Fishery-independent Bottom Trawl Surveys for Deep-water Fishes and Invertebrates of the U.S. Gulf of Mexico, 2002–08

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Introduction

Since before the first European settlers arrived to colonize the U.S. Gulf of Mexico (GOM) coast, fishery resources played an important role for sustaining indigenous peoples (Swanton, 1979; Gore, 1992) and later were a vital food source for nonindigenous immigrant populations (Sullivan, 1985). As human populations expanded and protein demands from the sea increased (along with market opportunities for a broader variety of consumer choices due to diverse ethnicity), harvesting seafood ranged from near-shore to coastal, then eventually further offshore.

In addition to offshore expansion of directed fisheries, mineral exploration and production (e.g. petroleum and natural gas) expanded from coastal to offshore areas as technologies kept pace with demands of the commercial industry (Managi et al., 2005). The potential for further expansion of mineral-resource exploration and extraction into deep waters of the GOM is evidenced by many active oil and gas platforms already in service, and by the geographic range of active leases and approved applications for future development of continental shelf and outer continental shelf waters (Fig. 1).

Considering the possibility of GOM offshore fisheries gaining a more prominent role for fulfilling increasing protein demands, and the scenario that offshore GOM fisheries could eventually be impacted by a variety of anthropogenic factors (e.g. the hypoxic zone of the north-central GOM and expansion of the offshore petroleum and natural gas industry), Mississippi Laboratories (MSL) of NOAA's NMFS/SEFSC, initiated a baseline fishery-independent project to document offshore-fisheries dynamics for deep-water bottom fishes and invertebrates captured with bottom trawls. Potential sources of survey bias (as related to survey design and gear type), are controlled by use of a standardized-random survey design and standardized survey gear.

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ABSTRACT—From 2002 through 2008, the Mississippi Laboratories of the NMFS Southeast Fisheries Science Center, NOAA, conducted fishery-independent bottom trawl surveys for continental shelf and outer-continental shelf deep-water fishes and invertebrates of the U.S. Gulf of Mexico (50–500 m bottom depths). Five-hundred and ninety species were captured at 797 bottom trawl locations. Standardized survey gear and randomly selected survey sites have facilitated development of a fishery-independent time series that characterizes species diversity, distributions, and catch per unit effort. The fishery-independent surveys provide synoptic descriptions of deep-water fauna potentially impacted by various anthropogenic factors.

Materials and Methods

Deep-water trawl surveys were conducted during October and November of each survey year (in general over a 6-wk period). The survey area spanned most of the GOM exclusive of prohibited areas and shipping lanes with significant vessel traffic (Fig. 1). The survey design utilized proportional allocation based on the width of GOM continental shelf and outer continental shelf waters.

Bottom trawl locations were randomly selected within 21 statistical zones (ranging from shore to the economic exclusive zone boundary) of 60° latitude (for north to south oriented shorelines) or longitude (for east to west oriented shorelines); some statistical zones were irregular-sized due to irregular shore contours. In general, bottom depths for station allocations ranged from 110–500 m (2002), 90–500 m (2003), and 50–500 m (2004, 2006, 2007, and 2008); however, depending on ancillary survey objectives (e.g. gear comparison study), sea conditions, or steep bottom depth contours some bottom trawl locations were in bottom depths < 50 m or > 500 m.

Prior to gear deployment the sea bottom was evaluated with echosounders to determine suitability for bottom trawling. If a bottom profile appeared prohibitive for bottom trawling (based on visual assessments of bottom-bathymetry irregularities or steep bottom inclines), the preselected station was not sampled. Sampling sites were occupied during any time period (24-h/day sampling) and were not designated as day or night sites prior to the survey, and were occupied in the most time-efficient manner possible.

The trawl sampling gear consisted of a two-seam bottom trawl (27.4 m length footrope), fished with W-style trawl doors (682 kg each, 3.5 m^2). The trawl opening averaged 15.5 m width by 10.0 m height, the codend mesh liner was 4.0 mm, and the trawl speed was 6.3 km/h (speed over sea floor). Bottom trawls

