

**Characterization of Northern Gulf of Mexico  
Deepwater Hard Bottom Communities with Emphasis  
on *Lophelia* Coral -  
*Lophelia* Reef Megafaunal Community Structure, Biotopes,  
Genetics, Microbial Ecology, and Geology  
(2004-2006)**

**USGS Open-File Report 2008-1148 (15 April 2008)  
OCS Study MMS 2008-015**



**Kenneth J. Sulak, Lead PI & Lead Editor  
U.S. Geological Survey  
Florida Integrated Science Center-Gainesville, Florida  
Coastal Ecology and Conservation Research Group**

**U.S. Department of the Interior  
U.S. Geological Survey**

**MMS** U.S. Department of the Interior  
Minerals Management Service  
Gulf of Mexico OCS Region



**Characterization of Northern Gulf of Mexico  
Deepwater Hard Bottom Communities with Emphasis  
on *Lophelia* Coral -  
*Lophelia* Reef Megafaunal Community Structure, Biotopes,  
Genetics, Microbial Ecology, and Geology  
(2004-2006)**

**USGS Open-File Report 2008-1148 (15 April 2008)  
OCS Study MMS 2008-015**

**Kenneth J. Sulak, Lead PI & Lead Editor  
Co-editors: Michael Randall, Kirsten E. Luke,  
April D. Norem, and Jana M. Miller**

**Contributors: R. Allen Brooks, John H. Caruso, Andréa Grottoli, William M. Harden, Robin L. Johnson, Christina A. Kellogg, Tim L. King, Kirsten E. Luke, Jana M. Miller, Cheryl Morrison, Martha S. Nizinski, April D. Norem, Andrew J. Quaid, Michael T. Randall, Michael J. Risk, Steve W. Ross, William B. Schill, Kenneth J. Sulak, Branwin Williams, and George E. Yeargin.**

**U.S. DEPARTMENT OF THE INTERIOR**  
Dirk Kempthorne, Secretary

**U.S. GEOLOGICAL SURVEY**  
Mark D. Myers, Director

U.S. Geological Survey, Reston, Virginia, 2008

**REPORT AVAILABILITY**

For product and ordering information:

U.S. Geological Survey

World Wide Web: <http://www.usgs.gov/pubprod>

Telephone: 1-800-ASK-USGS

Minerals Management Service

Gulf of Mexico OCS Region

Public Information Office, MS 5034

1201 Elmwood Park Boulevard

New Orleans, LA 70123-2394

1-800-200-GULF

This report has been prepared for distribution in a two-disc DVD set, and as a web-accessible report product (DVD-1 content in Adobe<sup>®</sup> .pdf and .html formats at <http://cars.er.usgs.gov/coastaleco/>)

For more information on the USGS, the Federal source for science about the Earth, its natural and living resources, natural hazards, and the environment:

World Wide Web: <http://www.usgs.gov>; Telephone: 1-800-ASK-USGS

**DISCLAIMER**

This report presents the results of research undertaken for the U.S. Geological Survey in response to natural resource information needs identified by the Minerals Management Service. This is not copyrighted and may be cited and copied freely. The report has been technically reviewed by USGS and MMS, and has been approved for publication. Approval does not signify that the contents necessarily reflect the view and policies of the USGS or the MMS, nor does mention of trade names or commercial products constitute endorsement or recommendation for use. This report is in compliance with USGS and MMS editorial standards. Although this report is in the public domain, permission must be secured from the individual copyright owners to reproduce any copyrighted material contained within this report.

**CITATION**

**SUGGESTED CITATION:** Characterization of Northern Gulf of Mexico Deepwater Hard Bottom Communities with Emphasis on *Lophelia* Coral - *Lophelia* Reef Megafaunal Community Structure, Biotopes, Genetics, Microbial Ecology, and Geology. K. J. Sulak, M. T. Randall, K. E. Luke, A. D. Norem, and J. M. Miller (Eds.). USGS Open-File Report 2008-1148; OCS Study MMS 2008-015, 15 April 2008, 8 Chapters, pp., 8 Master Appendices (incl. Interactive Dive Track DVD).

## CONTRIBUTORS

R. A. Brooks, J. H. Caruso, A. Grottoli, W. M. Harden, R. L. Johnson, C. A. Kellogg, T. L. King, K. E. Luke, J. M. Miller, C. L. Morrison, M. S. Nizinski, A. D. Norem, A. J. Quaid, M. T. Randall, M. J. Risk, S. W. Ross, W. B. Schill, K. J. Sulak, B. Williams, G. E. Yeargin.

## COVER PAGE ILLUSTRATION

Underwater vignette of the scorpaenid fish, *Helicolenus dactylopterus*, and the Galatheid crab, *Eumunida picta*, within *Lophelia pertusa* coral habitat, Viosca Knoll, 455 m depth, continental slope, northern Gulf of Mexico (Station No. USGS-GM-2005-04-4880), USGS File Photograph.

