Impact of the Deepwater Horizon oil spill on a deep-water coral community in the Gulf of Mexico


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To assess the potential impact of the Deepwater Horizon oil spill on offshore ecosystems, 11 sites hosting deep-water coral communities were examined 3 to 4 mo after the well was capped. Healthy coral communities were observed at all sites >20 km from the Macondo well, including seven sites previously visited in September 2009, where the corals and communities appeared unchanged. However, at one site 11 km southwest of the Macondo well, coral colonies presented widespread signs of stress, including varying degrees of tissue loss, sclerite enlargement, excess mucous production, bleached commensal ophiuroids, and covering by brown flocculent material (flocc). On the basis of these criteria the level of impact to individual colonies was ranked from 0 (least impact) to 4 (greatest impact). Of the 43 corals imaged at that site, 46% exhibited evidence of impact on more than half of the colony, whereas nearly a quarter of all of the corals showed impact to >90% of the colony. Additionally, 53% of these corals’ ophiuroid associates displayed abnormal color and/or attachment posture. Analysis of hopanoid petroleum biomarkers isolated from the flocc provides strong evidence that this material contained oil from the Macondo well. The presence of recently damaged and deceased corals beneath the path of a previously documented plume emanating from the Macondo well provides compelling evidence that the oil impacted deep-water ecosystems. Our findings underscore the unprecedented nature of the spill in terms of its magnitude, release at depth, and impact to deep-water ecosystems.

Benthic communities were evaluated at one site 11 km southwest of the Macondo well, including seven sites previously visited in September 2009, where the corals and communities appeared unchanged. However, at one site 11 km southwest of the Macondo well, coral colonies presented widespread signs of stress, including varying degrees of tissue loss, sclerite enlargement, excess mucous production, bleached commensal ophiuroids, and covering by brown flocculent material (flocc). On the basis of these criteria the level of impact to individual colonies was ranked from 0 (least impact) to 4 (greatest impact). Of the 43 corals imaged at that site, 46% exhibited evidence of impact on more than half of the colony, whereas nearly a quarter of all of the corals showed impact to >90% of the colony. Additionally, 53% of these corals’ ophiuroid associates displayed abnormal color and/or attachment posture. Analysis of hopanoid petroleum biomarkers isolated from the flocc provides strong evidence that this material contained oil from the Macondo well. The presence of recently damaged and deceased corals beneath the path of a previously documented plume emanating from the Macondo well provides compelling evidence that the oil impacted deep-water ecosystems. Our findings underscore the unprecedented nature of the spill in terms of its magnitude, release at depth, and impact to deep-water ecosystems.

