Investigations of Chemosynthetic Communities on the Lower Continental Slope of the Gulf of Mexico

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LONG-TERM GOALS

The long-term goals of this study are to add to the understanding of the oceanography and ecology of the deep-sea with emphasis on cold seep communities and hard bottom communities on the Gulf of Mexico (GoM) continental slope. Preliminary studies have shown that seep communities at the slope base are different from those on the upper slope, in much the same way that the normal background fauna differ. Compared to the upper-slope, there is limited understanding of seep and other hard bottom communities below 1,000 meters in the Gulf of Mexico.

OBJECTIVES

The objectives of this study are: Characterize known, or newly discovered chemosynthetic communities at depths below 1,000 meters in the central and western Gulf of Mexico. Characterize all other hard bottom biological communities encountered regardless of association with active hydrocarbon seep activity or living chemosynthetic community species in the central and western Gulf of Mexico. Determine the comparative degree of sensitivity of anthropogenic impacts for the above through a variety of approaches such as rarity, unique taxonomy/biodiversity, or other environmental risk assessment methodologies. Understanding how these deep communities are similar or different from their shallower water counterparts. Further develop successful assessment methodologies for correlation of remote sensing information such as bathymetry, seabed acoustic reflectivity, sub-bottom structure, and other geophysical signatures obtained by non-visual techniques with the “potential” presence of non-soft bottom biological communities at depths below 1,000 meters. The target objective is to provide some level of predictive capability that can be used by MMS to avoid impacts to lower slope sensitive biological communities such as presented by Roberts (2001) for upper slope communities. Assess and explain diversity distribution and abundance of marine species at depths below 1,000 m in the central and western Gulf, as well as improve the understanding of the functional role of marine species in areas of active hydrocarbon seep activity or living chemosynthetic communities. These objectives will be accomplished through a combination of both exploratory work and more focused studies including process-based work on known communities.

APPROACH AND WORK PLAN

In order to meet the objectives outlined above, the following scientific and technical plan is being implemented.

- Compile and analyze all of the appropriate available data to predict the location of significant chemoautotrophic or other hard-bottom communities at depths >1,000 m in the GoM. This resulted in the selection of 10 – 20 sites for visitation during the Reconnaissance Cruise. In addition to providing specific locations for most of the dives for the first submersible cruise, ground-truth data collected during the Reconnaissance Cruise allowed evaluation of the predictive value of the various criteria used for site selection and provides data on the types of communities present at the sites. of these data (geophysical and geochemical predictors, and presence/absence of various community types) These analyses were further enriched with multivariate analysis and when selected sites were more intensively imaged and sampled for macro and microbiology and chemistry. A third level of information comes from mapping community occurrence type and density onto the high resolution maps of surficial geology and seafloor topography made at of each of the three to four primary study sites. The“sub-goal” here is to enrich the predictive value of

these high-resolution data sets to include the occurrence of different types of communities/ habitats on a spatial scale of meters.

- Characterize types of significant hard bottom communities encountered. First order community characterization will be identification of component taxa and descriptions of communities present at different sites. Second order characterizations will include distributions and abundances of taxa with respect to chemistry and surficial geology and measures of community structure and function. Third order characterizations/analyses will include interactions with background fauna, taxonomic relations of species from key taxa to related species at other depths and in other areas, and community-level comparisons among sites and related communities at other depths and areas. All sites visited by submersible or ROV are characterized with respect to surficial geology, geochemistry of sediments and epibenthic bottom water, types of communities present, microbial activities, and mega/macrofaunal species present. At four sites more extensive survey and experimentation was conducted to better characterize and understand the communities, and test hypotheses relating to community composition, tubeworms, trophic interactions, and microbiology. During the submersible and ROV cruises we collect imagery that provides data on endemic species occurrence, distribution and densities, and visitation by vagrant mobile megafauna. We make quantitative collections of communities that provide the material needed for taxonomic, biogeographic, and trophic studies, and analyze the collections in ways that provide a variety of data on community structure and function as well as composition. *In situ* chemical measurements were made to describe the microhabitat chemistry of the major community types. Faunal distributions are mapped with respect to surficial geology and chemistry. The microbial communities in the sediments are characterized and temporal studies of the communities initiated (with time lapse camera, base line imaging, and growth).
- Descriptions of the communities encountered and analyses of background fauna trapped, trawled and imaged over the course of the study will contribute to the assessment of diversity, distributions, and abundance of marine species below 1,000 m in the GoM. Correlation analyses of faunal occurrence with geologic features and seep chemistry will further contribute to the explanation of these patterns. Trophic analyses, time-lapse camera data, community analyses, and growth studies greatly improve our understanding of the functional role of many of the marine species encountered. By working under the auspices of the Census of Marine Life ChEss program and providing all data collected to their database, we assure widespread international access to all biodiversity and biogeography data collected.
- Direct determination of sensitivity of individual species to particular potential anthropogenic impacts is addressed through assessment of rarity and unique taxonomy/biogeography of key species and communities, biodiversity of communities, and by interpretation made in the context of the degree of similarity to related communities on the upper Louisiana slope and what is known about those communities. The comparisons of community-level associations to similar communities elsewhere, and the proposed vestimentiferan growth studies will strengthen the power of these analyses. Existing collaborations with molecular and classical taxonomic experts will facilitate the identification of unknown species. The molecular analyses of foundation and other key species provide information necessary to detect significant levels of genetic isolation at any site, analyze relations to taxa at other sites, and determine bathymetric ranges of the meta-populations.

Key individuals participating in this work and their roles are: Dr. James Brooks (TDI-BI) is the project director and will take the lead in administration of this project and assist in the geochemical studies. Dr. Charles Fisher (PSU) coordinates the biological studies, Dr. Harry Roberts (LSU) coordinates the geological/geophysical studies, and Ms. Liz Goehring (PSU) coordinates the education and outreach

