HYPOXIA IN LOUISIANA COASTAL WATERS DURING 1983: IMPLICATIONS FOR FISHERIES

MAURICE L. RENAUD[1]

ABSTRACT

Hypoxic bottom water (≤2.0 ppm dissolved oxygen) was present in shallow (9-15 m) waters south of central Louisiana in June and July 1983. It was patchy in distribution from south of Barataria Pass to south and west of Marsh Island. Data suggested that bottom water hypoxia did affect the abundance and distribution of shrimp and bottomfish. Offshore bottom water dissolved oxygen was significantly correlated with 1) combined catches of brown and white shrimp (r = 0.56, $P < 0.002$), 2) fish biomass (r = 0.56, $P < 0.001$), and 3) vertical density gradient (r = −0.73, $P < 0.001$). Several hypoxic stations were in regions designated as potentially hypoxic through a posteriori analysis of satellite data. *Micropogonius undulatus* was the dominant fish species nearshore and offshore. *Penaeus aztecus* and *P. setiferus* were sparsely distributed throughout the study area.

The presence of bottom water hypoxia (≤2.0 ppm dissolved oxygen) in the nearshore Gulf of Mexico is a common, recurring, and mostly seasonal (June-August) event. It is generally thought to be associated with temperature and salinity stratification initiated by freshwater runoff and with phytoplankton blooms during hot, calm weather (Fotheringham and Weissberg 1979; Bedinger et al. 1981; Comiskey and Farmer 1981; Turner and Allen 1982a, b; Boesch 1983; Leming and Stuntz 1984). Phytoplankton respiration and decomposition of sinking organic matter are major oxygen consuming processes. High oxygen demand of the organic load in freshwater runoff (Gallaway 1981) and lack of a direct oxygen replenishing mechanism (strong winds) in the presence of vertical stratification contribute to hypoxia formation (Harris et al. 1976; Ragan et al. 1978; Swanson and Sindermann 1979; Harper et al. 1981). Christmas (1973) and Boesch (1983) discussed possible nitrate pollution in rivers and coastal hypoxia. Boesch (1983) presented a brief history of hypoxia in the Gulf of Mexico and evaluated its causes and consequences. The extent to which any factor is involved with hypoxia formation is unknown.

Hypoxia in the Gulf of Mexico has been most noticeable in shallow (<20 m) Louisiana waters. It has been reported infrequently on the Texas shelf (Harper et al. 1981; Gallaway and Reitsema 1981). Low oxygen levels have also been measured east of the Mississippi River Delta inshore of barrier islands and in inland bays (May 1973; Christmas 1973) and offshore of Mobile Bay, AL (Turner and Allen 1982b). Abnormally high concentrations of moribund fish and crustaceans near the shoreline ("jubilees") in Alabama have also been linked to hypoxia (May 1973).

Considerable interest in hypoxia has been renewed by a less than average shrimp harvest in 1982 (Klima et al. 1983) and 1983[2]. In this paper I report the locations and extent of Louisiana coastal hypoxia in 1983 and discuss the interrelationships of fish and shrimp abundance and distribution with environmental parameters.

METHODS

Nearshore data were collected in a 7.3 m Aqua-Sport at a total of 56 stations from nine transects west of the Mississippi River Delta (long. 89°33′W to 90°14′W) from 1 to 16 June 1983 (Fig. 1). The transects, perpendicular to shore, ranged from 5 to 8 km in length and 1 to 16 m in depth. The six easternmost transects were sampled twice, with a sampling interval of 14 d. Shrimp and bottomfish were collected at 23 of 56 stations in 15-min tows with a 3.0 m box trawl. Towing speed was about 3 kn. Before each tow, water temperature, salinity, and dissolved oxygen concentration were recorded at 1 m depth intervals with a Hydrolab 8000. Hydrographic profiles were made at the remaining 33 stations.

An offshore study area extending from long.

[1]Southeast Fisheries Center Galveston Laboratory, National Marine Fisheries Service, NOAA, 4700 Avenue U, Galveston, TX 77550.

[2]1983 Gulf Coast Shrimp Data, NOAA, NMFS.

Manuscript accepted January 1985.
FISHERY BULLETIN: VOL. 84, NO. 1, 1986.