hopane | sterane | Paramuricea | sediment

Between October 15 and November 1, 2010, approximately 6 months after the Deepwater Horizon blowout and 3 months after the Macondo well was capped, nine sites hosting deep-water coral communities were examined with the remotely operated vehicle (ROV) Jason II. This effort was part of an ongoing study funded by the Bureau of Ocean Energy Management (BOEM) and the National Oceanic and Atmospheric Administration’s Ocean Exploration and Research program. These sites, located between 29.16 °N and 27.42 °N and between 87.31 °W and 82.16 °W (Fig. S1), were ~20 km from the Macondo well, ranged in depth from 290 to 2600 m, and hosted coral communities including scleractinian, gorgonian, and antipatharian corals. At these sites, no visible evidence of impact to the corals and associated communities was observed (Fig. 1). However, on November 2, 2010, the ROV Jason II investigated an area in lease blocks Mississippi Canyon (MC) 294 and 338, 11 km to the SW of the site of the Deepwater Horizon spill. This area was explored because 3D seismic reflectivity data (Fig. S1) suggested there was a strong likelihood of hard grounds, and hence likely coral substrate present. Its location (28.40N, 88.29W, 1,370 m) also placed it in the path of a 100-m-thick deep-water plume of neutrally buoyant water enriched with petroleum hydrocarbons from the Macondo well that was documented at 1,100 m in June 2010 (1, 2). Numerous coral colonies were discovered at this location and many were partially or completely covered in a brown, flocculent material (hereafter referred to as flocc). They showed signs of recent and ongoing tissue damage (Fig. 2) not observed elsewhere at this time (Fig. 1) or in the previous 10 y of baseline studies in the Gulf of Mexico (GoM) (3–5). Between December 8 and 14, 2010 additional surveys were performed with the deep submersible vehicle (DSV) Alvin at MC 294 and a newly discovered site 22 km to the ESE of the Macondo well in MC 388 (1,850 m depth). Visible signs of recent impact or stress were not evident in the corals imaged at MC 388. To determine whether the cause of the overall decrease in coral health at MC 294 was related to the Deepwater Horizon oil spill, the flocc covering the corals and nearby sediment was examined for the presence of petroleum hydrocarbons originating from the Macondo well. Determining the source of petroleum hydrocarbons in these samples posed a significant challenge. The complexity of the petrogeochemical signatures in the GoM environment is considerable (6). Specific crude oils can be differentiated from their source rock groups using biomarkers (molecular fossils), which are highly resistant to abiotic and biotic processes and have been invaluable tools for characterizing and fingerprinting crude oils (7). For example, sterane biomarkers are derived primarily from marine phytoplankton and vary depending on geologic age. Hopanes, which are another class of biomarkers, can be used individually or in concert with sterane distributions to provide even greater certainty in characterizing oils (7). The use of biomarkers by the petroleum industry and subsequently in environmental forensics has, however, been performed in much different environments than the Deepwater Horizon spill, where oil and gas at 105 °C were released at pressure into 5 °C seawater at ~1,400 m depth (2). We used traditional 1D gas chromatography (GC) and comprehensive two-dimensional gas chromatography (GCxGC, as in refs. 8, 9 and 10) to analyze flocc and sediment samples from MC 294. These samples were compared


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Data deposition: The octocoral and ophiuroid sequences reported in this paper have been deposited in the GenBank database (accession nos. JQ241124–52, JQ411462–9 and JQ771615–JQ771617) and all images have been submitted to the US National Oceanographic Data Center (accession no. 0084636).

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with oil collected from directly above the broken riser pipe at the Macondo well (2) and field samples from surface water and salt marshes in areas oiled by the Deepwater Horizon spill.

Here we report on the analyses of the visible impact to the gorgonian corals and coral associates at MC 294 based on in situ video imagery, shipboard microscopic analyses, and petroleum biomarker analysis of the floc adherent to the coral. In addition, we compare the petroleum hydrocarbon content and biomarkers with the surrounding surface and subsurface sediments and compare the condition of the corals and associates between November and December 2010 visits.

**Results and Discussion**

Gorgonian and other corals present at MC 294 are predominantly found in a central area 10 × 12 m in extent, composed of two adjacent carbonate slabs. Scattered boulders surround this region over an area of 50 × 50 m, and some of the isolated boulders host one or two additional coral colonies. The majority of the colonial corals were *Paramuricea biscaya*, with one or two colonies of *Swiftia pallida*, *Paragorgia regalis*, *Acanthogorgia aspera*, and *Clavularia rudis* (Fig. S2). The majority of these colonies exhibited signs of stress response, including excessive mucous production and retracted polyps, which have been observed in corals experimentally exposed to crude oil (11). Impact to the corals was quantified from close-up images (<1 m away) for 43 of the 58 coral colonies identified in the central area (Fig. S3) (not all of the corals could be approached for close-up imaging with ROV Jason II or DSV Alvin without disturbing other colonies). The level of impact to individual colonies was ranked from 0 (least impact) to 4 (greatest impact) according to the percentage of the colony exhibiting one or more of the following visual indications of stress: bare skeleton above the basal region, loose tissue or heavy mucous hanging from the skeleton, and/or coverage with brown flocculent material (Fig. 3). Eighty-six percent of the coral colonies imaged in the central area exhibited signs of impact. Forty-six percent exhibited impact to at least 50% of the colony (impact level 3 or 4), and 23% of the colonies sustained impact to more than 90% of the colony (impact level 4).