activities. Dr. Erik Cordes will work with Fisher's team on studies of seep communities and synthesis and publication of results for other hard bottom communities discovered. Dr. Stephane Schaeffer oversees molecular phylogenetic screening of foundation species and their symbionts (tubeworms, mussels and clams) and other potential new species (and symbioses), as needed. Dr. Robert Carney leads the studies of interactions with background fauna and trophic exchange between seep/hard bottom communities and larger mobile fauna. Drs. Fisher, Carney, and Cordes share responsibility for coordination with taxonomists and molecular phylogenists and proper curation of samples. Dr. Ian MacDonald directs the use of digital imagery in all phases of the study. Dr. Samantha Joye is responsible for the microbial ecology and sulfide geochemistry studies. Dr. Tim Shank (WHOI) will phylogentically characterize new species of megafaunal crustaceans and include at least the shrimp in his ongoing biogeographic analyses. Dr. Bob Vreijenhoek (MBARI) will do the same with clams and their symbionts and other gastropods as needed. Limpets and snails will be sent to Anders Waren (Swedish Museum of Natural History) and chitons to Julia Sigwart (University College Dublin) for morphological characterization. Dr. Stéphane Hourdez (Stacione Biologique de Roscoff, France) leads the polychaete phylogenetic characterizations and descriptions of new species of polynoids and siboglinids (using both molecular and classical approaches). He also assists with molecular characterization of foundation species. Dr. Stephane Cairns (Smithsonian) oversees curation and identification of cnidarians, with assistance of Daphne Fautine (University of Kansas) and Dennis Opreska (Oak Ridge). Dr. Cheryl Morrison (USGS Leetown Science Center) will include any samples of *Lophelia pertusa* collected in her ongoing studies of the phylogeography and population genetics of this foundation coral species and also collaborate with Dr. Cairns by contributing to the molecular systematics of other hard corals, as needed. Dr. Sabine Stohr (Swedish Museum of Natural History) has agreed to examine all ophuiroids collected. Dr. Monika Bright and her research team (Univ. Vienna) will sort and identify meiofauna collected with mussel and tubeworm communities and in sediment cores. Other faunal groups will be sent to appropriate experts as needed. Additionally, two internationally recognized research groups from the Max Planck Institute of Marine Microbiology in Bremen will bring unique expertise and equipment to bear on the study. Dr. Nicole Dublier's group will use quantitative mRNA analyses to determine the relative activities of chemoautotrophic and methanotrophic symbiont populations in the dual symbiont-containing mussels. Dr. Antje Botieus' group will bring their *in-situ* seep-chemistry analysis system and expertise on the ALVIN and ROV cruises. Dr. Bernie Bernard coordinates the isotope, hydrocarbon and ancillary measurements. Dr. Thomas McDonald is the principal hydrocarbon chemist for the project. Dr. Gary Wolff is the project data manager, Ms. Susan Wolff is the project's technical editor. Ms. Suzanne Cardwell provides financial and project administrative support.

The planned work will be primarily with analysis and interpretation of data collected from the completed field work.

WORK COMPLETED

The historical data review was completed the beginning of 2006. The Reconnaissance Cruise was conducted on the TDI-Brooks research vessel R/V GYRE from 11 to 25 March 2006, using over-the-side imaging equipment and shipboard acoustic methods and was the initial cruise conducted for this contract. The cruise was completed in two, week-long legs with an interim port call in Venice, LA. Leg I (11-18 March) was dedicated to drift camera work to survey the seabed at selected sites. Leg II (19-25 March) involved both drift camera and trawling/box core work efforts for isotopic characterization of the seep-background interactions near seep sites in the deep GoM. Twenty-four sites were studied. The cruise mobilized and embarked from Freeport, Texas. The objective was to

provide timely input for the site selection process for the subsequent ALVIN expedition (May 2006). The Deep Chemosynthetic Community Characterization Cruise (DCCC) was conducted on the Wood's Hole Oceanographic Institute (WHOI) research vessel R/V ATLANTIS and the ALVIN Deep Submergence Vehicle (DSV) from 7 May – 2 June 2006, and was the second cruise conducted for this contract. The cruise mobilized and embarked from Key West, Florida, and de-mobilized at Galveston, Texas. Twenty-four dives were completed on ALVIN. At some sites, multiple dives were made while at other sites only a single dive was completed. The Deep Chemosynthetic Reconnaissance II Cruise (DCR2) was conducted on the NOAA Ship research vessel *Ronald H. Brown* and the ROV JASON from 4 June - 6 July 2007, and was the fourth cruise conducted for this contract. The cruise mobilized and embarked from Panama City, Florida, and de-mobilized at Galveston, Texas. Post-cruise reports were completed for all cruises and were submitted to MMS. The data from these two cruises was up-loaded to a site located on the TDI-Brooks International Website. All program researchers have password-protected access to these data.

RESULTS

Reconnaissance Cruise - Trawls were completed at three sites, MC685, MC548 and AT209. Two box cores were collected at site WR265, survey photos captured with the bottom in view (BIV) were 10,922, site characterization and evaluation was completed on 24 sites. DCCC Cruise – Multiple dives were made at four sites and the geology, geochemistry, microbiology and biology of the sites thoroughly characterized using growth rate analysis. Push cores were collected for geological, geochemical, and microbial analyses, chemical analysis, quantitative collections of other tubeworm communities, mussel beds, and clam beds were made. Trawls were completed, traps and cameras were used to capture and identify the visitors to the seep and coral communities. A rotary camera was left on the bottom for up to a year. More than 14,000 down-camera and 400 macro images were recorded. DCR2 - Sixteen dives with the ROV JASON provided essential information on the ecology and biodiversity of these deep-sea communities.

IMPACT AND APPLICATIONS

National Security

This program will provide critical information on the location and function of seep communities to MMS. As manager of the nation's seafloor mineral resources, MMS will use this information to aid in the development of critical energy resources, which may affect domestic energy production.

Economic Development

Increased energy and mineral production will have a positive economic impact at numerous levels in industry.

Quality of Life

Information on the location and functioning of seep communities gathered by this program will have a positive impact on other ocean users, the natural environment, and the human environment. It will aid in minimizing the environmental impact on sensitive habitat and mitigate any potential damage to these communities.

Science Education and Communication

Education outreach efforts outside of the cruise website and since the last report have focused on the merging the MMS deep slope outreach with the development of FLEXE. FLEXE (From Local to

Extreme Environments) is one of four major NSF-funded projects within the GLOBE program (www.globe.gov), bringing the remote environments of hydrothermal vents and cold seeps for the first time to GLOBE. GLOBE is a NASA and NSF funded web-based science education program emphasizing K-12 Earth System Science concepts, and is currently operating in 109 countries involving over 17,000 schools and over one million students worldwide. As the name suggests, FLEXE guides students in understanding deep-sea extreme environments through a comparison with analogous local environmental measures. FLEXE builds on the success of the SEAS "Classroom to Sea" lab concept and extends it by embedding these labs in curricular units built on Earth Systems Science essential concepts. The FLEXE project started in 2006, completed initial pilot testing in Spring 2007 and is currently testing the full system and first curricular unit this Fall 2007.