## ACKNOWLEDGMENT

We thank the captain, ship's crew, and submersible operations team of the RV Seward Johnson and RV Seward Johnson II, Harbor Branch Oceanographic Institution, and the captain and crew of the RV Tommy Munro, Gulf Coast Research Laboratory, for excellent support of our research effort. Thanks are extended as well to the large number of graduate students, undergraduate students, support personnel, and volunteers who assisted in research and logistics at sea and in the laboratory. Special thanks go to B. Albert, J. Berg, J. C. Carr, M. M. Cheung, W. M. Harden, S. C. Keitzer, A. Quaid, M. Randall, P. Reynolds, J. Rochello, J. T. Smith, and master gear technician G. Yeargin. K. Luke provided GIS expertise for mission planning and final map products. J. Miller provided graphics expertise. Additional JSL dive DVDs for comparative study were contributed by S. Viada, CSA and W. Schroeder, Dauphin Island Marine Laboratory. Schroeder also provided an advance multibeam map to assist mission planning. Taxonomic identifications were contributed by S. Cairns, Smithsonian Institution; J. H. Caruso, Tulane University; J. Castro, Mote Marine Laboratory; D. Felder, Louisiana State University, Baton Rouge, LA; and T. Munroe, NOAA Fisheries Systematics Laboratory, Smithsonian Institution; E. Macpherson, Institut de Ciències del Mar, Barcelona, Spain; C. Messing, Nova Southeastern University; M. Nizinski, NOAA Fisheries Systematics Laboratory, Smithsonian Institution; G. Pohle, Atlantic Reference Centre, Huntsman Marine Science Centre, St. Andrews, NB, Canada; J. Reed, Harbor Branch Oceanographic Institution, Ft. Pierce, FL; and G. Sedberry, South Carolina Dept. of Natural Resources. B. Ghaleb, RCL-GEOTOP, University of Quebec at Montreal; M. Taviani, ISMAR, National Research Council, Bologna, Italy; and P. Aharon, University of Alabama at Tuscaloosa, contributed radioage and isotope analyses. L. Robbins, USGS, FISC-St. Petersburg contributed x-ray diffraction analyses of rock samples. Historical trawl records of demersal fishes were provided by NOAA Fisheries, Mississippi Laboratories, Pascagoula, Mississippi. S. Hartley, USGS, Wetlands Science Center, Lafayette, LA, contributed GIS expertise at sea. R. Dorazio, USGS, FISC, contributed advice on video data analysis methods. The editors and contributors appreciate the efforts of the several critical USGS, MMS and external reviewers of individual chapters and/or the overall report. Reviewer comments and suggestions substantially improved the final product. This investigation was supported by the USGS Outer Continental Shelf Ecosystem Program, sponsored and facilitated by the Minerals Management Service, and augmented by logistic contributions from NOAA and the U.S. Naval Research Laboratory, Stennis Space Center, MS.

## TABLE OF CONTENTS

	<u>Page</u>
<b>LIST OF TABLES</b> .....	vii
<b>LIST OF FIGURES</b> .....	xii
<b>LIST OF APPENDICES</b> .....	xxiii
<b>CONVERSION FACTORS</b> .....	xxv
<b>COMPENDIUM OF ABSTRACTS</b> .....	xxix
<b>CH. 1</b> INTRODUCTION TO THE INVESTIGATIONS .....	1-1
<b>CH. 2</b> DEMERSAL FISHES ASSOCIATED WITH <i>LOPHELIA PERTUSA</i> CORAL AND ASSOCIATED BIOTOPES ON THE CONTINENTAL SLOPE, NORTHERN GULF OF MEXICO .....	2-1
<b>CH. 3</b> QUANTITATIVE DEFINITION OF VIOSCA KNOLL BIOTOPES AVAILABLE TO FISHES OF THE CONTINENTAL SLOPE, 325-500 M, NORTHERN GULF OF MEXICO .....	3-1
<b>CH. 4</b> MOLECULAR ASSESSMENT OF DEEP-SEA SCLERACTINIAN CORAL BIODIVERSITY AND POPULATION STRUCTURE OF <i>LOPHELIA PERTUSA</i> IN THE GULF OF MEXICO .....	4-1
<b>CH. 5</b> EXPRESSED GENES OF THE DEEP-WATER CORAL, <i>LOPHELIA PERTUSA</i> .....	5-1
<b>CH. 6</b> MICROBIAL ECOLOGY OF <i>LOPHELIA PERTUSA</i> IN THE NORTHERN GULF OF MEXICO .....	6-1
<b>CH. 7</b> DEEP WATER ANTIPATHARIANS: PROXIES OF ENVIRONMENTAL CHANGE .....	7-1
<b>CH. 8</b> ORIGINS, COMPOSITION, AGE AND STRUCTURAL DIVERSIFICATION OF VIOSCA KNOLL <i>LOPHELIA</i> CORAL REEFS AND SUBSTRATE – A SYNOPSIS OF PRELIMINARY RESULTS.....	8-1
 <b><u>MASTER APPENDICES</u></b>	 <b><u>DISK</u></b>
<b>A</b> Interactive Video Tour of Dive Highlights.....	DVD-2
<b>B</b> Sampling Cruises Data Tables (1.4-1.10). Also available online at: <a href="http://cars.er.usgs.gov/coastaleco/">http://cars.er.usgs.gov/coastaleco/</a> .....	DVD-1
<b>C</b> Demersal Fishes of Viosca Knoll	