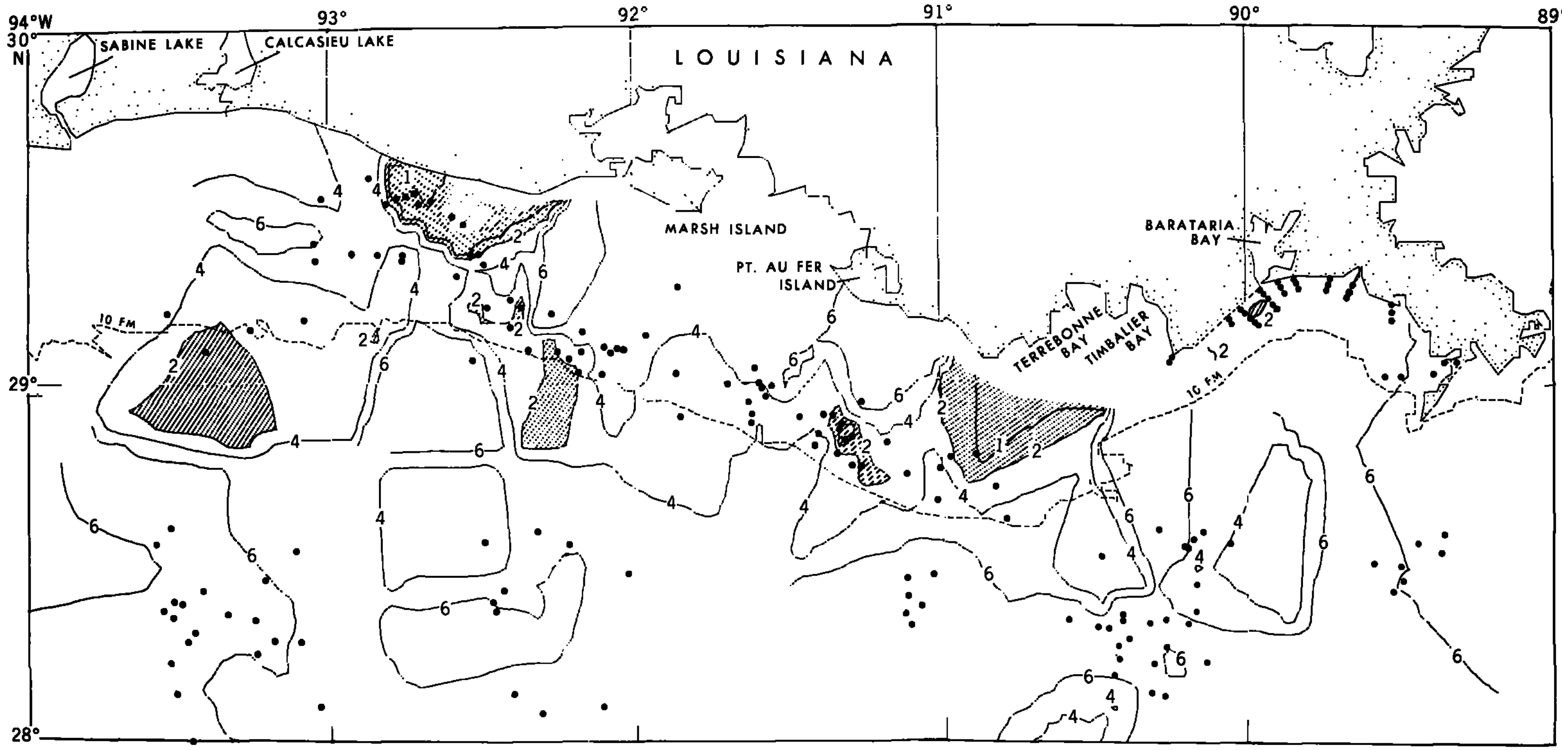

FIGURE 1.—Dissolved oxygen contours in Louisiana coastal waters, June-July 1983. Shaded portions represent dissolved oxygen levels ≤2.0 ppm; solid circles are station locations.

90°47′W to 93°02′W was sampled with a 24.4 m steel-hull commercial shrimp trawler from 30 June to 6 July 1983 (Fig. 1). Depth varied from 4 to 20 m and distance from shore ranged from 8 to 54 km. Shrimp and bottomfish were collected at 34 of 65 stations in 20-min tows with a 12.2 m semiballoon trawl. The same trawl was used as a midwater shrimp sampler above previously identified hypoxic water. Surface and bottom measurements of water temperature, salinity, and dissolved oxygen concentration were recorded before each tow. Water samples were collected with a Kemmerer bottle. Salinities were measured with a refractometer. Temperature and dissolved oxygen concentration were measured with a YSI Model 51-B. Surface and bottom hydrographic data were collected at the remaining 31 stations. The Southeast Area Monitoring and Assessment Program (SEAMAP)[3] personnel collected similar data off Louisiana in June 1983. SEAMAP dissolved oxygen data were included in the contour analyses.