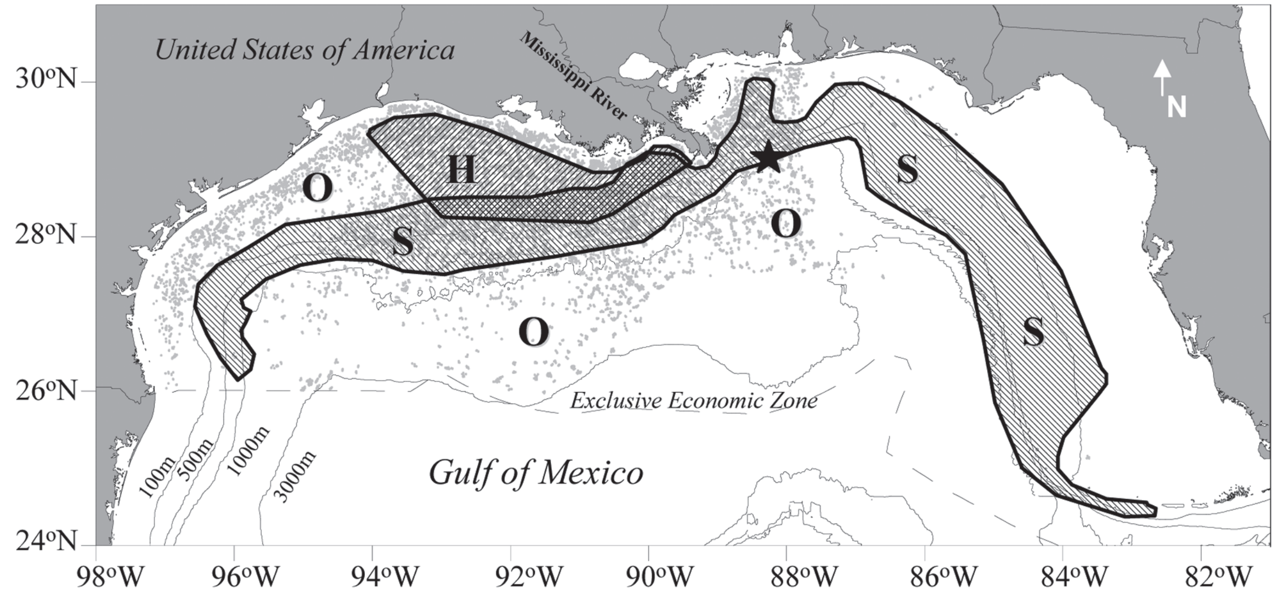

Figure 1.—Deep-water bottom trawl survey area (S); approximate area of the predicted 2008 hypoxic zone (H); offshore locations of active petroleum and natural gas platforms (O) including approved applications to drill (locations are represented by small-gray dots); Deepwater Horizon Macondo/MC252 exploration oil platform (★).

were 30-min duration once the trawl settled on bottom (as determined by net mensuration systems or trawl descent rate charts).

At termination of the 30-min trawl, the ship pulsed speed to 10.5 km/h for 5 min to flush catch from the trawl through a web-constructed fish funnel and into the trawl codend, then the trawl was hauled. After hauling, the catch was weighed either by individual baskets or, for relatively large catches, by use of a remotely-controlled electronic scale (dynamometer) used to weigh the entire trawl codend with catch; the trawl codend weight was subtracted from the total weight. Environmental sampling was conducted at each trawl location and included profiles of sea-surface to sea-bottom environmental parameters: temperature, salinity, dissolved oxygen, transmissivity (turbidity), and indirect measures of chlorophyll-*a* via a fluorometer.

Results

From 2002 to 2008, six deep-water bottom trawl surveys were conducted in the GOM; sampling did not occur during 2005. Bottom trawl effort (797 tows, 398 h 30 min total tow time) resulted in the capture of 590 species (finfish, noncrustacean invertebrates, and crustaceans collectively), representing 54 orders, 192 families, and 373 genera (Table 1). Total catch weight for all groups collectively was 74,987 kg; finfish were the primary catch component (94.2%), followed by noncrustacean invertebrates (5.2%), and crustaceans (0.6%). For the finfish catch component ranked by weight (Table 2), 22.8% was rough scad, *Trachurus lathami,* which was also the top ranked by number and weight for all groups collectively; followed by gulf butterfish, *Peprilus burti,* 13.5%; and longspine porgy, *Stenotomus caprinus,* 10.7%.

One of the most important finfish species of GOM management concern, the red snapper, *Lutjanus campechanus*, was ranked 27th by weight within the finfish group. The top-ranked elasmobranch by weight (finfish group) was the Atlantic angel shark, *Squatina dumeril,* ranked 6th, followed by the roughtail stingray, *Dasyatis centroura,* ranked 13th. Of 44 finfish orders known to occur in the GOM, 32 (73%) were represented during the surveys.