Between the November and December 2010 research cruises, changes in condition were assessed for all corals or portions of colonies for which high-resolution imagery was available from similar perspectives. Although differences in camera placement...
on the two underwater vehicles, lighting, and quality of images limited the size of this data set to 18 colonies, neither progression of the visible damage nor clear evidence of recovery or growth was apparent in the majority of corals. Possible recovery was noted for one colony (A14, highlighted by box in Fig. 2). The relatively light covering of floc over more than 50% (impact level 3) of this colony in November was ranked as less than 10% impacted (impact level 1) by the time it was revisited in December, when extended polyps were visible in areas that had been partially covered with floc in November.

Sampling of a *P. biscaya* coral (E3) in December enabled microscopic analysis to be made after removal of the floc. Varying degrees of tissue loss and sclerite enlargement were observed (Fig. S4). The skeleton was bare and entirely devoid of tissue at the base and along the main axis of the colony. At increasing distances from the basal point of attachment, less extensive tissue loss resulted in the exposure of the calcite skeletal elements that are normally embedded in the tissue layers and connecenchyme. These sclerites were still in their normal form of a polyp but appeared enlarged. The localized alteration of growth form, including excessive secretion of gorgonin and sclerite production to form granuloma-like structures, has previously been observed in gorgonians as an acute stress response (12, 13). Near the tips of some branches, which were not covered by the floc in situ, a few polyps on this coral appeared normal.

Coral associates at MC 294 included 13 actinarian anemones and 78 *Asteroschema clavigerum* (a symbiotic ophiuroid). Of the 52 individual corals examined for coral associates, 25% hosted none, 2% hosted actinarian anemones, and 73% hosted *A. clavigerum*, with 70% of the ophiuroids present on *P. biscaya*, 18% on the single individual of *P. regalis*, and 12% on *A. aspera. A. clavigerum* is typically tan to red in color (Fig. 1); however, at this site only 47% were tan to red, whereas 44% had distinctly white arms (Fig. 2), and 9% (all hosted by *P. biscaya*), were bleached almost entirely white. In November, 27% of the ophiuroids displayed behaviors other than their normal attached posture of arms tightly coiled around their coral host. Between visits, 13% of the ophiuroids transitioned from tightly to loosely coiled (i.e., Fig. 2). Two ophiuroids (Fig. S5) transitioned from tightly coiled to a posture with splayed out arms, a previously undocumented behavior in this species.

The floc samples collected (∼72 μm in size) were removed from the surface of the corals in situ and when filtered were found to contain dead coral polyp fragments, detached sclerites, and small brown droplets (Fig. S6). Solvent extracts of all of the floc examined were dominated by C16 and C18 saturated and unsaturated fatty acids and cholesterol, which are dominant lipids in biological tissue. Petroleum residues were also present and quantified via 1D gas chromatography coupled to a flame ionization detector (GC-FID; Table 1). An unresolved complex mixture (UCM) with n-alkane carbon range of C15–C42 indicates the presence of weathered petroleum (e.g., ref. 8; Table 1). Slight variations in UCM carbon range and distributions of n-alkanes among samples showed no consistent relationship to the pure Macondo Well oil (described in ref. 2; Table 1). Rather, it is evident that the n-alkanes in the samples represent input from a mixture of sources such as plants, biofilms, and differentially weathered subsurface hydrocarbons, including some that may have come from natural seeps. Acoustic mapping cruises performed from late May to August 2010 mapped several natural gas seeps in near proximity to both the Macondo well and the sample sites presented here, which could provide additional sources of subsurface hydrocarbons (14).