The Harvard SYMAP program (Dougenik and Sheehan 1975), a Northwest Alaska Fisheries Center Contour Subroutine, and the Galveston Laboratory Generalized Mapping system were utilized to produce a map of dissolved oxygen contours off Louisiana. Koi[4] presents an indepth explanation of these contour mapping programs. Vertical density gradient of the water column, shrimp catch, and fish catch were regressed with bottom water dissolved oxygen concentration. A "best fit" line through the data was determined using the least squares concept.

Surface water temperature (°C) and chlorophyll content (mg/m^3) were measured off Louisiana by the Coastal Zone Color Scanner (CZCS) aboard the Nimbus-7 satellite. Personnel from the Mississippi Laboratories of the Southeast Fisheries Center, working at the National Space Technology Laboratories, Mississippi, used CZCS and "ground truth" field data to predict potentially hypoxic areas in coastal Louisiana waters.

RESULTS AND DISCUSSION

Regions of hypoxic bottom water have been detected along portions of the Texas-Louisiana coastline every summer from 1972 to 1983 (Harris et al. 1976; Ragan et al. 1978; Bedinger et al. 1981; Harper et al. 1981; Reitsema et al. 1982; Boesch 1983). Hypoxia was noted from 16 June to 6 July 1983. It was patchy in distribution and found mainly in 9 to 15 m depths from south of Barataria Pass to south and west of Marsh Island (Fig. 1).

A total of 34 fish and 11 invertebrate species were collected offshore. The Atlantic croaker, *Micropogonius undulatus*, and the Atlantic threadfin, *Polydactylus octonemus*, were the dominant bottomfish at 58% and 30% of the stations, respectively; Atlantic bumper, *Chloroscombrus chrysurus*, was the common pelagic. Brown shrimp, *Penaeus aztecus*; white shrimp, *P. setiferus*; mantis shrimp, *Squilla empusa*; and broken-back shrimp, *Trachypenaeus* sp., were the most common invertebrates collected, but in small quantities. Total crustacean catch was always <5.0 kg/h.

Bottom water dissolved oxygen concentration was significantly correlated with 1) fish biomass (r = 0.56, P < 0.001) (Fig. 2) and the number of brown and white shrimp present (r = 0.56, P < 0.002) (Fig. 3). Shrimp and bottomfish were generally absent from hypoxic stations. Atlantic croaker were not at stations with hypoxic bottomwater, and shrimp catches never exceeded 2 kg/h in the areas. Sea catfish, *Arisus felis*; butterfish, *Peprilus paru*; and Atlantic bumper were common in trawls at hypoxic sites. These were also the most abundant fish in mid-

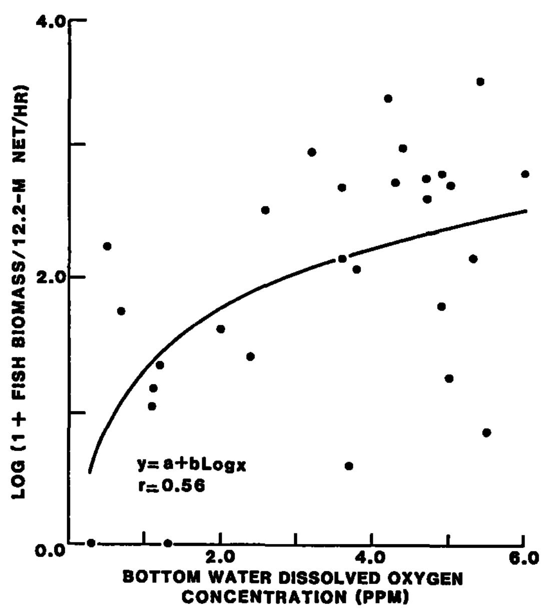

FIGURE 2.—Offshore fish biomass in relation to bottom water dissolved oxygen concentration.

[3]Southeast Area Monitoring and Assessment Program: a State-Federal cooperative research effort organized to assess the distribution and abundance of shrimp and bottomfish in the Gulf of Mexico.

[4]Koi, D. 1985. Generalized geographic mapping system. Unpubl. manuscr., 47 p. Southeast Fisheries Center Galveston Laboratory, National Marine Fisheries Service, NOAA, 4700 Avenue U, Galveston, TX 77550.