TRANSITIONS

Data is provided to the ChEss database, which is a component of the Census of Marine Life (CoML) Ocean Biogeographic Information System (OBIS) data base. All gene sequences will be submitted to the international genetic data base, GenBank. The work proposed here will contribute significantly to the goals of the Atlantic Equatorial Belt studies of the ChEss program, particularly the components that will allow interpretation of our findings in the context of seeps around the world. The second component of the CoML program relevant to this project is the CoMargE component. Dr. Carney, co-director of CoMargE and supported by the MMS Coastal Marine Program, will transfer past MMS survey data into the CoML OBIS database system.

RELATED PROJECTS

- Chemosynthetic Ecosystems Study (MMS Report 95-0021). http://www.gomr.mms.gov/homepg/regulate/environ/studies/1995/95-0021%20Vol%20I.pdf.
- Stability and Change in Gulf of Mexico Chemosynthetic Communities (MMS Report 2002-036). http://www.gomr.mms.gov/homepg/regulate/environ/studies/2002-036.pdf.
- The Deepwater Program: Northern Gulf of Mexico Continental Slope Habitat and Benthic Ecology (MMS contract 1435-01-99-CT-30991).
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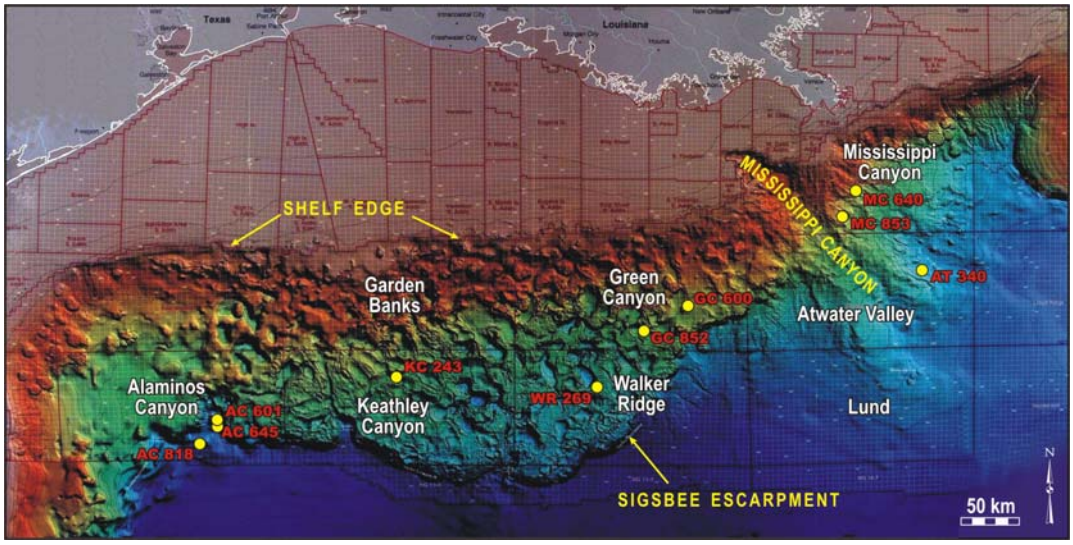

Figure 1. Site locations of JASON dives.

REFERENCES RELATED TO THIS PROJECT

Adkins, J.F., H. Cheng, E.A. Boyle, E.R.M. Druffel, and R.L. Edwards. 1998. Deep-sea coral evidence for rapid climate change in ventilation of the deep North Atlantic 15,400 years ago. Science 280:725-728.

Adkins, J.F., E.A. Boyle, W.B. Curry, and A. Lutringer. 2003. Stable isotopes in deep-sea corals and a new mechanism for "vital effects". Geochim. Cosmochim. Acta 67: 1129-1143.

Aharon, P. and B.S. Fu. 2000. Microbial sulfate reduction rates and sulfur and oxygen isotope fractionations at oil and gas seeps in deepwater Gulf of Mexico. Geochim. Cosmochim. Acta 64:233-246.

Aloisi, G., I. Bouloubassi, S.K. Heijs, R.D. Pancost, C. Pierre, J.S.S. Damste, J.C. gottschal, L.J. Forney, J.M. Rouchy. 2002. CH4-consuming microorganisms and the formation of carbonate crusts at cold seeps. Earth and Planetary Science Letters 203:195-203.

Ambrose, R.F. and T.W. Anderson. 1990. Influence of an artificial reef on the surrounding infaunal community. Mar. Biol. 107:41-52.

Andersen, A.C., S. Hourdez, B. Marie, D. Jollivet, F.H. Lallier, and M. Sibuet. 2004. *Escarpia southwardae* sp. nov., a new species of vestimentiferan tubeworm (Annelida, Siboglinidae) from West African cold seeps. Can. J. Zool. 82: 980-999.

Andrews, A.H., E.E. Cordes, M.M. Mahoney, K. Munk, K.H. Coale, G.M. Cailliet, and J. Heifetz. 2002. Age, growth and radiometric age validation of a deep-sea, habitat-forming gorgonian (*Primnoa resedaeformis*) from the Gulf of Alaska. Hydrobiologia 471:101-110.

Arvidson, R.S., J.W. Morse, and S.B. Joye. 2004. The sulfur biogeochemistry of chemosynthetic cold seep communities, Gulf of Mexico, USA. Mar. Chem. 87: 97–119.

Bergquist, D.C., I.A. Urcuyo, and C.R. Fisher. 2002. Establishment and persistence of seep vestimentiferan aggregations from the upper Louisiana slope of the Gulf of Mexico. Mar. Ecol. Prog. Ser. 241: 89-98.

Bergquist, D.C., T. Ward, E.E. Cordes, T. McNelis, R. Kosoff, S. Hourdez, R. Carney, and C.R. Fisher. 2003a. Community structure of vestimentiferan-generated habitat islands from upper Louisiana slope cold seeps. J. Exp. Mar. Bio. Ecol. 289: 197-222.

Bergquist, D.C., J. Andras, T. McNelis, S. Howlett, M.J. van Horn, and C.R. Fisher. 2003b. Succession in upper Louisiana slope cold seep vestimentiferan aggregations: the importance of spatial variability. PSZN Mar. Ecol. 24:31-44.

Bergquist, D.C., C. Fleckenstein, J. Knisel, B. Begley, I. R. MacDonald, and C.R. Fisher. 2005. Variations in seep mussel bed communities along physical and chemical environmental gradients. Mar. Ecol. Prog. Ser 293:89-97.