Polycyclic aromatic hydrocarbon (PAH) distributions from coral E3 and sediment sample 4664 0–2 cm show good correspondence to Macondo well oil, with similar relative abundances of naphtalene, phenanthrene, and their alkylated derivatives as well as dibenzothiophenes, benz(e)anthracene, and chrysenes. The remaining coral samples are inconclusive owing to the small quantity of sample available for analysis, as well as the fact that these samples have been extensively weathered, as evidenced by the dominance of biodegradation-resistant chrysene in all extracts. Petroleum systems in the GoM do not display significant differences in the presence or absence of specific biomarkers indicative of differences in the relative amounts of biomarkers present have previously allowed sources to be determined (15, 16). Analysis of biomarkers such as hopanes is critical because these compounds are more resistant to biodegradation and water washing than n-alkanes and PAHs and provide insight into petroleum source determination (as in ref. 17). At the Macondo well, oil sampled from above the broken riser pipe (2) contains abundant hopanoids, diasteranes, and steranes (Fig. S7). Hopanoid biomarker ratios have been calculated for comparison with coral and sediment samples, as well a reference surface water (S1) and two reference coastal water (M1 and M2) samples (shown in Fig. 1 and described in ref. 18). These reference samples represent Macondo well oil that has undergone vertical transport from the seabed to the ocean surface (∼1,400 m) and subsequent lateral dispersion over ranges of 1–175 km, respectively (Table 1).

Comparison of the hopanoid portion of the GC×GC chromatographic plane for the Macondo well oil to the S1 and M1 samples indicates a high degree of similarity (Fig. S8A–C). This similarity is also seen in the floc from coral B8 (Fig. S8D) and in the surface sediment sample taken in the immediate vicinity of the corals (core 4664 0–2 cm; Fig. S8E). Slight but significant differences in hopanoid biomarker ratios are observed, by contrast, both in comparable core-top sediments collected away from the impacted corals at the MC 294 site (core 4662 0–2 cm; Table 1 and Fig. S8F) and at greater depths (2–5 cm and 5–10 cm; Table 1) in the core 4664 sediments. Further, the concentrations of oil present in the uppermost sediments of core 4664 (0–2 cm) are much higher (9.25 mg/g; Table 1) than the deeper sediments (2–5 cm and 5–10 cm) in the same core, which range in concentration from 0.02 to 0.03 mg/g (Table 1). They are also higher than the oil concentrations observed in surface sediments (0–2 cm) collected away from the impacted corals at the MC 294 site (3.46 mg/g; Table 1), where a bimodal n-alkane distribution indicative of inputs from mixed sources is observed. Significant variations in sediment oil concentrations have been previously documented in the GoM, particularly in areas of known natural oil seepage such as Green Canyon, where oil concentrations may be as high as 39.0 mg/g (19). The oil concentration and biomarker data from sediments collected away from the impacted corals and sediments at depth at MC294, are, however, most consistent with long-term background inputs of oil derived from petroleum sources that are quite distinct to that present in the most superficial (hence, recent) core-top sediments and floc.
samples collected from site MC 294. Similarly, a comparison of the sterane portion of the GC×GC chromatographic plane for the Macondo well oil and floc from the coral samples also shows significant differences, particularly in the relative distributions of \( \text{DiaC}_{30}\text{[aR-20S, C}_{27}\text{[aR-30-norhopane; Tm, 17}\text{[aR,R-22,29,30-trinorneohopane.} \)