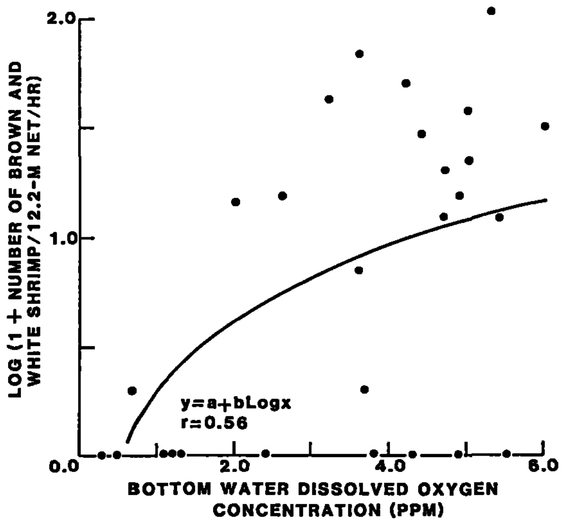

FIGURE 3.—Offshore shrimp abundance in relation to bottom water dissolved oxygen concentration.

water trawls above previously identified hypoxic areas. Therefore, it was concluded that they were captured from the upper water column as the trawl passed through it. Four brown shrimp, three lesser blue crabs, *Callinectes similus*, and one mantis shrimp were the only crustaceans captured in five midwater trawls. The relationship between shrimp and bottomfish abundance and distribution indicates that they do not pass through or over hypoxic water masses. Actual avoidance behavior in the field has not been documented.

Nearshore, a total of 20 fish and 5 invertebrate species were collected. Atlantic croaker was the dominant species. Brown shrimp were present in low numbers at most stations. White shrimp; blue crabs, *Callinectes sapidus*; lesser blue crabs; and sea bobs, *Xiphopenaeus* sp., were the only other crustaceans collected. A high variability in fish and shrimp abundance was probably due to the low fishing efficiency of the small net at the deeper nearshore stations. As a result, no significant correlation was present at nearshore stations between bottom water dissolved oxygen concentration and fish or shrimp abundance.

Vertical density stratification was present at both nearshore and offshore stations. Dissolved oxygen concentration and vertical density gradient were negatively correlated ($r = -0.73$, $P < 0.001$) (Fig. 4). This agrees with Leming and Stuntz (1984) who found a high correlation between bottom dissolved oxygen content and surface to bottom density gradients off Louisiana in 1982 ($r = -0.74$, $P < 0.001$). Offshore, the mean difference between surface and bottom dissolved oxygen was 6.4 ppm (standard error = 0.40) in hypoxic areas and 1.6 ppm (standard error = 0.08) in nonhypoxic areas. Temperature generally did not vary more than 2°C between the surface and bottom regardless of the area.

During the first week of July, 92% of the hypoxic stations were in areas predicted as potentially hypoxic through a posteriori analyses of remote sensing data. Hypoxic areas were characterized by surface water temperatures near 30°C, which agrees with Leming and Stuntz (1984). They discussed satellite data acquisition, its value in identifying and forecasting hypoxic regions in the Gulf of Mexico,

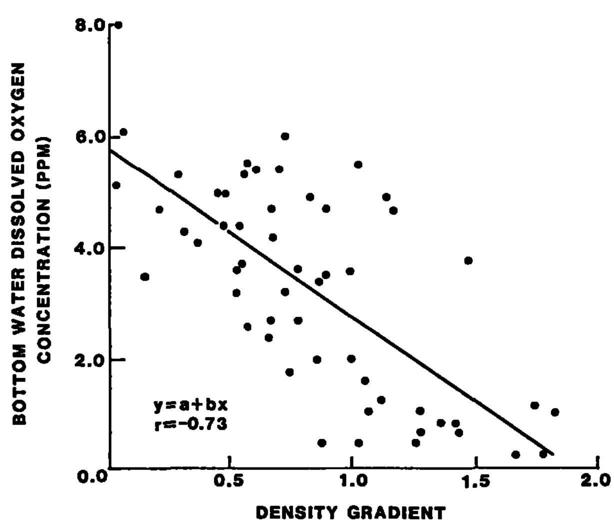

FIGURE 4.—Bottom water dissolved oxygen concentration in relation to vertical density gradient of the water column. Density gradient is expressed as (bottom sigma-t minus surface sigma-t)/depth.

nd its implications regarding shrimp management.

The effect of hypoxia on shrimp is not completely nderstood. It is possible that an extensive area of ypoxic bottom water can act as a physical barrier o juvenile shrimp migration offshore and to postarval migration into nursery grounds. Limited inirect evidence supports this hypothesis. Gazey et l. (1982) described a shrimp mark-release study in ouisiana. Extensive longshore and offshore movenent occurred before the recapture of the shrimp luring 1979, when hypoxia was not reported off ouisiana (Fig. 5). In 1978, when hypoxia was widepread along the Louisiana coastline (Fig. 6), shrimp lid not move comparable distances. It was possible hat hypoxia reduced shrimp movement into offshore vaters.