Bett, B.J. 1997. Atlantic Margin Environmental Survey: Seabed Survey of the Shelf Edge and Slope west of Shetland. Published by Challenger Division for Seafloor Processes: Southampton Oceanography Centre, NERC/ University of Southampton. Pp.165.

Boetius, A., K. Ravenschlag, C. Schubert, D. Rickert, F. Widdel, A. Gieseke, R. Amann, B.B. Jørgensen, U. Witte, and O. Pfannkuche. 2000. A marine microbial consortium apparently mediating anaerobic oxidation of methane. Nature 407:623-626.

Brooks, J.M., D.A. Wiesenburg, H. Roberts, R.S. Carney, I.R. MacDonald, C.R. Fisher, N.L. Guinasso Jr., W.W. Sager, S.J. McDonald, R.A. Burke Jr., P. Aharon, and T.J. Bright. 1990. Salt, seeps and symbiosis in the Gulf of Mexico. EOS 71(45):1772-1773

Cairns, S.D. 1978. A checklist of the ahermatypic scleractinia of the Gulf of Mexico, with the description of a new species. Gulf Res. Rep.6: 9-15.

Cairns, S.D. 2001. A brief history of taxonomic research on azooxanthellate Scleractinia (Cnidaria: Anthozoa). Bull. Biol. Soc. Wash. 10:191-203.

Cairns, S.D., D.M. Opresko, T.S. Hopkins, and W.W. Schroeder. 1993. New records of deep-water Cnidaria (Scleractinia & Antipatharia) from the Gulf of Mexico. Northeast Gulf Sci. 13:1-11.

Carney, R.S. 1994. Consideration of the oasis analogy for chemosynthetic communities at Gulf of Mexico hydrocarbon vents. Geo-Mar. Let. 14:149-159.

Carney, R.S. 1997. Basing conservation policies for the deep-sea floor on current diversity concepts: a consideration of rarity. Biodiv. Conserv. 6:1463-1485

Carney, R.S. 2005. Zonation of deep biota on continental margins. Oceanogr. Mar. Biol. Ann. Rev. 43:211-278.

Cary, S.C. 1989. Multiple trophic resources for a chemoautotrophic community at a cold water brine seep at the base of the Florida escarpment. Mar. Biol. 100:411-418

Cary, S.C., C.R. Fisher, and H. Felbeck. 1988. Mussel growth supported by methane as sole carbon and energy source. Science 240:78-80.

Childress, J.J., C.R. Fisher, J.M. Brooks, M.C. Kennicutt II, R. Bidigare, and A.E. Anderson. 1986. A methanotrophic marine molluscan symbiosis: Mussels fueled by gas. Science 233: 1306-1308.

Clarke, K.R., and R.M. Warwick. 2001. Change in marine communities: An approach to statistical analysis. Primer-E, Plymouth, UK. 170 pp.

Cordes, E.E., D.C. Bergquist, K. Shea, and C.R. Fisher. 2003. High hydrogen sulfide demand of long-lived vestimentiferan tube worm aggregations modifies the chemical environment at deep-sea hydrocarbon seeps. Ecology Letters 6: 212-219.

Cordes, E.E., M.A. Arthur, K. Shea, and C.R. Fisher. 2005. Modeling the mutualistic interactions between tubeworms and microbial consortia. PLoS Biol. 3: e77.

Cordes, E.E., S. Hourdez, B.L. Predmore, M.L. Redding, and C.R. Fisher. In press. Succession of hydrocarbon seep communities associated with the long-lived foundation species *Lamellibrachia luymesi*. Mar. Ecol. Prog. Ser.

Craddock, C., W.R. Hoeh, R.G. Gustafson, R.A. Lutz, J. Hashimoto, and R.J. Vrijenhoek 1995. Evolutionary relationships among deep-sea mytilids (Bivalvia: Mytilidae) from hydrothermal vents and cold water methane sulfide seeps. Mar. Biol. 121(3):477-485

De Beukelaer, S.M., I.R. MacDonald, N.L. Guinnasso, and J. A. Murray. 2003. Distinct side-scan sonar, RADARSAT SAR, and acoustic profiler signatures of gas and oil seeps on the Gulf of Mexico slope. Geo-Marine Letters 23(3-4):177-186.

Dhillon, A., A. Teske, J. Dillon, D.A. Stahl, and M.L. Sogin. 2003. Molecular characterization of sulfate-reducing bacteria in the Guaymas Basin. App. Env. Microbiol. 69: 2765-2772.

Dodge, R.E. and J. Thomson. 1974. The natural radiochemical and growth records in contemporary hermatypic corals from the Atlantic to the Caribbean. Earth Planet Sci 36:339-356.

Dodge, R.E. and G.W. Brass. 1984. Skeletal extension, density, and calcification of the reef coral, *Montastrea annularis*: St. Criox, U.S. Virgin Islands. Bull Mar Sci 34:288-307.

Doerries, M.B. and C.L. Van Dover. 2003. Higher-taxon richness as a surrogate for species richness in chemosynthetic communities. Deep-Sea Res. I 50:749-755.

Druffel, E.R.M., L.L. King, R.A. Belastock, and K.O. Buesseler. 1990. Growth rates of a deep-sea coal using ^{210}Pb and other isotopes.

Dunbar, R.B., G.M. Wellington, M.W. Colgan, and P.W. Glynn. 1994. Eastern Pacific sea surface temperature since 1600 A.D.: The ^{18}O record of climate variability in Galapagos corals. Paleoceanography 9:291-315.

Espedal, H. and T. Wahl. 1999. Satellite SAR oil spill detection using wind history information. Int. J. Remote Sensing 20(1):49-65.

Fisher, C.R. 1996. Ecophysiology of primary production at deep-sea vents and seeps. In: Deep-sea and extreme shallow-water habitats: affinities and adaptations. R. Uiblein, J. Ott, and M. Stachowtish (eds.) Biosystematics and Ecology Series 11: 311-334.

Fisher, C.R., J.J. Childress, S.A. Macko, and J.M. Brooks. 1994. Nutritional interactions at Galapagos hydrothermal vents: Inferences from stable carbon and nitrogen isotopes. Mar. Ecol. Prog. Ser. 103: 45-55.

Frazer, T.K., W.J. Lindberg, and G.R. Stanton. 1991. Predation on sand dollars by gray triggerfish, *Ballistes capriscus*, in the northeastern Gulf of Mexico. Bull. Mar. Sci. 48:159-164.