Table 1.—Catch summary for finfish, noncrustacean invertebrates, and crustaceans, from deep-water bottom trawl surveys, 2002–08.

Category	Finfish	Noncrustacean invertebrates	Crustaceans	Total
Orders	32	14	8	54
Families	124	25	43	192
Genera	260	34	79	373
Species	445	39	106	590

For the noncrustacean invertebrate catch component ranked by weight (Table 3), 73.8% were longfin squid, *Loligo pealeii,* also the highest percent frequency of occurrence of total trawls for all groups collectively; 21.9% were southern shortfin squid, *Illex coindetti*, and 2.7% were arrow squid, *Loligo plei*. For the crustacean catch component ranked by weight (Table 4), 33.0% were brown shrimp, *Farfantepenaeus aztecus*, followed by the longspine swimming crab, *Portunus spinicarpus*, 12.0%, and the rose shrimp, *Parapenaeus politus*, 7.3%. In addition to commercially important brown shrimp, three other commercially important shrimp (ranked within the crustacean group) were royal red shrimp, *Pleoticus robustus*, 4.4%; pink shrimp, *Farfantepeneaus duroraum*, 1.1%; and white shrimp, *Litope-*

Table 2.—Finfish (top 10 ranked by weight) captured during deep-water bottom trawl surveys, 2002–08. Depth, temperature, salinity, and oxygen saturation values are minimum-maximum/mean.

Taxon	Total wt. (kg)	Total no.	% Frequency of occurrence	Depth (m)	Temp. (°C)	Salinity (ppt)	Oxygen (mg/l)
Trachurus lathami, rough scad	16,138	264,273	69.4	30–497/36	8.8–28.7/18.2	31.0–36.6/36.2	2.8–8.0/4.3
Peprilus burti, gulf butterfish	9,499	135,268	34.3	42–347/117	11.0–28.7/19.1	28.2–36.6/36.2	2.8–8.0/4.3
Stenotomus caprinus, longspine porgy	7,606	158,951	31.1	30–178/100	15.2–28.7/20.3	28.2–36.6/36.3	2.8–8.0/4.5
Pristipomoides aquilonaris, wenchman	4,329	68,327	64.1	48–481/136	9.1–28.7/18.0	28.2–36.6/36.1	3.4–8.0/4.2
Etrumeus teres, round herring	3,746	158,928	18.3	54–239/132	14.0–24.7/17.9	31.0–36.6/36.2	3.5–6.7/4.1
Squatina dumeril, Atlantic angel shark	2,297	783	36.6	41–423/165	10.1–25.7/16.5	34.6–36.7/36.0	3.4–6.4/4.1
Saurida normani, shortjaw lizardfish	2,168	30,359	38.4	53–355/152	10.2–25.2/17.0	34.6–36.7/36.1	3.4–6.4/4.1
Lagodon rhomboides, pinfish	2,162	24,742	22.1	30–209/94	15.6–28.7/21.3	28.2–36.6/36.2	2.8–6.7/4.6
Trichiurus lepturus, Atlantic cutlassfish	2,016	26,430	25.6	47–341/115	12.0–28.7/19.5	28.2–36.6/36.2	2.8–6.7/4.4
Micropogonias undulatus, Atlantic croaker	1,940	21,904	10.4	42–141/71	16.0–28.7/23.3	35.6–36.6/36.4	2.8–6.4/4.9

Table 3.—Noncrustacean invertebrates (top 10 ranked by weight) captured during deep-water bottom trawl surveys, 2002–08. Depth, temperature, salinity, and oxygen saturation values are minimum-maximum/mean.