The most extensive occurrence of hypoxic bottom vater recorded in Louisiana coastal waters occurred rom May 1973 to May 1974 (Flowers et al. 1975; Ragan et al. 1978). It was widespread between Barataria and Timbalier Passes and extended up to 30 km offshore in some regions. Ragan et al. (1978) reported several areas to be anoxic. The duration and severity of this hypoxic condition may have had an mpact on the offshore brown shrimp fishery in 1973. Total brown shrimp catch and CPUE (catch per unit effort) in 1973 were significantly lower (paired *t*-test, $P < 0.05$) than in 1972 (fn. 2). Catch declined 36% (2.8 million kg) and the mean CPUE was reduced by 120 kg/vessel per d. Movement of juvenile brown shrimp to the offshore fishery occurs from May to August (Cook and Lindner 1970). Monthly catch and CPUE of brown shrimp from January through April 1973 did not differ from the same time period in 1972; however, catch and CPUE from May through December were significantly lower (paired *t*-test, $P < 0.01$) in 1973. Postlarval recruitment of brown shrimp occurs from January to May (Baxter and Renfro 1966). An interaction between hypoxia and postlarval recruitment in 1974 might have been responsible for the continued poor harvest of brown shrimp that year. Catch and CPUE were still significantly lower than in 1972 (paired *t*-test, $P < 0.05$). It was not until 1976 that brown shrimp catch surpassed the 1972 levels (Table 1). A decline in total shrimp catch of Louisiana in 1982 may have been related to a large region of hypoxic bottom water reported by Stuntz et al. (1982).

Although hypoxia has not been directly linked to declines in annual catch, its presence during critical

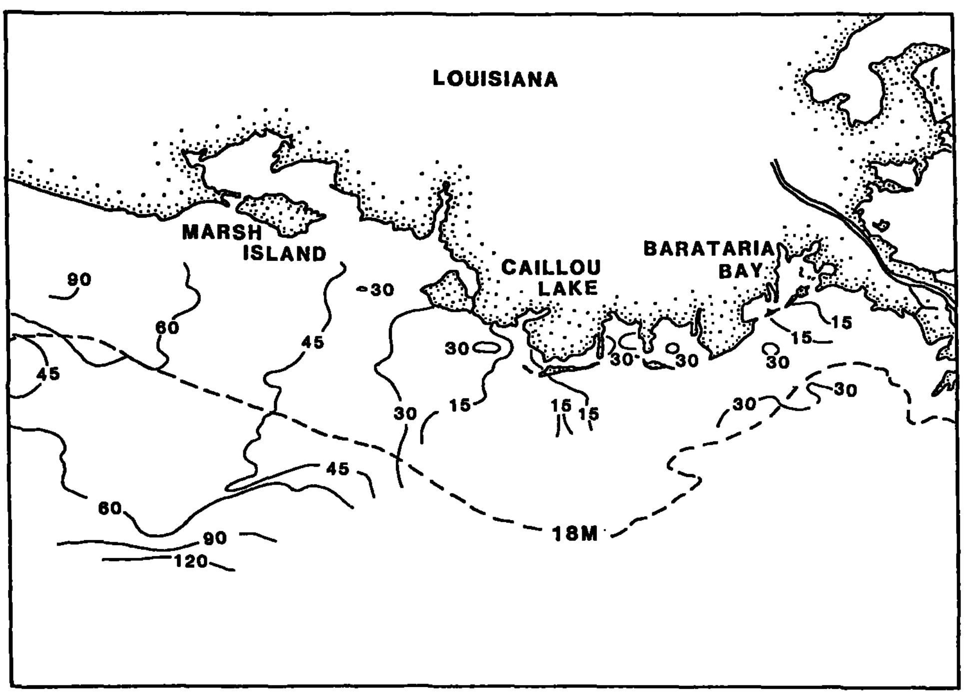

FIGURE 5.—Movement of tagged juvenile brown shrimp from Caillou Lake and Barataria Bay expressed as days at large before recapture (from Gazey et al. 1982). Shrimp were released in July 1979. Hypoxia was not documented off this coastal area in 1979.