Frederiksen, R., A. Jensen, and H. Westerberg. 1992. The distribution of the scleractinian coral *Lophelia pertusa* around the Faroe Islands and the relation to internal mixing. Sarsia 77:157-171.

Freidwald, A., R. Heinrich, and J. Patzold. 1997. Anatomy of a deep water coral reef mound from Sternsund, west Finnmark, northern Norway: James, N.P. and J.A.D. Clarke Eds. Cool-water carbonates. Society for Sedimentary Geology, Special Volume 56:144-146.

Freytag, J.K., P. Girguis, D.C. Bergquist, J.P. Andras, J.J. Childress, and C.R. Fisher. 2001. Sulfide acquisition by roots of seep tubeworms sustains net chemoautotrophy. Proc. Nat. Acad. Sci. 98; 13408-13413.

Gardiner, S.L. and S. Hourdez. 2003. On the occurrence of the vestimentiferan tube worm Lamellibrachia luymesi van der Land and Nørrevang, 1975 (Annelida: Pogonophora) in hydrocarbon seep communities in the Gulf of Mexico. Proc. Biol. Soc. Wash. 116(2):380-394.

Gilliam, J.F. 1989. Strong effects of a foraging minnow on a stream benthic community. Ecology 70:445-452.

Glover, A.G. and C.R. Smith. 2003. The deep-sea floor ecosystem: current status and prospects of anthropogenic change by the year 2025. Conserv. Biol. 30:219-141.

Heifetz, J. 2002. Coral in Alaska: distribution, abundance, and species associations. Hydrobiologia 471:19-28.

Heikoop, J.M., J.J. Dunn, M.J. Risk, H.P. Schwarcz, T.A. McConnaughey, and I.M. Sandeman. 2000. Separation of kinetic and metabolic isotope effects in carbon-13 records preserved in reef coral skeletons. Geochem Cosmochim Acta 64:975-987.

Helmle, K.P., K.E. Kohler, and R.E. Dodge. 2002. Relative Optical Densitometry and The Coral X-radiograph Densitometry System: Coral*XDS*. Presented Poster, Int. Soc. Reef Studies 2002 European Meeting. Cambridge, England. Sept. 4-7.

Highsmith R.C. 1979. Coral growth rates and environmental control of density banding. J. Exp. Mar. Bio. Ecol. 37:105-125.

Hovland, M. and E. Thomsen. 1997. Cold-water corals- are they hydrocarbon seep related? Mar. Geol. 137:159-164.

Hovland, M., P.B. Mortensen, T. Brattegard, P. Strass, and K. Rokoengen. 1998. Ahermatypic coral banks off mid-Norway: Evidence of a link with seepage of light hydrocarbons. Palaios 13:189-200.

Hudson J.H., E.A. Shinn, R.B. Halley, and B. Lidz. 1976. Sclerochronology: a tool for interpreting past environments. Geology 4:361-364.

Ivany, L.C., W.P. Patterson, and K.C. Lohmann. 2000. Increase in seasonality across the Eocene-Oligocene boundary inferred from fossil otoliths. Nature 407:887-890.Jensen, A., and R. Frederiksen. 1992. The fauna associated with the bank-forming deepwater coral *Lophelia pertusa* (Scleractinia) on the Faroe shelf. Sarsia 77:53-69.

Ivany, L.C., K.C. Lohmann, and W.P. Patterson. 2003. Paleogene temperature history of the U.S. Gulf Coastal Plain inferred from ^{18}O of fossil otoliths, pp. 232-251. In:D.R. Prothero, L.C. Ivany and E.A. Nesbitt Eds. From Greenhouse to Icehouse, The Marine Eocene-Oligocene Transition. Columbia Univ. Press, New York.

Joye, S.B., A. Boetius, B.N. Orcutt, J.P. Montoya, H.N. Schulz, M.J. Erickson, and S.K. Lugo. 2004. The anaerobic oxidation of methane and sulfate reduction in sediments from Gulf of Mexico cold seeps. Chem. Geol. 205: 219–238.

Kennicutt II, M.C., R.H. Green, P. Montagna, and P.F. Roscigno. 1996. Gulf of Mexico Offshore Operations Monitoring Experiment (GOOMEX), Phase I: Sublethal responses to contaminant exposure-introduction and overview. Can. J. Fish. Aquat. Sci. 53:2540-2553.

Knittel, K., A. Boetius, A. Lemke, H. Eilers, K. Lochte, O. Pfannkuche, P. Linke, and R. Amann. 2003. Activity, distribution, and diversity of sulfate reducers and other bacteria in sediments above gas hydrate (Cascadia Margin, OR). Geomicrobiol. J. 20:269-294.

Knittel, K., T. Lösekann, A. Boetius, R. Kort, and R. Amann. 2005. Diversity and distribution of methanotrophic Archaea at cold seeps. Applied and Environmental Microbiology, pp. 467–479.

Kornacki, A.S., J.W. Kendrick and J.L. Berry. 1994. The impact of oil and gas vents and slicks on petroleum exploration in the deepwater Gulf of Mexico. Geo-Marine Letters 14(2/3): 160-169.

Koslow, J.A., K. Gowlett-Jones, J.K. Lowry, T. O'Hara, G.C.B. Poore, and A. Williams. 2001. Seamount benthic macrofauna off southern Tasmania: community structure and impacts of trawling. Mar. Ecol. Prog. Ser. 213:111-125.

Kulm, L.D., E. Suess, J.C. Moore, B. Carson, B.T. Lewis, S.D. Ritger, D.C. Kadko, T.M. Thornburg, R.W. Embley, W.D. Rugh, G.J. Massoth, M.G. Langseth, G.R. Cochrane, and R.L.

Scamman, 1986, Oregon subduction zone: Venting, fauna, and carbonates, Science, v. 231, p. 561-566.

Lanoil, B.D., R. Sassen, M.T. La Duc, S.T. Sweet, and K.H. Nealson. 2001. Bacteria and Archaea physically associated with Gulf of Mexico gas hydrates. Appl. Environ. Microbiol. 67(11):5143-5153.

Levin, L.A., W. Ziebis, G.F. Mendoza, V.A. Growney, M.D. Tryon, K.M. Brown, C. Mahn, J.M. Gieskes, and A.E. Rathburn. 2003. Spatial heterogeneity of macrofauna at northern California methane seeps: Influence of sulfide concentration and fluid flow. Mar. Ecol. Prog. Ser. 256: 123–139.

LGL Ecological Research. 1987. Northern Gulf of Mexico Continental Slope Study Technical Volume, Minerals Management Service, Gulf of Mexico OCS Regional Office**:** 632.

