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ECOGIG: Oil Spill Effects on Deep-Sea Corals Through the Lenses of Natural Hydrocarbon Seeps and Long Time Series

By Erik E. Cordes, Steven Auscavitch, Iliana B. Baums, Charles R. Fisher, Fanny Girard, Carlos Gomez, Jennifer McClain-Counts, Howard P. Mendlovitz, Miles, Styles Smith, Samuel Vohsen, and Alaina Weinheimer

The 2015 Ecosystem Impacts of Oil and Gas Inputs to the Gulf (ECOGIG) expedition was a continuation of a three-year partnership between our Gulf of Mexico Research Institute-funded research consortium and the Ocean Exploration Trust to study the effects of oil and dispersant on corals and closely related communities affected by the 2010 Deepwater Horizon oil spill (White et al., 2012, 2014; Hsing et al., 2013; Fisher et al., 2014a,b; Figure 1A– C). As part of our analysis, we explored a new site to the west of the Macondo well in lease block Mississippi Canyon (MC) 462 where we examined 50 new corals for impact from the spill (Figure 1D). A total of over 250 corals were re-imaged in 2015 for this ongoing time-series study. Another goal was to initiate a study to determine how proximity to natural seeps affects corals and infauna in these communities.

On this cruise, four new study sites were established in areas that host large coral communities: Atwater Valley 357, Green Canyon 234, Mississippi Canyon 751, and Mississippi Canyon 885. In each area, we established two sets of study sites, one close to seeps and another away from any visual evidence of seepage. At some of these hydrocarbon seep sites, one coral species in particular, *Callogorgia delta* (Figure 2F), is able to survive and, in fact, thrives (Quattrini et al., 2013). Stable carbon ($\delta^{13}C$) and nitrogen ($\delta^{15}N$) isotope analyses of tissue samples revealed that some of the corals collected near signs of active seeps have incorporated seep primary production into their tissues (unpublished data of author Charles R. Fisher). Other subsamples from the corals will be used to determine whether exposure to oil and gas induces changes in gene expression either in the corals or the microbial communities associated with the corals. Metabolomic analysis of coral tissues is also in progress to determine whether the metabolomes (the complete sets of small-molecule chemicals found within biological samples) of corals collected near and far from active seeps differ. These studies will improve our understanding of observed responses documented in corals exposed to high concentrations of oil and dispersant during the Deepwater Horizon oil spill.

Also during this expedition, we collected a variety of corals at four different sites spanning a depth range from 394 m to 1,060 m for laboratory-based analyses and experiments with live specimens (Figure 2). These collections included the scleractinian coral *Lophelia pertusa*, the black coral *Leiopathes glaberrima,* and the octocorals *Paramuricea* sp., *Callogorgia delta, Muriceides* sp., *Chrysogorgia* sp., *Clavularia rudis,* and two colonies that represent two different species of bubblegum corals. *Lophelia pertusa, Callogorgia delta, Muriceides* sp., *Paramuricea* sp., and *Leiopathes glaberrima* were kept alive during the cruise and transported to Temple University and Pennsylvania State University, where marine aquaria in our laboratories provide their basic requirements for survival and growth. Keeping live corals enables us to conduct experiments that will help to answer questions related to the corals' responses under different anthropogenic stressors such as climate change and oil exposure. After six months, these corals remain in excellent condition (Figure 3), and some of them have grown measurably. Corals were also collected for morphological analyses to address questions related to their ecology and evolution, and to determine how the different environmental conditions