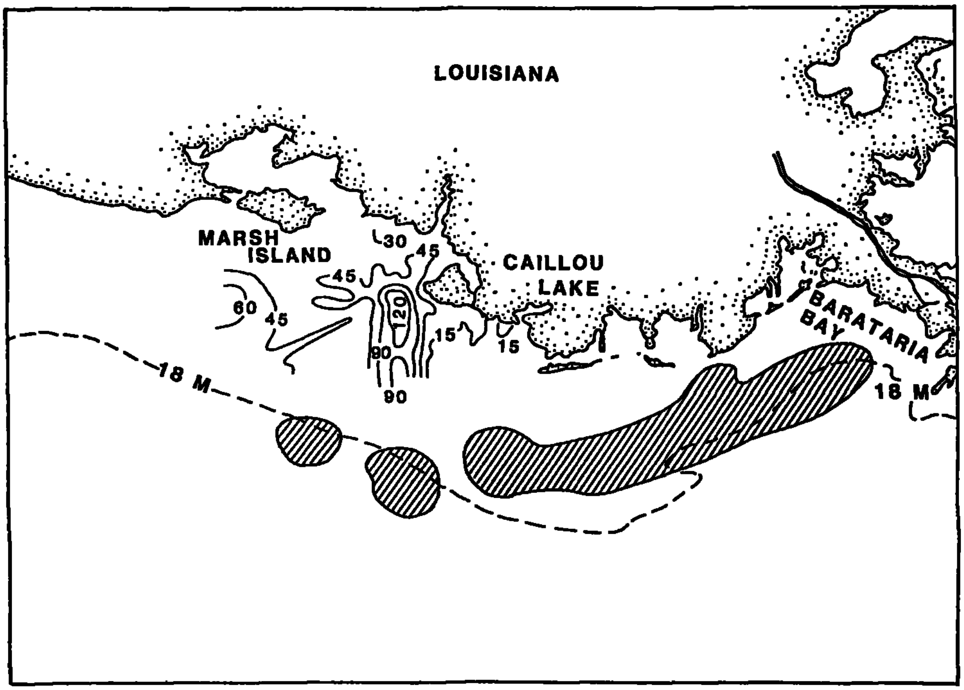

FIGURE 6.—Movement of tagged juvenile brown shrimp from Caillou Lake, expressed as days at large before recapture (from Gazey et al. 1982). Shrimp were released in June 1978. Regions of hypoxic bottom water, noted from June to August, are overlaid onto this map (Fotheringham and Weissberg 1979; Bedinger et al. 1981; Comiskey and Farmer 1981).

TABLE 1.—Louisiana brown shrimp catch data.

		1972	1973	1974	1975	1976	5-yr average
Catch per unit effort	Jan.-Apr.	190	216	180	196	208	198
(kg/vessel per d)	May-Aug.	383	225	249	296	348	300
	Sept.-Dec.	376	233	328	346	268	310
	Annual average	344	[1]223	[1]256	288	302	284
Catch	Jan.-Apr.	0.831	1.478	0.633	0.645	1.020	0.921
(millions of kg)	May-Aug.	4.529	2.630	2.702	2.112	5.966	3.588
	Sept.-Dec.	2.293	0.822	1.578	1.414	2.601	1.742
	Total	7.653	[1]4.930	[1]4.913	4.171	9.587	6.251
Effort	Jan.-Apr.	4,379	6,870	3,509	3,288	4,903	4,590
(24-h days fished)	May-Aug.	11,828	11,722	10,852	7,128	17,127	11,731
	Sept.-Dec.	6,361	3,528	4,805	4,083	9,715	5,698
	Total	22,568	22,120	19.166	14,499	31,745	22,020

[1]CPUE and catch data in 1973 and 1974 were significantly lower than that in 1972 (paired t-test, $P < 0.05$).

portions of the shrimp life cycle implicate it as a probable source of variation in annual shrimp yield. Support for this viewpoint has been documented in laboratory experiments which indicate that brown and white shrimp detect and avoid water with low oxygen levels.[5] Brown shrimp were the least tolerant of the two species. They avoided dissolved oxygen concentrations up to and including 2.0 ppm. White shrimp did not avoid oxygen levels higher than 1.5 ppm. Variable behavior was exhibited by both species at higher treatment levels. Total time (TT) spent in water with 1.5 ppm did not differ between species,

[5]Renaud, M. 1985. Detection and avoidance of oxygen depleted water by *Penaeus setiferus* and *Penaeus aztecus*. Unpubl. manuscr., 16 p. Southeast Fisheries Center Galveston Laboratory, National Marine Fisheries Service, NOAA, 4700 Avenue U, Galveston, TX 77550.