Conclusions

Observations of recently damaged corals and the presence of Macondo well oil on corals indicates impact at a depth of 1,370 m, 11 km from the site of the blowout. This finding provides insight into the extent of the impact of the spill, which is significantly complicated by physical mixing processes (23) and fractionation of the oil constituents (24). Because deep-water corals are sessile and release mucus that may trap material from the water column, these corals may provide a more sensitive indicator of the impact from petroleum hydrocarbons than marine sediment cores and may record impacts from water masses passing through a community, even if no deposition to the sediment occurs. Deep-water colonial corals exhibit extreme longevity as sessile adults (hundreds to thousands of years; 25–27) and typically inhabit areas exposed to a moderate current regime (28). The presence of a deep-water coral community dominated by recently impacted, visibly unhealthy, and recently dead individuals (as evidenced by skeletons free of encrusting organisms), together with ophiuroid symbionts with unhealthy color and atypical posture, provides evidence of a recent waterborne impact. Although the spatial and temporal proximity of this impact to the Deepwater Horizon oil spill might be coincidental, the normal longevity of deep-water corals and the lack of visual evidence of impact to deep-water corals elsewhere in the GoM suggest that this may not be the case. Importantly, even though there are multiple inputs of oil to the GoM, the use of hopanoid biomarker compositions and ratios in the floc collected from the surface of corals allows us to establish a connection to the oil spill even though other biomarkers for characterizing oil in these environments (e.g., PAHs and sterane biomarker ratios) are affected by severe weathering (20) and, hence, are not robust under the conditions of this spill.

The data suggest the Deepwater Horizon oil spill impacted a community of deep-water corals near the Macondo well. The numerous apparently healthy deep-water coral communities in other parts of the GoM may indicate that the localized impact in MC 294 found to date, is not part of a much larger, acute, GoM-wide event. However, life in deep-water coral ecosystems is known to operate at a slow pace. Consequently it is too early to fully evaluate the footprint and long-term effects of acute and subacute exposure to potential waterborne contaminants resulting from the Deepwater Horizon oil spill.

Materials and Methods

Discovery. Areas for exploration were chosen according to examination of 3D seismic data in the BOEM database. Areas of high reflectivity and bathymetric relief were targeted for visual examination, and during the ROV dive, onboard sonar was used to find exposed carbonates that might host corals.

Image Analyses. A down-looking mosaic (as in ref. 29) was constructed from 379 partially overlapping images, taken 3 m above the seafloor using...
a Nikon E959 camera in pressure housing mounted on the ROV Jason II. Individual coral colonies were labeled (Fig. 3). Close-up images of individual corals from a side-looking perspective were obtained from frame grabs using a dedicated NDS/AIVL Adimec 2000 HDTV digital video camera mounted on the ROV Jason II vehicle frame and the starboard manipulator of DSV Alvin. Close-up imagery was used for assessment of impact to all corals that could be approached by ROV Jason II or DSV Alvin without damaging other corals. Bare skeleton above the coral’s basal region, obviously damaged tissue (strands of mucus or loose tissue hanging from the skeleton), and areas covered by floc were scored as impacted. Levels of impact were broadly binned into five categories according to the percentage of the impacted portion of the colony showing impact: rank 0, 0–1% of the colony impacted; rank 1, 1–10% of the colony impacted; rank 2, 10–50% of the colony impacted; rank 3, 50–90% of the colony impacted; or rank 4, >90% of the colony impacted. In three cases in which the ranking category changed between the November and December visits, reexamination of images and the original video did not substantiate significant changes in the corals, and the higher-quality images obtained from DSV Alvin in December were used for the overall rankings (Fig. 3). All images can be accessed through the US National Oceanographic Data Center (accession no. 0084636).

Coral and Invertebrate Associate Collection. Corals and their associated ophiuroids were collected by the ROV Jason II and DSV Alvin in October and December 2010, respectively. The manipulator claws were modified with a cutting blade to aid in the collection of host corals and attached ophiuroid associates. Individuals were collected into temperature-insulated biobags on the sea floor and processed immediately after recovery of the vehicles. Approximately 2 to 3 cm of a coral branch or arms of individual ophiuroids were subsampled and frozen at −80 °C or in 70% ethanol for shore-based morphological and genetic analyses. Voucher specimens were either preserved in 95% ethanol or dried.

Microscopic Examination. Tissue necrosis and the presence of bare skeleton were documented on a Leica S6D microscope with an attached Nikon D300 camera.