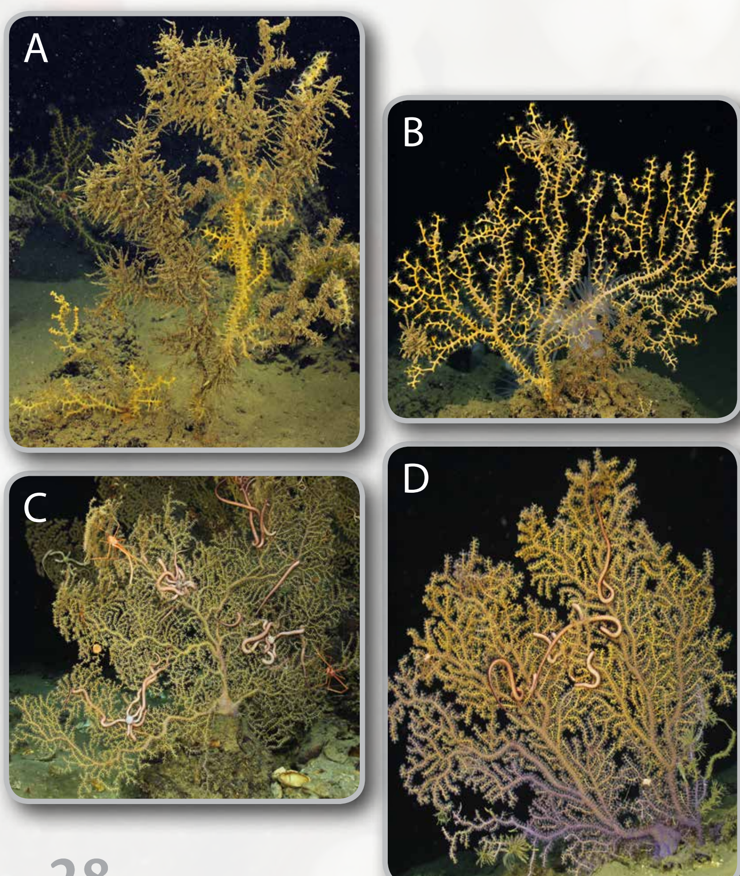

Figure 1. Images taken in 2015 for monitoring of coral impact and recovery from the 2010 Deepwater Horizon oil spill in the Gulf of Mexico. (A) *Paramuricea biscaya* at the first site observed with damaged corals in lease block Mississippi Canyon (MC) 294. Note extensive hydroid growth over most of the remaining colony branches. (B) *Paramuricea biscaya* from the site in lease block MC 297 first seen in 2011, with patchy hydroid growth on damaged portions of the colony. (C) *Paramuricea* sp. b3 from a control site in lease block Atwater Valley 357, with associated brittle stars and crabs and no apparent damage to the colony. (D) *Paramuricea* sp. b colony from a new site for this study in lease block MC 462, with attached brittle star and hydroid growth on damaged portions near the sediment surface.

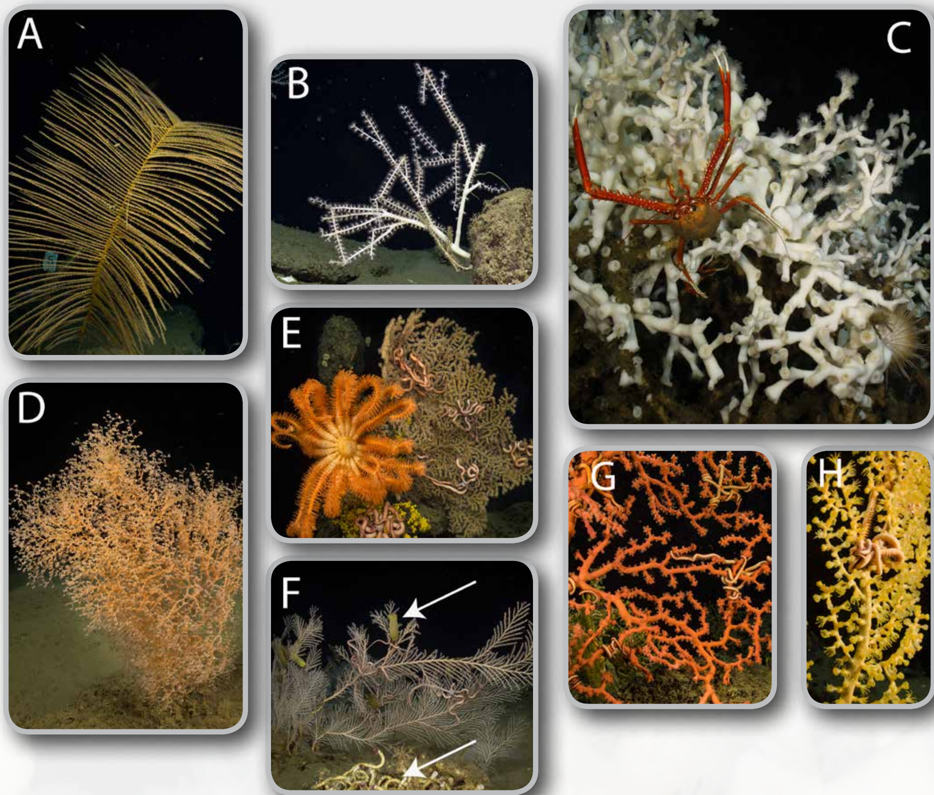

Figure 2. Representative deep-sea corals photographed and collected during *Nautilus* cruise NA057. (A) Black coral *Bathypathes* in lease block MC 344 at 1,850 m depth. (B) Bamboo coral (Subfamily Keratoisidinae) found at ~1,800 m depth in MC 344. (C) *Lophelia pertusa* from Viosca Knoll 906 photographed at 400 m depth. (D) *Chrysogorgia* sp. found at ~960 m depth in MC 462. (E) In a typical deep-sea association, octocorals of the genus *Paramuricea* and different species of brittle stars and sea stars top a small boulder in a photograph taken in MC 462 at ~1,000 m depth. (F) *Callogorgia delta* were often observed growing close to seepage activity in association with the tube worm *Lamellibrachia luymesi* (bottom arrow) and scyliorhinid catshark egg cases, which attach to branches (upper arrow). MC 885 is at ~640 m depth. (G) Bubblegum coral *Paragorgia* cf. *regalis* photographed in MC 294 at 1,370 m depth. (H) *Paramuricea* cf. *biscaya* with a brittle star associate, also in MC 294.

found at various depths affect patterns of community assembly.