nor did their response time (RT), i.e., time taken to retreat into normal seawater. However, these measurements were significantly (t-test, $P < 0.001$) shorter for brown shrimp (TT = 6.2, RT = 3.8 min) versus white shrimp (TT = 20.0, RT = 6.2 min) when tested at 2.0 ppm. Behavioral responses of brown and white shrimp exposed to hypoxic water included 1) an initial increase in activity, 2) walking or swimming retreat, and 3) rapid eye movements. White shrimp also exhibited notable abdominal flexing, periods of exhaustion, and sometimes death. These three latter behaviors were not observed with brown shrimp. Dissolved oxygen levels tested are common along Louisiana's Gulf Coast during the summer and early fall. Therefore it is not unreasonable to assume that similar behavioral responses occur in nature.

Hypoxia in the New York Bight (Swanson and Sindermann 1979) had a severe impact on the commercial fisheries of sedentary species. Surf clam, *Spisula solidissima*; ocean quahog, *Arctica islandica*; and scallop, *Placopectin magellanicus*, abundance was reduced by 92%, 25%, and 12%, respectively, in the affected area. The response of recreational fish species, summer flounder, *Paralichthys dentatus*, and bluefish, *Pomatomus saltatrix*, to low oxygen levels was noted by changes in their distribution patterns during the hypoxic event. Temperature stratification, phytoplankton blooms, spoil deposition, and sewage treatment outflow were alleged major contributors to hypoxia formation in the New York Bight. It was concluded, however, that abnormal climatological and hydrological phenomena were responsible for this hypoxic event. Swanson and Sindermann (1979) stated that effective regulation of waste disposal into riverine and oceanic environments may control or restrict bottom water hypoxia formation.

Future research on the phenomenon of hypoxia should be centered on its predictability; remote sensing has potential in this area. Timely information dissemination on the extent and location of hypoxic areas would help fishermen to avoid areas where low catches might be anticipated or to harvest a crop before it dies or migrates.

ACKNOWLEDGMENTS

The author expresses his sincere appreciation to 1) the Lousiana Wildlife and Fisheries Department for providing NMFS personnel with services at their Grand Terre Island Marine Laboratory and at their Field Station in Caillou Lake; 2) the Gulf States Marine Fisheries Commission for access to the 1983 SEAMAP data; 3) David Trimm for this major contribution to data collection; 4) Dennis Koi for computer services and related software analyses, especially those relevant to contour mapping; 5) Frank Patella for acquisition and transformation of several years of Gulf coast shrimp data; 6) Tom Leming for satellite data; and 7) Beatrice Richardson for typing the manuscript.

LITERATURE CITED

BAXTER, K. N., AND W. C. RENFRO.
1966. Seasonal occurrence and size distribution of postlarval brown and white shrimp near Galveston, Texas, with notes on species identification. U.S. Fish Wildl. Serv., Fish. Bull. 66:149-158.

BEDINGER, C. A., R. E. CHILDERS, J. W. COOPER, K. T. KIMBALL, AND A. KWOK.
1981. Pollution fate and effect studies. *In* C. A. Bedinger (editor), Ecological investigations of petroleum production platforms in the central Gulf of Mexico, Vol. 1, Part 1, 53 p. Report to the Bureau of Land Management, New Orleans, LA, Contract No. AS551-CT8-17.

BOESCH, D. F.
1983. Implications of oxygen depletion on the continental shelf of the northern Gulf of Mexico. Coastal Ocean Pollut. Assess. News 2:25-28.

CHRISTMAS, J. Y. (editor).
1973. Cooperative Gulf of Mexico estuarine inventory and study, Mississippi: Phase I, area description, Phase II, hydrology, Phase II, sedimentology, Phase IV, biology. Gulf Coast Research Laboratory, Ocean Springs, MS, 434 p.

COMISKEY, C. E., AND T. A. FARMER (editors).
1981. Characterization of base-line oceanography for the Texoma region brine disposal sites. Vol. I. Final Report to U.S. Department of Energy, Strategic Petroleum Reserve Office, Wash., D.C., Contract No. DEAC01-774508788, 130 p.

COOK, H. L., AND M. J. LINDNER.
1970. Synopsis of biological data on the brown shrimp *Penaeus aztecus aztecus* Ives, 1891. *In* M. N. Mistakidis (editor), Proceedings of the World Scientific Conference on the Biology and Culture of Shrimps and Prawns, p. 1471-1497. FAO Fish. Rep. 57(4).

DOUGENIK, J. A., AND D. E. SHEEHAN.
1975. SYMAP User's Manual. Camera Stat of Bedford, Cambridge, MA, 187 p.