Lough, J.M. and D.J. Barnes. 2000. Environmental controls on growth of the massive coral *Porites*. J. Exp. Mar. Bio. Eco. 245:225-243.

Loya, Y. and B. Rinkevich. 1980. Effects of oil pollution on coral reef communities. Mar. Ecol. Prog. Ser. 3: 167-180.

MacAvoy, S.E., R.S. Carney, C.R. Fisher, and S.A. Macko. 2002. Use of chemosynthetic biomass by large, mobile, benthic predators in the Gulf of Mexico. Mar. Ecol. Prog.Ser. 225: 65-78.

MacAvoy, S.E., C.R. Fisher, R.S. Carney, and S.A. Macko. 2005. Nutritional associations among fauna at hydrocarbon seep communities in the Gulf of Mexico. Mar. Ecol. Prog. Ser. 225: 65-78.

MacDonald, I.R., N.L. Guinasso, Jr., S.G. Ackleson, J.F. Amos, R. Duckworth, R. Sassen, and J.M. Brooks. 1993. Natural oil slicks in the Gulf of Mexico visible from space. J. Geophys. Res. 98 C9:16351-16364.

MacDonald, I.R., N.L. Guinasso, Jr., R. Sassen, J.M. Brooks, L. Lee, and K.T. Scott. 1994. Gas hydrate that breaches the sea floor on the continental slope of the Gulf of Mexico. Geology 22:699-702.

MacDonald, I.R., J.F. Reilly Jr., S.E. Best, R. Venkataramaiah, R. Sassen, J. Amos, and N.L. Guinasso, Jr. 1996. A remote-sensing inventory of active oil seeps and chemosynthetic communities in the northern Gulf of Mexico. Hydrocarbon migration and its near-surface expression. D. Schumacher and M. A. Abrams, American Association of Petroleum Geologists. Memoir 66:27-37.

MacDonald, I.R., D. Buthman, W.W. Sager, M.B. Peccini, and N.L. Guinasso Jr. 2000. Pulsed oil discharge from a mud volcano. Geology 28(10):907-910.

MacDonald, I.R., R. Arvidson, R.S. Carney, C. F. Fisher, N.L. Guinasso Jr., S. Joye, P. Montagna, J.W. Morse, D.C. Nelson, E. Powell, W. Sager, R. Sassen, S. Schaeffer, and G.A. Wolff. 2002. Stability and Change in Gulf of Mexico Chemosynthetic Communities: Final Report. New Orleans, LA, U.S. Dept. Interior, Minerals Management Service, Gulf of Mexico OCS Region, Contract 14-35-001-31813.

MacDonald, I.R., I. Leifer, R. Sassen, P. Stine, R. Mitchell, and N.L. Guinasso Jr. 2002. Transfer of hydrocarbons from natural seeps to the water column and atmosphere. Geofluids 5: 95-107.

MacDonald, I.R., W.W. Sager,and M.B. Peccin. 2003. Association of gas hydrate and chemosynthetic fauna in mounded bathymetry at mid-slope hydrocarbon seeps: northern Gulf of Mexico. Mar. Geol. 198:133-158.

MacDonald, I.R., G. Bohrmann , E. Escobar , F. Abegg , P. Blanchon , V. Blinova , W. Brückmann, M. Drews , A. Eisenhauer, X. Han , K. Heeschen , F. Meier , C. Mortera , T. Naehr , B. Orcutt , B. Bernard , J. Brooks, and M. de Faragó. 2004. Asphalt volcanism and chemosynthetic life, Campeche Knolls, Gulf of Mexico. Science 304: 999-1002.

MacDonald, I.R., L.C. Bender, M. Vardaro, B. Bernard, and J.R. Brooks. 2005. Thermal and visual time-series at a seafloor gas hydrate deposit on the Gulf of Mexico Slope. Earth and Planetary Science Letters 233:45-59.

Masson, D.G, B.J. Bett, D.S.M. Billett, C.L. Jacobs, A.J. Wheeler, and R.B. Wynn. 2003. The origin of deep-water, coral-topped mounds in the northern Rockall Trough, Northeast Atlantic. Mar. Geol. 194: 159-180.

McConnaughey, T. 1989. ^{13}C and ^{18}O isotopic disequilibrium in biological carbonates: I. Patterns. Geochim Cosmochim Acta 53:151-162.

McCulloch, M., S. Fallon, T. Wyndham, E. Hendy, J. Lough, and D. Barnes. 2003. Coral record of increased sediment flux to the inner Great Barrier Reef since European settlement. Nature 421:727-730.

McMullin, E.R., S. Hourdez, S.W. Schaeffer, and C.R. Fisher. 2003. Phylogenetics and biogeography of deep sea vestimentiferan tubeworms and their bacterial symbionts. Symbiosis. 34:1-41.

Mikkelsen, N., H. Erlenkauser, J.S. Killingley, and W.H. Berger. 1982. Norwegian corals: radiocarbon and stable isotopes in *Lophelia pertusa*. Boreas 5:163-171.

Milkov, A.V. and R. Sassen. 2000. Thickness of the gas hydrate stability zone, Gulf of Mexico continental slope. Marine and Petroleum Geology 17:981.

Mills, H. J., C. Hodges, K. Wilson, I.R. MacDonald, and P.A. Sobecky. 2003. Microbial diversity in sediments associated with surface-breaching gas hydrate mounds in the Gulf of Mexico. FEMS Microbiol. Ecol. 46: 39-52.

Mills, H. J., R.J. Martinez, S. Story, and P.A. Sobecky. 2005. Characterization of the microbial community structure in Gulf of Mexico gas hydrates: comparative analysis of DNA- and RNA-derived clone libraries. Applied and Environmental Microbiology 71: 3235-3247.

Mitchell, R., I.R. MacDonald, and K. Kvenvolden. 1999. Estimates of total hydrocarbon seepage into the Gulf of Mexico based on satellite remote sensing images. EOS Supplement 80(49): OS242.

Moore, D.R. and H.R. Bullis. 1960. A deep-water coral reef in the Gulf of Mexico. Bull. Mar. Sci. 10:125-128

Mortensen, P.B., M. Hovland, T. Brattegard, and R. Farestveit. 1995. Deep-water bioherms of the scleractinian coral *Lophelia pertusa* L. at 64^{o} on the Norwegian shelf: structure and associated megafauna. Sarsia. 80:145-158.

