin et al. (in press), chlorophyll concentrations beneath the pycnocline were low (80 to >90% transmission at 660 nm) suggesting that the algal population occupied and increased in the upper layer. It appears that *Heterosiphonia* physiological tolerance to cool water is greater than that of the normal "June grass" bloom of *Cladophora*, a warm water alga. As nutrients in the upper layer were depleted by growth of the algal bloom which co-occurred with blooms of non-toxic dinoflagellates and other phytoplankters, the *Heterosiphonia* population began to die, sank beneath the pycnocline, and contributed to a positive feedback loop of increasing biological oxygen demand (BOD) and decreasing dissolved oxygen concentrations. Wiseman et al. (1997) demonstrated the strong relationship between hypoxia and stratification. Evidence supporting very low dissolved oxygen concentrations is weak, and based on one credible measurement. Hypoxic oxygen concentrations ($\leq 2\ mg \cdot L^{-1}$) were not encountered by Nowlin et al. (1998), although concentrations near 3 mgL^{-1} were measured during cruise N2 in early May. Mass mortalities attributed to low dissolved oxygen concentrations also occurred after cruise N2, suggesting that hypoxic or anoxic conditions also occurred after mid May. For this view to have merit, it must be assumed that hypoxia or anoxia developed rapidly — not only in the benthic boundary layer, but a sufficient distance above the bottom to account for the vertical reach of wrecks and reefs. Under a strong pycnocline it may be possible that respiration in resident benthic communities, coupled with the consumption of oxygen by microbial decomposers, could have been great enough to rapidly lower dissolved oxygen concentrations to levels stressful or fatal to marine organisms. Rabalais et al. (1994) states that hypoxia could develop in the lower water column in days, weeks, or months.

A second speculation is coupled with the first. Elevated nutrient concentrations in upwelled water were observed at inner and midshelf depths offshore St. Andrew Bay, Choctawhatchee Bay and Santa Rosa Sound, where organically rich sediments and high nutrient levels have been well documented (SAIC, 1997). It is possible that Hurricanes Allison, Erin and Opal, which passed over these estuaries in 1995, translocated large amounts of their sediments to the shelf (see Isphording et al., 1987). With the additional flushing of nutrients and organically-rich sediments during flood conditions in mid-March 1998, chemical oxygen demand (COD), in addition to an increased biological oxygen demand associated with algal decomposition, may have consumed much of the oxygen from upwelling water as it moved shoreward.

Other, somewhat less convoluted explanations are proposed. These suggest that: (1) Hypoxic ($< 2\ mg \cdot L^{-1}$) or anoxic water believed to be responsible for mass mortalities from mid-May through early July may not have originated in DeSoto Canyon, but advected into the region from the west; or (2) Water from DeSoto Canyon upwelled onto the shelf (but not to the surface) in April, where it remained as a relatively cool bottom layer beneath a strong pycnocline. During succeeding weeks (until about mid-May) dissolved oxygen in the relic water mass was gradually depleted as a result of high BOD/COD demand. It is difficult to attribute mass mortalities to causes other than oxygen stress. Toxic dinoflagellates were not present in abundance, and results of toxic screening by the Florida Marine Research Institute were negative (FMRI, pers. comm.).

Although many marine organisms died during the upwelling event, systematic sampling was not possible, and neither the numbers of organisms nor the species involved can be known or approximated with confidence. Divers tend to avoid reefs known to have suffered extensive mortalities, and follow-on observations of benthic, reef-associated organisms, if made, are unknown to the authors. In late July, however, pelagic fishes in the vicinity of reefs were reported to appear normal in abundance and diversity.

Summary and Conclusions

Atypical climatic conditions in portions of the NEGOM, including eastward winds and early formation of a pycnocline were related to the 1997-1998 ENSO and atmospheric dynamic conditions (ENSO-NP). Eastward and shoreward shelf currents and the upwelling of deep water from DeSoto Canyon were attributable to a persistent anticyclone located over the canyon. Correlations but not causation between climate and ocean conditions were found. Mass mortalities of pelagic and benthic organisms in the Panama City-Destin region are attributed to putative hypoxic, or perhaps anoxic conditions caused by a large biological oxygen demand. BOD was clearly exacerbated by a dense algal population of a tropical, but cool water-tolerant species of red alga, *Heterosiphonia* cf. *gibbesii*. Resuspension of nutrient-rich sediments deposited on the shelf by floods in 1998, and by hurricanes in 1995 may have contributed to increased total oxygen demand. Correlations but not causation between cool water upwelling, hypoxia, anoxia, and mass mortalities were found. The ecological consequences of dramatic, but relatively short-term mass mortalities in populations of adult benthic and pelagic animals, and of meroplankters recruiting to shelf habitats could not be adduced from the information available. Major long-term consequences of the upwelling event are expected to be relatively minor.

It is important to notice that oceanographic conditions (e.g. stratification) associated with this event are similar to those associated with hypoxia events in the Louisiana shelf. While in Louisiana the summer pynocline is essentially a halocline (Wiseman et al., 1994), the 1998 NEGOM pynocline resulted from salinity differences due to higher than usual runoff plus temperature differences due to atypical cool-upwelled waters. The nutrient pulse from the high river discharge and/or sediment resuspension created the algal bloom, driving the high BOD/COD and the ensuing hypoxic conditions.

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The Department of the Interior Mission

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

The Minerals Management Service Mission

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

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

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

Minerals Management Service
Gulf of Mexico OCS Region

U.S. Department of the Interior
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Managing America's offshore energy resources

Protecting America's coastal and marine environments