FLOWERS, C. W., W. T. MILLER, AND J. D. GANN.
1975. Water chemistry. *In* J. G. Gosselink, R. H. Miller, M. Hood, and L. M. Bahr (editors), Environmental assessment of a Louisiana offshore port and appertinent pipeline and storage facility. Vol. II, App. V, Sect. 1, 86 p. Final Report to Louisiana Offshore Oil Port, New Orleans, LA.

FOTHERINGHAM, N., AND G. H. WEISSBERG.
1979. Some causes, consequences and potential environmental impacts of oxygen depletion in the northern Gulf of Mexico. Proc. 11th Annu. Offshore Tech. Conf., April 30-May 3, 1979, 3611:2205-2208.

GALLAWAY, B. J.
1981. An ecosystem analysis of oil and gas development on the Texas-Louisiana continental shelf. U.S. Fish Wildl. Serv., Off. Biol. Serv., Wash., D.C., FWS/OBS-81-27, 88 p.

GALLAWAY, B. J., AND L. A. REITSEMA.
1981. Shrimp spawning site survey. *In* W. B. Jackson and E. P. Wilkens (editors), Shrimp and redfish studies; Bryan Mound brine disposal site off Freeport, Texas 1979-1981.

NOAA Tech. Memo. NMFS-SEFC-67, Vol. IV, 84 p. Available from National Technical Information Service, Springfield, VA 22151.

GAZEY, W. J., B. J. GALLAWAY, R. C. FECHHELM, L. R. MARTIN, AND L. A. REITSEMA.
1982. Shrimp mark release and port interview sampling survey of shrimp catch and effort with recovery of captured tagged shrimp. *In* W. B. Jackson (editor), Shrimp population studies: West Hackberry and Big Hill brine disposal sites off southwest Louisiana and upper Texas coasts, 1980-1982, Vol. II, 306 p. NOAA/NMFS Final Report to Department of Energy.

HARPER, D. E., L. D. MCKINNEY, R. R. SALZER, AND R. J. CASE.
1981. The occurrence of hypoxic bottom water off the upper Texas coast and its effects on the benthic biota. Contrib. Mar. Sci. 24:53-79.

HARRIS, A. H., J. G. RAGAN, AND R. H. KILGEN.
1976. Oxygen depletion on coastal waters. La. State Univ. Sea Grant Summ. Rep., Proj. No. R/BOD-1, 161 p.

KLIMA, E. F., K. N. BAXTER, F. J. PATELLA, AND G. A. MATTHEWS.
1983. Review of 1982 Texas closure for the shrimp fishery off Texas and Louisiana. NOAA Tech. Memo. NMFS-SEFC-108, 22 p. Available from National Technical Information Service, Springfield, VA 22151.

LEMING, T. D., AND W. E. STUNTZ.
1984. Zones of coastal hypoxia revealed by satellite scanning have implications for strategic fishing. Nature (Lond.) 310: 136-138.

MAY, E. B.
1973. Extensive oxygen depletion in Mobile Bay, Alabama. Limnol. Oceanogr. 18:353-366.

RAGAN, J. G., A. H. HARRIS, AND J. H. GREEN.
1978. Temperature, salinity and oxygen measurements of surface and bottom waters on the continental shelf off Louisiana during portions of 1975 and 1976. Nicholls State Univ., Prof. Pap. Ser. (Biol.) 3:1-29.

REITSEMA, L. A., B. J. GALLAWAY, AND G. S. LEWBEL.
1982. Shrimp spawning site survey. *In* W. B. Jackson (editor), Shrimp population studies: West Hackberry and Big Hill brine disposal sites off southwest Louisiana and upper Texas coasts, 1980-1982, Vol. IV, 88 p. NOAA/NMFS Final Report to Department of Energy.

STUNTZ, W. E., N. SANDERS, T. D. LEMING, K. N. BAXTER, AND R. M. BARAZOTTO.
1982. Area of hypoxic bottom water found in northern Gulf of Mexico. Coastal Ocean. Climatol. News 4:37-38.

SWANSON, R. L., AND C. J. SINDERMANN (editors).
1979. Oxygen depletion and associated benthic mortalities in New York Bight, 1976. NOAA Prof. Pap. No. 11, 345 p. Rockville, MD.

TURNER, R. E., AND R. L. ALLEN.
1982a. Bottom water oxygen concentration in the Mississippi River Delta Bight. Contrib. Mar. Sci. 25:161-172.
1982b. Plankton respiration rates in the bottom waters of the Mississippi River Delta Bight. Contrib. Mar. Sci. 25:173-179.