Seawater samples were collected with Niskin bottles mounted on the remotely operated vehicle (ROV) *Hercules* directly above different *L. pertusa* reefs to characterize the seawater chemistry around these coral mounds. These samples will be used to continue our investigations on the effects of ocean acidification in coral habitats. *L. pertusa* has been shown to survive and grow under some of the most adverse conditions known for colonial stony corals (Lunden et al., 2013; Georgian et al., in press), and we continue to examine the processes that underlie these abilities in order to provide insight into the responses of all scleractinian corals to ocean acidification.

Sediment push cores also were collected for multiple analyses, including microbiome, macrofaunal abundance and biodiversity, isotope ($\delta^{13}C$, $\delta^{14}C$, and $\delta^{15}N$), and particle size. Sediments were collected adjacent to corals sampled in previous years in order document further changes and potential recovery of the macrofaunal community structure following the oil spill. As part of our study of the microbes associated with corals and the effects of natural seepage on the coral microbiome, we examined the microbial communities found in sediment beneath coral colonies, as well as from the water around the corals. In order to collect enough bacteria from the water near the corals for this study, we used a submersible pump (McLane Research Laboratories model WTS-LV) on loan from the Max Planck Institute for Marine Microbiology in Bremen, Germany. The pump filtered bacteria from 40 liters of water near the corals while *Hercules* was busy with other tasks on the seafloor.

Together, these studies provide a holistic view of the ecology and physiology of deep-sea corals in their habitats. By combining the expertise of investigators with diverse interests, we hope to gain a better understanding of these remarkable ecosystems. It is only through this integrative approach that we can fully understand the response of corals to anthropogenic impacts and work to preserve them from future human disturbance in deep waters.

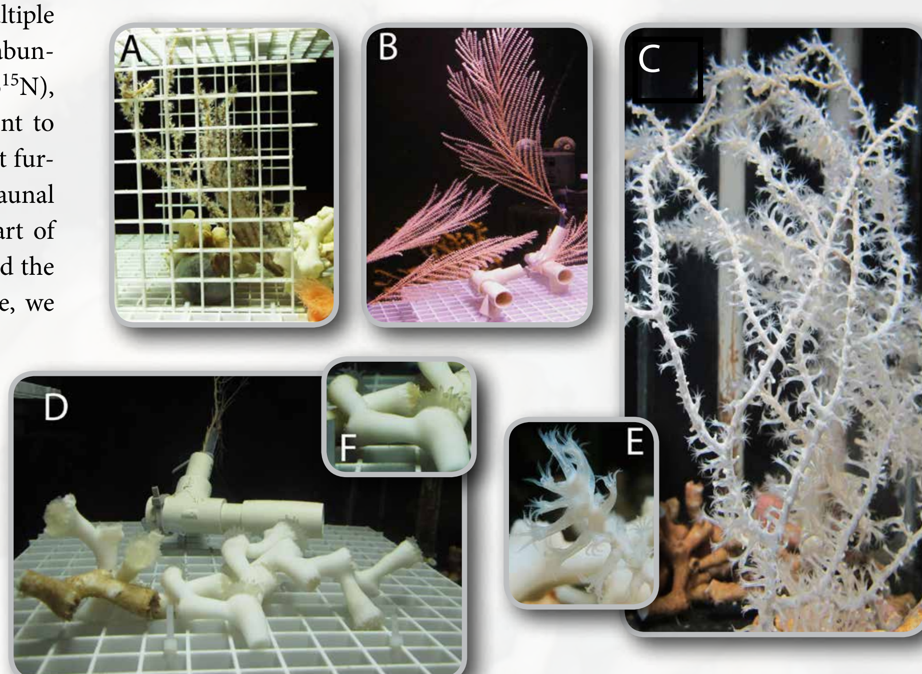

Figure 3. Octocoral colonies collected at 445 m water depth in MC 751 during *Nautilus* cruise NA057 and kept alive at Temple University. (A) *Paramuricea* sp. (B) *Callogorgia delta*. (C and E) *Muriceides* cf. *hirta*. (D and F) The scleractinian coral *Lophelia pertusa* collected at Viosca Knoll 906 at 400 m depth.

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