Mortensen, P.B. and H.T. Rapp. 1998. Oxygen and carbon isotope ratios related to growth line patterns in ckeletons of *Lophelia pertusa* (L) (Anthozoa, Scleractinia): Implications for determination of linear extension rates. Sarsia 83:433-446.

Nikolaus, R., J.W. Ammerman, and I.R. MacDonald. 2003. Distinct pigmentation and trophic modes in *Beggiatoa* from hydrocarbon seeps in the Gulf of Mexico. Aquat. Micr. Ecol. 32: 85-93.

Nix, E., C.R. Fisher, K.M. Scott, and J. Vodenichar. 1995. Physiological ecology of a mussel with methanotrophic symbionts at three hydrocarbon seep sites in the Gulf of Mexico. Mar. Biol. 122: 605-617.

Olu, K., S. Lance, M. Sibuet, P. Henry, A. Fiala-Medioni, and A. Dinet. 1997. Cold seep communities as indicators of fluid expulsion patterns through mud volcanoes seaward of the Barbados accretionary prism. Deep-Sea Res. 44(5):811-841.

Olu, K., V. Rigaud, A. Fifis, M.C. Fabri, P. Cochonat, H. Ondréas, and M. Sibuet. 2001. Spatial distribution of chemosynthetic fauna from video records and mosaic analysis at a new cold seep site in the Gulf of Guinea. Program and abstracts volume. Second Internatinal Symposium on Deep-sea Hydrothermal Vent Biology. October 8-12, Brest, France. Pp. 208.

Orange, D.L., M.M. Angell, J.R. Brand, J. Thompson, T. Buddin, M. Williams, W. Hart, and W. Berger. 2003. Geological and shallow salt tectonic setting of the Mad Dog and Atlantis fields: Relationship between salt, faults, and seafloor geomorphology: Proceedings of the Offshore Technology conference, Houston, Texas, May 5-8, 2003, OTC 15157, 16 p.

Orphan, V.J., L.T. Taylor, D. Hafenbradl, and E.F. Delong. 2000. Culture-dependent and culture-independent characterization of microbial assemblages associated with high-temperature petroleum reservoirs. App. Env. Microbiol. 66: 700-711.

Parrish, J.D. 1989. Fish communities of interaction shallow water habitats in tropical oceanic regions. Mar. Ecol. Prog. Ser. 58:143-160.

Paull, C.K., B. Hecker, R. Commeau, R.P. Freeman-Lynde, C. Neumann, W.P. Corso, S. Golubic, J.E. Hook, E. Sikes, and J. Curray. 1984. Biological communities at the Florida escarpment resemble hydrothermal vent taxa. Science 226:965-967

Paull, C.K., A.J.T. Jull, L.J. Toolinand, and T. Linick. 1985. Stable isotope evidence for chemosynthesis in an abyssal seep community. Nature 317:709-711

Posey, M.H. and W.G. Ambrose Jr. 1994. Effects of proximity to an offshore hard bottom reef on infaunal abundances. Mar. Biol. 118:745-753.

Reed, J.K. 2002. Comparison of deep-water reefs and lithoherms off southeastern USA. Hydrobiologia 471:57-69.Ricciardi, A. and E. Bourget. 1998. Weight to weight conversion factors for marine benthic invertebrates. Mar. Ecol. Prog. Ser. 163:245-251.

Risk, M.J., J.M. Heikoop, M.G. Snow, and R. Beukens. 2002. Lifespans and growth patterns of two deep-sea corals: *Primnoa resedaeformis* and *Desmophyllum cristagalli*. Hydrobiologia 471:125-131.

Ritger, S., B. and Carson, E. Seuss. 1987. Methane-derived authigenic carbonates formed by subduction-induced pore-water expulsion along the Oregon-Washington margin: GSA Bulletin 98:147-156.

Roberts, H.H. 1996. Surface amplitude data: 3D-seismic for interpretation of sea floor geology (Louisiana slope): Transactions of the Gulf Coast Association of Geological Societies 46:353-362.

Roberts, H.H. 2001. Improved geohazards and benthic habitat evaluations: digital acoustic data with ground truth calibrations. U.S. Dept. of the Interior, Minerals Management Service, Gulf of Mexico OCS Region, New Orleans, LA. OCS Study MMS 2001-050. 116 pp + appendices.

Roberts, H.H. 2001. Fluid and gas expulsion on the northern Gulf of Mexico continental slope: Mud-prone to mineral-prone responses: American Geophysical Union, Geophysical Monograph 124:145-161.

Roberts, H.H., P. Aharon, R. Carney, J. Larkin, and R. Sassen. 1990. Responses to hydrocarbon seeps, Louisiana continental slope: Geo-Marine Letters 10:232-243.

Roberts, H.H., and P Aharon. 1994. Hydrocarbon-derived carbonate buildups of the northern Gulf of Mexico continental slope: A review of submersible investigations, Geo-Marine Letters 14:135-148.

Roberts, H.H., and R. Carney. 1997. Evidence of episodic fluid, gas and sediment venting on the northern Gulf of Mexico continental slope, Economic Geology 92: 863-879.

Roberts, H.H. and J.M. Coleman. (In Preparation). Improving the predictive capability of 3-D seismic surface amplitude data for identifying chemosynthetic communities: Contract no. 143-01-99-CA-30951, task order 17801.

Robinson, C.A., J.M. Bernhard, L.A. Levin, G.F. Mendoza, and J.K. Blanks. 2004. Surficial hydrocarbon seep infauna from the Blake Ridge (Atlantic Ocean, 2150m) and Gulf of mexico (690-2240m). PSZNI Mar. Ecol. 25:313-336.

Rogers, A.D. 1999. The biology of *Lophelia pertusa* (Linnaeus 1758) and other deep-water reef forming corals and impacts from human activities. Int. Rev. Hydrobiol. 844:315-406.

Rowan, M.G., M.P.A. Jackson, and B.D. Trudgill. 1999. Salt-related fault families and fault welds in the northern Gulf of Mexico: AAPG Bulletin 83:1454-1484.

Sager, W.W., C.S. Lee, I.R. MacDonald, and W.W. Schroeder. 1999. High-frequency near-bottom acoustic reflection signatures of hydrocarbon seeps on the northern Gulf of Mexico continental slope. Geo-Mar. Lett. 18:267-276.