Ooctoral Identification. Octocorals were identified to the lowest possible taxon using molecular barcodes and morphological characters (following refs. 30–32). DNA was extracted from frozen or preserved (95% ethanol) specimens using the Qiagen DNeasy kit. The 5′ end of the mitochondrial msh gene and the COI+igr region were PCR amplified (33). Sequences were edited, combined with related sequences from GenBank, and aligned by ClustalW, resulting in a 1,430-bp region. Bayesian phylogenetic inference was conducted using the GTR+G+I model (MrBayes v3; number of generations = 2,000,000; sample frequency = 100; burnin = 5,000). Because the original video did not substantiate significant changes in the corals, and the higher-quality images obtained from DSV Alvin in December were used for the overall rankings (Fig. 3). All images can be accessed through the US National Oceanographic Data Center (accession no. 0084636).

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Oil Analysis. Samples were solvent extracted and purified with fully activated silica gel. Extracts were analyzed for hydrocarbons via GC-FID, gas chromatography–mass spectrometry (GC-MS), and comprehensive GC×GC. For quantification and identification, GC×GC was coupled to an FID (GC×GC-FID), and identities of biomarkers were confirmed by coupling with MS (GC×GC-MS). SI Materials and Methods provides a complete discussion of these analyses.

Supporting Information

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SI Materials and Methods

Hydrocarbon Extraction and Purification. One GF/F filter containing the occluded material was taken from each coral sample and extracted using a Microwave Accelerated Reaction System at 100 °C and 800 W for 30 min with 20 mL of methanol:dichloromethane (DCM:MeOH, 9:1). Extracts were reduced in volume, and 50% of the extract was archived. The remaining 50% was solvent exchanged into hexane and charged onto a glass column (8 cm x 0.6 cm) packed with fully activated silica gel (100–200 mesh). The column was eluted with 4 mL of 5% DCM in hexane (F1), 1:1 DCM hexane (F2), 1% formic acid in DCM (F3), and 1% formic acid in MeOH (F4). The F1 fraction was analyzed for hydrocarbons via gas chromatography (GC). The combined F1 and F2 fraction was analyzed for polycyclic aromatic hydrocarbons via gas chromatography–mass spectrometry (GC-MS).

One-Dimensional Gas Chromatography. Extracts were analyzed on a 1D Agilent 7890 series gas chromatograph interfaced to a flame ionization detector (FID). Compounds were separated on a J&W DB-XLB capillary column (30 m, 0.25 mm internal diameter (I.D.), 0.25-μm film) with helium carrier gas at a constant flow of 1 mL min⁻¹. The GC oven had an initial temperature of 40 °C (1 min hold) and was ramped at 5 °C min⁻¹ until 320 °C (15 min hold). Contributions of an unresolved complex mixture (UCM) to the extracts were quantified by integrating the total FID area.

Gas Chromatography–Mass Spectrometry. The samples were analyzed on an Agilent 7890 series gas chromatograph with an Agilent 5975 mass selective detector (MSD). The MSD was operated in the selected-ion monitoring mode for quantification of target polycyclic aromatic hydrocarbon (PAHs). Compounds were separated on a J&W DB-XLB capillary column (60 m, 0.25 mm I.D., 0.25-μm film) with helium carrier gas at a constant flow of 1 mL min⁻¹. The GC oven had an initial temperature of 50 °C (1 min hold) and was ramped at 10 °C min⁻¹ until 320 °C (37 min hold). Parent PAHs and alkylated PAHs were identified using standard solutions prepared from the National Institute of Standards and Technology Standard Reference Material 2260 “Aromatic Hydrocarbons in Toluene.”