Taxon	Total wt. (kg)	Total no.	% Frequency of occurrence	Depth (m)	Temp. (°C)	Salinity (ppt)	Oxygen (mg/l)
Loligo pealeii, longfin squid	2,872	73,028	78.9	30–563/150	8.4–27.9/17.4	28.2–36.7/36.0	3.4–8.0/4.2
Illex coindetti, southern shortfin squid	852	5,881	13.9	128–563/297	8.4–19.7/12.8	33.1–36.6/35.6	3.4–4.6/3.9
Loligo plei, arrow squid	105	7,826	8.3	39–213/98	13.5–28.7/21.5	34.3–36.7/36.3	3.4–6.7/5.0
Octopus vulagris, common octopus	13	85	5.1	39–189/116	9.3–26.1/19.2	35.1–36.7/36.3	3.5–6.5/4.5
Amusium papyraceum, paper scallop	5	459	5.0	55–132/89	16.7–27.7/21.1	36.2–36.6/36.4	3.4–6.3/4.7
Tonna galea, giant tun	5	16	0.9	130–176/151	14.4–17.4/16.1	34.6–36.3/35.9	3.6–4.3/3.9
Pholidoteuthis adami, pink scaled squid	4	14	0.5	373–563/480	8.4–13.9/10.0	33.2–35.8/34.5	3.5–4.2/3.8
Abralia redfieldi (no common name)	2	995	7.3	69–516/246	8.7–24.7/14.2	34.5–36.6/35.8	3.4–6.7/4.0
Illex oxygonius, sharptail shortfin squid	2	10	0.4	172–444/270	8.9–16.0/13.0	35.1–36.1/35.7	3.8–4.0/3.9
Semirossia equalis, greater shining bobtail	2	574	11.5	59–436/153	9.5–25.7/17.2	35.0–36.6/35.8	3.5–6.9/4.2

Table 4.—Crustaceans (top 10 ranked by weight) captured during deep-water bottom trawl surveys, 2002–08. Depth, temperature, salinity, and oxygen saturation values are minimum-maximum/mean.

Taxon	Total wt. (kg)	Total no.	% Frequency of occurrence	Depth (m)	Temp. (°C)	Salinity (ppt)	Oxygen (mg/l)
Farfantepenaeus aztecus, brown shrimp	163	5,255	13.8	48–144/86	16.1–28.7/21.5	35.5–36.6/36.3	3.3–6.7/4.8
Portunus spinicarpus, longspine swimming crab	59	6,968	26.1	46–217/125	14.2–27.0/18.7	34.6–36.7/36.1	3.4–8.0/4.3
Parapenaeus politus, rose shrimp	36	21,227	18.1	51–436/164	10.2–28.7/16.6	34.5–36.6/35.8	3.4–8.0/4.1
Solenocera vioscai, humpback shrimp	25	7,267	29.9	41–337/144	9.5–28.7/17.7	34.3–36.6/36.0	3.4–8.0/4.2
Calappa sulcata, yellow box crab	25	86	4.0	48–166/97	16.3–27.7/21.1	28.2–36.6/36.1	3.6–6.3/4.6
Pleoticus rodustus, royal red shrimp	22	431	3.4	201–563/416	8.4–15.2/10.3	33.1–36.0/35.1	3.5–9.0/3.8
Stenocionops spinosissimus, tenspine spider crab	20	33	3.4	103–418/168	10.1–19.2/16.1	33.3–36.5/36.1	3.5–4.4/4.0
Penaeopsis serrata, pinkspeckled shrimp	11	7,760	10.3	41–516/200	8.7–25.7/15.9	34.3–36.6/36.0	3.4–6.4/4.1
Anasimus latus, stilt spider crab	10	985	13.2	52–314/133	10.2–27.0/18.0	28.2–36.6/36.2	3.5–5.9/4.1
Sicyonia brevirostris, brown rock shrimp	8	460	3.9	46–134/69	17.1–28.0/23.2	35.9–36.6/36.4	3.5–6.4/5.1

naeus setiferus, 0.3%. Distribution of the top-ranked by weight rough scad (for the finfish group) and longfin squid (for the non-invertebrate crustacean group), was relatively uniform across the survey area in bottom depths 100–500 m; distribution of the top-ranked by weight brown shrimp (for the crustacean group) was primarily west of long. 88°W in bottom depths 30–200 m.

Discussion

The importance of developing a fishery-independent time series for assessing life histories and distributions is of particular significance for populations that are unexploited or minimally exploited (Johnson, 1994; Jennings and Blanchard, 2004). On a global basis, with many fisheries fully exploited or nearing full exploitation due to increasing demands for fishery products (FAO, 2004), with regards to outer-continental shelf bottom fishes and invertebrates, the MSL GOM survey represents a rare opportunity to assess species-specific population dynamics from a largely unexploited geographic region.