Sahling, H., D. Rickert, R.W. Lee, P. Linke, and E. Suess. 2002. Macrofaunal community structure and sulfide flux at gas hydrate deposits from the Cascadia convergent margin. Mar. Ecol. Prog. Ser. 231:121–138

Sassen, R., J.M. Brooks, I.R. MacDonald, M.C.Kennicutt, N.L. Guinasso, and A. G. Requejo. 1993. Association of oil seeps and chemosynthetic communities with oil discoveries, upper continental slope, Gulf of Mexico. Trans GCAGS 43:349-355.

Schroeder, W.W. 2002. Observations of Lophelia pertusa and the surficial geology at a deep-water site in the northeastern Gulf of Mexico. Hydrobiologia 471:29-33.

Sharp, Z.D. and T.E. Cerling. 1996. A laser GC-IRMS technique for *in situ* stable isotope analyses of carbonates and phosphates. Geochim. Cosmochim. Acta 60:2909-2916.

Sibuet, M. and K. Olu. 1998. Biogeography, biodiversity and fluid dependence of deep-sea cold-seep communities at active and passive margins. Deep-Sea Res. 45:517-567.

Smith, J.E., H.P. Schwarcz, M.J. Risk, T.A. McConnaughey, and N. Keller. 2000. Paleotemperatures from deep-sea corals: overcoming 'vital effects'. Palaios. 15:25-32.

Snelgrove, R.V.R. and C.R. Smith. 2002. A riot of species in an environmental calm. Oceanogr. Mar. Biol. Ann. Rev. 40:311-342.

Southward, E.C. 1988. Development of the gut and segmentation of newly settled stages of *Ridgeia* (Vestimentifera): implications for relationship between Vestimentifera and Pogonophora. J. Mar. Biol. Ass. UK. 68: 465-487.

Stohr, S. and M. Segonzac. 2005. Deep- sea ophiuroids (Echinodermata) from reducing and non-reducing environments in the North Atlantic Ocean. J. Mar. Biol. Ass. U.K. 85:383-402.

Suess, E., B. Carson, S. Ritger, J.C. Moore, M. Jones, L.D. Kulm and G. Cochrane, 1985, Biological communities at vent sites along the subduction zones off Oregon, Bulletin of the Biological Society of Washington, v. 6, p. 475-484.

Summerson, H.C. and C.H. Peterson. 1984. Role of predation in organizing benthic communities of a temperate zone seagrass bed. Mar. Ecol. Prog. Ser. 15:63-77.

Swart P.K. 1983. Carbon and oxygen isotope fractionation in scleractinian corals. Earth Sci Rev. 19:51-80.

Thiel, H. and J.A. Koslow, eds. 2001. Managing Risks to Biodiversity and the Environment on the High Sea, Including Tools such as Marine Protected Areas. Scientific Requirements and Legal Aspects, Proceedings of the Expert Workshop held at the International Academy for Nature Conservation, Isle of Vilm Germany, 27 February- 4 March 2001. www.bfn.de/09/090203.htm.

Turnipseed, M., K.E. Knick, R.N. Lipcius, J. Dreyer, and C.L. Van Dover. 2003. Diversity in mussel beds at deep-sea hydrothermal vents and cold seeps. Ecology Letters 6: 518-523.

Turnipseed, M., C.D. Jenkins, and C.L. Van Dover. 2004. Community structure in Florida Escarpment seep and Snake Pit vent mussel beds. Mar. Biol. 145(1):121-132

Tyler, P.A. (ed). 2003. Ecosystems of the deep oceans. Ecosystems of the World Vol. 28. Elsevier, Amsterdam, 569p.

Tyler, P.A., C.R. German, E. Ramirez-Llodra , and C.L. Van Dover. 2003. Understanding the biogeography of chemosynthetic ecosystems. Oceanol. Acta 25:227–241

Van Dover, C.L. 2002a. Community structure of mussel beds at deep-sea hydrothermal vents. Mar. Ecol. Prog. Ser. 230: 137-158.

Van Dover, C.L. 2002b. Trophic relationships among invertebrates at the Kairei hydrothermal vent field (Central Indian Ridge). Mar. Biol. 141:761-772.

Van Dover, CL. 2003. Variation in community structure within hydrothermal vent mussel beds of the East Pacific Rise. Mar. Ecol. Prog. Ser. 253:55-66.

Van Dover, C.L. and B. Fry. 1994. Microorganisms as food resources at deep-sea hydrothermal vents. Limnol. Ocean. 39:51-57.

Van Dover, C.L. and J.L. Trask. 2000. Diversity at deep-sea hydrothermal vent and intertidal mussel beds. Mar. Ecol. Prog. Ser. 195:169-178.

Van Dover, C.L., C.R. German, K.G. Speer, L.M. Parson, and R.C. Vrijenhoek . 2002. Evolution and biogeography of deep-sea vent and seep invertebrates. Science 295:1253-1257.

Van Dover, C.L., P. Aharon, J.M. Bernhard, M. Doerries, W. Flickinger, W. Gilhooly, K. Knick, S. Macko, S. Rapoport, C. Ruppel, J. Salerno, R. Seitz, B.K. Sen Gupta, T.M. Shank, M. Turnipseed, R. Vrijenhoek, and E. Watkins. 2003. Blake Ridge methane seeps: characterization of a soft-sediment, chemosynthethically based ecosystem. Deep-Sea Res. 50:281-300.

Vardaro, M., I.R. MacDonald, L.C. Bender, and N.L. Guinasso Jr. Accepted. Dynamic biological and physical processes observed at a gas hydrate outcropping on the continental slope of the Gulf of Mexico. Geo-Marine Letters.

von Cosel, R. and Olu K. 1998. Gigantism in Mytilidae. A new *Bathymodiolus* from cold seep areas on the Barbados Accretionary Prism. C. R. Acad. Sci (Ser. 3) 321:655-663.

Voordouw, G., S.M. Armstrong, M.F. Reimer, B. Fouts, A.J. Telang, Y. Shen, and D. Gevertz. 1996. Characterization of 16S rRNA genes from oil field microbial communities indicates the presence of a variety of sulfate-reducing, fermentative, and sulfide-oxidizing bacteria. App. Env. Microbiol. 62:1623-1629.

Wainright, S.A. 1964. Studies of the mineral phase of coral skeleton. Exp Cell Research, 34:213-230.

Weinstein, M.P. and K.L. Heck. 1979. Ichthyofauna of seagrass meadows along the Caribbean coast of Panama and in the Gulf of Mexico-composition, structure, and community ecology. Mar. Biol. 50:97-107.

Wilson, J.B. 1979. ‘Patch’ development of the deep-water coral *Lophelia pertusa* (L.) on Rockall Bank. J. Mar. Biol. Ass. U.K. 59:165-177.