Comprehensive 2D Gas Chromatography (GC×GC). GC×GC-MS and GC×GC-FID conditions were similar to methods previously described (1). GC×GC-FID was primarily used for both identification and quantification. Briefly, first-dimension separations were performed on a nonpolar column (Restek Rtx-1, 60 m length, 0.25 mm I.D., 0.25-μm film thickness) that was programmed to remain isothermal at 100 °C for 0.5 min and then ramped from 110 to 155 °C at 10 °C min⁻¹, then 155 to 305 °C at a ramp rate of 0.66 °C min⁻¹, resulting in a boiling point separation. Compounds eluting from the first-dimension column were cryogenically trapped, concentrated, focused, and reinjected (modulated) onto a second-dimension column. The second-dimension separations were performed on a 50% phenyl polysilphenylene-siloxane column (SGE BPX50, 1.50 m length, 0.10 mm I.D., 0.1-μm film thickness), programmed to remain isothermal at 105 °C for 0.5 min, and then ramped from 105 to 160 °C at 10.0 °C min⁻¹, then 160 to 310 °C at a ramp rate of 0.66 °C min⁻¹, to yield a polarity-base separation. The carrier gas was hydrogen at a constant flow rate of 1.00 mL min⁻¹. The FID detector signal was sampled at 100 data points s⁻¹.

GC×GC–TOF-MS was used to confirm identities. The GC×GC–TOF-MS GC×GC-FID with the following exceptions: the main GC oven on the Pegasus GC×GC-TOF system is a 6890N, the carrier gas used was helium instead of hydrogen, the first-dimension column on the GC×GC-TOF system was a Restek Rtx-1, (30 m length, 0.25 mm I.D., 0.25-μm film thickness), and the second-dimension column was a SGE BPX50 (1.25 m length, 0.10 mm I.D., 0.1-μm film thickness). The TOF-MS detector signal was sampled at a data rate of 50 spectra per second. The transfer line from the second oven to the TOF-MS was deactivated fused silica (0.5 mm length, 0.18 mm I.D.), which was held at a constant temperature of 275 °C. The TOF source temperature was 225 °C, the detector voltage was 1,575 V, the mass scan range was 50–650 amu, and the mass defect was manually set at 100.8 mu/100u (optimized for C27 steranes). The mass spectrometer employs 70 eV electron ionization and operates at a push pulse rate of 5 kHz, allowing sufficient signal averaging time to ensure good signal-to-noise ratios, while still operating at a high enough data acquisition rate to accurately process (signal average) spectra from peaks that elute from the second dimension column in this high-resolution separation technique.

Fig. S1. Acoustic amplitude map from 3D seismic data with bathymetry overlay. The acoustic signal for conventional 3D seismic data used in this study is generated by 100-Hz airguns. The acoustic amplitude response of the reflected sound is controlled by the hardness and thickness of the seafloor and subsurface stratigraphic layers. Authigenic carbonate hardgrounds formed at hydrocarbon seep sites cause high positive amplitude response (red, green, and yellow), soft bottom muds have a background response of blue and white, and very soft, gaseous muds at high flux vent sites appear white. Data courtesy of TGS-NOPEC. The Macondo well is shown as a star on map, and MC 294 is indicated as a filled circle.
Fig. S2.  (A) Bayesian inference of octocoral species that occur at MC294 and control sites (in bold) along with similar haplotypes downloaded from GenBank (indicated by accession number). Additional Paramuricea haplotypes (A–E) collected from Gulf of Mexico control sites were also included in analyses. Bayesian posterior probabilities denoted by an asterisk (*) are >95% at each node. Sequences for the msh gene are deposited in GenBank under JQ241244 through JQ241252 and the COI+igr region under JQ411462 through JQ411469. (B) Neighbor-joining tree of deep-water ophiuroid species in the Gulf of Mexico (in bold), along with other closely related species downloaded from GenBank (indicated by accession number) on the basis of a portion of the 16S mitochondrial gene. Asteroschema clavigerum was the identified ophiuroid epibiont on Paramuricea at MC294 and DC673. Bootstrap support from 500 replicates of >95% are denoted by an asterisk (*). Ophiuroid sequences are deposited in GenBank under JQ771615 through JQ771617. Both trees were rooted at the midpoint.
Fig. S3. Down-looking mosaic of central area of MC 294 coral site. Fifty-eight individual coral colonies on two carbonate slabs were identified and labeled (indicated by both red and yellow circles). Corals that were partially sampled for analyses in this study are shown in yellow and those that were not sampled are shown in red.