Even though the variety of factors potentially affecting deep-water fish and invertebrate GOM populations overlap those in other global regions, three primary factors are encompassed (to varying degrees) within the geographic range of the MSL GOM deep-water trawl surveys: the north-central GOM hypoxic zone, the probable expansion of fisheries offshore into deep waters (in particular bottom-trawl prosecuted fisheries), and the offshore petroleum and natural gas industry.

One of the world's most extensive hypoxic zones (dissolved oxygen concentration < 2.0 mg/l) is found along the GOM north-central coast (Rabalais et al., 1999, 2002a; Fig. 1). Hypoxic-zone dynamics are influenced by the Mississippi River (flow rate 14,000 m^3/

sec, Bratkovich et al., 1994), and effects of the hypoxic zone are varied and can include species displacement and eutrophication (Rabalais et al., 2002b) on both small and large geographic scales. It is common for the GOM-hypoxic zone to extend from near shore to well offshore to bottom depths of 60 m (Rabalais et al., 2007). Even though hypoxic conditions were not recorded from any of the MSL bottom trawl locations, some of the dissolved oxygen levels were as low as 2.8 mg/l (Table 2).

During peak hypoxic events from June through August (hypoxic conditions have been recorded from late February to October (Rabalais et al., 2002a)), the effects on continental-shelf and outer-continental shelf fishes can be especially pronounced, and this in turn can affect the distribution, abundance, and behavior of fish (Stanley and Wilson, 2004) and invertebrates (Leming and Stuntz, 1984; Craig et al., 2005). Since the hypoxic zone is dependent in part on Mississippi River effluent that often contains various amounts of hypoxic precursors (i.e. nitrogen and phosphorus from fertilizer use (Diaz, 2001; Rabalais et al., 2002a)), the likelihood exists that the GOM hypoxic phenomena will continue to influence fish and invertebrate distributions and their associated trophic relationships in the north-central GOM.

According to a Louisiana Universities Marine Consortium Press Release[1], the predicted size of the 2008 hypoxic zone (Fig. 1) was one of the largest in area on record (22,790 km^2) and was attributed to a 37% increase above the 2007 nitrate-nitrogen loading level of the Mississippi River (the highest level since measurements began in 1970); the press release also stated that increased farming of more land for the production of biofuels contributed to the 2008 increased nitrogen-loading rate.

Even though the actual size for the 2008 hypoxic zone was less than predicted due to a number of contributing factors[2], the potential for significant annual hypoxic events remains likely for the north-central GOM. Prior to 1993, the average areal extent of the hypoxic zone was 8,000–9,000 km^2 (Rabalais et al., 1999), therefore, during various years since 1993 the hypoxic zone has more than doubled in size[3], and has continued to expand westward[4] and further offshore toward the deep waters of the outer-continental shelf.

As many commercial marine fisheries continue to decline on a global basis (Pauly et al., 2005), it stands to reason that the search for additional fishery resources will be driven by market incentives (Pauly et al., 2003). As fisheries-harvesting technology continues to improve (Pauly et al., 2002), offshore deep-water fishery resources are increasingly accessible to harvesting (Moore, 1999). Globally, the mean fishing depth for bottom fisheries has increased since 1950 (Morato et al., 2006), and in all likelihood the trend eventually will apply to GOM deep-water bottom fisheries.

Even though the various species prone to capture by deep-water offshore GOM trawl fisheries are relatively unexploited at present (landings are primarily from the Florida GOM coast[5]), there is a GOM-wide fisheries complex of potential exploitation: the coastal-pelagic fishes (estimated biomass 2,928,000 t (Brown et. al., 1999, Table 5)). However, the effects of fishing on relatively unexploited populations are often difficult to quantify (Jennings and Blanchard, 2004; Morato et al., 2006; Anderson et al., 2008) and equally difficult to qualify (Moore, 1999; Pauly et al., 1999; Watson and Pauly, 2001), a situation that is often complicated when offshore fishery-dependent landings are grouped in non-specific generically-broad categories.

Table 5.—Coastal pelagic finfish species from Brown et al. (1999) in common with deep-water bottom trawl surveys.

Taxon
Sardinella aurita, Spanish sardine
Opisthonema oglinum, Atlantic thread herring
Decapterus punctatus, Round scad
Trachurus lathami, Rough scad
Harengula jaguana, Scaled sardine
Etrumeus teres, Round herring
Chloroscombrus chrysurus, Atlantic bumper
Engraulidae, Anchovies (general category)
Ariomma bondi, Silver-rag
Peprilus burti, Gulf butterfish

The range of effects on deep-water GOM fish and invertebrate populations from offshore petroleum and natural gas structures includes increased offshore structures (3,740 active platforms[6]) possibly enhancing desirable habitats and productivity for a variety of species (Keenan et al., 2007; Shipp and Bortone, 2009), altered fish and invertebrate distributions (Lindberg, 1997; Stanley and Wilson, 2003; Sammarco et al., 2004; Shipp and Bortone, 2009), and benthic-organism responses to associated hydrocarbons (Montagna and Harper, 1996; Peterson et al., 1996).

The likely expansion of the offshore petroleum and natural gas industry is reflected in a report released by the U.S. Department of the Interior[6]; in 2007 approximately 72% of GOM oil production and 54% of GOM leases were in water depths greater than 305 m. For what is classified as approved applications to drill (37,293 applications[7]), 90% of applications are in bottom depths 0–200 m, 3% from 201–400 m, 2% from 401–800 m, 1% from 801–1,000

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[1] LUMCOM, 28 July 2008, Dead Zone Again Rivals Record Size (online at http://www.gulfhypoxia.net/news/documents/HypoxiaForecast13July2008.pdf).

[2] NOAA News Releases, 27 July 2009, Smaller than expected, but severe, dead zone in Gulf of Mexico (online at http://www.gulfhypoxia.net/News/default.asp?XML Filename=200908111033.xml).

[3] 2009 Forecast of the summer hypoxic zone size, northern Gulf of Mexico (online at http://www.gulfhypoxia.net/research/Shelfwide Cruises/2009/Files/2009_Hypoxia_Forecast.pdf).

[4] 2009 Real-time environmental monitoring from a wind farm platform in the Texas hypoxia zone (online at http://ieeexplore.ieee.org/Xplore/login.jsp?url=http%3A%2F%2Fieeexplore.ieee.org%2Fstamp%2Fstamp.jsp%3Ftp%3D%26arnumber%3D5422304&authDecision=-203).

[5] 2008 Florida Fish and Wildlife landing statistics (online at http://research.myfwc.com/features/view_article.asp?id=19224).

[6] U.S. Department of the Interior, Minerals Management Service, Office of Public Affairs, 2008, (OCS Report MMS 2008-013, Deepwater Gulf of Mexico 2008: America's Offshore Energy Future).

[7] U.S. Department of the Interior, Minerals Management Service, 2009a, Gulf of Mexico Fast Facts, April 2009 (online at http://www.gomr.mms.gov/homepg/fastfacts/WaterDepth/WaterDepth.html).

m, and 4% (or 1,501 applications) from deeper than 1,000 m. Additionally, 13 bids were received for the 181 South Area offshore of the central GOM[8] with maximum bottom depths for available leases exceeding 3,000 m.

Conclusion

The importance of the MSL GOM deep-water bottom trawl surveys is firmly established when considering various anthropogenic factors that potentially affect population dynamics of continental shelf and outer-continental shelf marine species (the expanding hypoxic zone, offshore expansion of fisheries, offshore petroleum and natural gas industry). Since the deep-water trawl surveys do not target specific species and employ a randomized survey design with standardized survey gear, the time series is applicable as a fishery-independent index for several key species that are of historic and future concern. Potential sources of survey bias are controlled as best they can be considering the limitations of the annual survey period (October and November), the geographic extent and bottom depth range (limited by survey logistics as a function of sea-day allocation), and gear selectivity (deep-water fish trawls are not ideally suited for efficient capture of all species or the sampling of all habitats (Herring, 2004)). As additional anthropogenic factors continue to influence the GOM, the MSL GOM deep-water fishery-independent time series will contribute to important synoptic summaries of the abundance and distribution of biological communities.

Deepwater Horizon Macondo/ MC252 Oil Spill

On 20 April 2010, there was a north-central Gulf of Mexico oil spill (50 n.mi. southeast of the Mississippi River delta, Fig. 1) from a deep-water exploration oil platform (Deepwater Horizon Macondo/ MC252, 1,523 m bottom depth). The oil-spill event spanned 91 days and at one point lead to a fishery closure by NOAA that comprised 33.2% of Gulf of Mexico Federal waters.[9] The annual deep-water trawl surveys conducted by Mississippi Laboratories will be an important time-series component for assessing potential oil-spill related anthropogenic effects on marine fauna.

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