Fig. S4. Microscopic images of Paramuricea biscaya (coral E3) collected on Alvin dive 4,662 from MC294. (A) Proximal bare gorgonin and calcite skeleton of the colony with two polyps attached in different states of decay. Denuded polyp consisting primarily of calcite spicules on the left, and a mostly intact polyp on the right. (B) Distal end of one of the branches with spicules in the form of a polyp and a relatively healthy polyp still covered in some of the sampled flocculent material. (C) Small branch with three polyps in varying states of decay, from the proximal polyp mostly covered in tissue with enlarged sclerites, to a polyp with a few enlarged sclerites in the middle, and a relatively healthy polyp showing some evidence of enlarged sclerites protruding from the tissue at the distal tip of the branch.
Fig. S5. Ophiuroids (*Asteroschema clavigerum*) living in association with the octocoral *Paramuricea biscaya* at MC294 in November 2010 (A) and December 2011 (B). Ophiuroids (e.g., white arrow) were notably lighter in color than previous in situ documentation and apparently transitioned from an attachment of “tightly-coiled” arms to “splayed-out” arms, which is a previously undocumented behavior in this ophiuroid species. Anemones observed at the nodes of internal branches appeared unchanged over this time. Field of view across the bottom of A and B is approximately 0.9 m and 1.2 m, respectively.

Fig. S6. Photographs of the brown flocculent material collected from (A) coral F6; (B) coral E3; (C) coral B8; and (D) coral A5.
Fig. S7. A portion of GC×GC chromatographic plane (3D surface rendering or mountain plot) for the Macondo well crude oil (MW-1). The x and y axis represent the first and second dimension retention time, and the z axis represents detector signal intensity. Labeled compounds are as follows: 1, 13β(H),17α(H)-20S-diacholestane (DiaC27βα-20S); 2, 13β(H),17α(H)-20R-diacholestane (DiaC27βα-20R); 3, 5α(H),14β(H),17β(H)-20R-cholestan-3-one (C27αββ-20R); 4, 24-ethyl-13β(H),17α(H),17α(H)-20S-diacholestane (DiaC27βα-20S); 5, 5α(H),14β(H),17β(H)-20R-cholestan-3-one (C27αββ-20S); 6, 24-ethyl-5α(H),14β(H),17β(H)-20R-cholestan-3-one (C27αββ-20R); 7, 24-ethyl-5α(H),14β(H),17β(H)-20S-cholestan-3-one (C27αββ-20S); 8, 24-ethyl-5α(H),14β(H),17β(H)-20S-cholestan-3-one (C27αββ-20S); 9, 18α(H)-22,29,30-triarnhydrocarbon (Ts); 10, 17α(H)-22,29,30-triarcholestan-3-one (Ts); 11, 17α(H),21β(H)-30-norhopane (NH); 12, 17α(H),21β(H)-30-norhopane (NH); 13, 17α(H),21β(H)-30-norhopane (NH); 14, 17α(H),21β(H)-30-norhopane (NH); 15, 17α(H),21β(H)-30-norhopane (NH); 16, 17α(H),21β(H)-30-norhopane (NH).

Fig. S8. A portion of GC×GC chromatographic plane (3D surface rendering or mountain plot) rotated from the representation used in Fig S7 to focus on the hopanoid region for samples (A) Macondo well crude oil, (B) surface water oil sample (S1), (C) coastal water oil reference sample (M1), (D) coral B8, (E) sediment 4664 0-2 cm, and (F) sediment 4662 0-2 cm. The region of the GC×GC chromatographic plane shown for each sample is the same. The yellow arrow is used to label the first dimension and the white arrow labels the second dimension.
Fig. S9. A portion of GC×GC chromatographic plane (3D surface rendering or mountain plot) focused on the sterane region for samples (A) Macondo well crude oil (MW-1) and (B) coral B8. The region of the GC×GC chromatographic plane shown for each sample is the same and identical to that shown in Fig. S7.