**TABLE OF CONTENTS  
(CONTINUED)**

<b><u>MASTER APPENDICES</u></b>	<b><u>DISK</u></b>
Key to Plates in Master Appendix C.....	DVD-1
Appendix C.....	DVD-1
<b><u>MASTER APPENDICES</u></b>	<b><u>DISK</u></b>
<b>D</b>	
Megafaunal Invertebrates of Viosca Knoll	
Key to Plates in Master Appendix D.....	DVD-1
Appendix D.....	DVD-1
<b>E</b>	
Biotopes of Viosca Knoll	
Key to Plates in Master Appendix E.....	DVD-1
Appendix E.....	DVD-1
<b>F</b>	
Antipatharian Growth Chronology.....	DVD-1
<b>G</b>	
Coral Point Count, (CPCe) Raw Data Matrix. Available online at: <a href="http://cars.er.usgs.gov/coastaleco/">http://cars.er.usgs.gov/coastaleco/</a> .....	DVD-1
<b>H</b>	
Publications and Scientific Presentations.....	DVD-1

## LIST OF TABLES

### **Chapter 1** **Page**

Table 1-1.	Scientific Crew, all cruises and post-cruise support .....	1-19
Table 1-2.	Sampling Station Data .....	1-22
Table 1-3.	JSL Dive Station Data.....	1-28

**Tables Below Accessible in Master Appendix B (and Online at:**  
<http://cars.er.usgs.gov/coastaleco/>

Table 1-4.	Log of fish specimens sampled during 3 USGS <i>Lophelia</i> investigation cruises	
Table 1-5.	Log of fish specimens sampled for stomach contents from 3 USGS <i>Lophelia</i> investigation cruises	
Table 1-6.	Log of digital layout images for specimens sampled during 3 USGS <i>Lophelia</i> investigation cruises	
Table 1-7.	Log of invertebrate specimens sampled during 3 USGS <i>Lophelia</i> investigation cruises	
Table 1-8.	Log of invertebrate layout photographs from USGS <i>Lophelia</i> investigation cruises	
Table 1-9.	Log of sediment samples obtained during 2 USGS <i>Lophelia</i> investigation cruises	
Table 1-10.	Log of tissue samples obtained for stable isotope analyses during USGS <i>Lophelia</i> investigation cruises	

### **Chapter 2** **Page**

Table 2-1.	Submersible dives and surface vessel bottom sampling stations conducted by USGS during three Viosca Knoll cruises, 2004-2005 .....	2-40
Table 2-2.	Biotope categories and descriptions, as applied to analysis of Viosca Knoll study sites.....	2-42

**LIST OF TABLES (CONTINUED)**

<b><u>Chapter 2</u></b>	<b><u>Page</u></b>
Table 2-3A. Demersal fish taxa documented by USGS submersible (JSL) video and collections on Viosca Knoll study sites, versus those from comparative USGS trawl, sled, and trap collections, and NOAA bottom trawl Collections .....	2-43
Table 2-3B. Demersal fish taxa recorded in NOAA bottom trawl database, but not recorded by USGS, 2004-2005, in either submersible video or suction samples, or in trawl and sled samples.....	2-48
Table 2-4. Abundance scores per taxon for Viosca Knoll study sites demersal fish taxa from transect frame-by-frame analysis for USGS 2004-2005 submersible video records.....	2-49
Table 2-5. Dominance rank by total occurrences per taxon for Viosca Knoll study sites demersal fish taxa from frame-by-frame analysis of non-transect time segments of all USGS 2004-2005 submersible dive video records.....	2-51
Table 2-6. Chi-square test of observed versus expected count data by biotope for 12 key Viosca Knoll demersal fish taxa ( $N \geq 10$ ).....	2-53
<b><u>Chapter 3</u></b>	<b><u>Page</u></b>
Table 3-1. Synopsis of sampling operations conducted during two USGS submersible and one surface vessel cruise, 2004-2005. ....	3-40
Table 3-2. Biotope category descriptions, Viosca Knoll study sites, based on physical structure and characteristic sessile megafauna .....	3-43
Table 3-3. Megafaunal invertebrate taxa recorded from USGS JSL video operations on VK-826 and VK-906/862, 2004-2005 .....	3-44
Table 3-4. Results of ANOSIM test of Null Hypothesis $H_1$ (sampling site test)	3-47
Table 3-5A. Results of ANOSIM test of Null Hypothesis $H_2$ (biotope contrast test)	3-48

**LIST OF TABLES (CONTINUED)**

<b><u>Chapter 3</u></b>	<b><u>Page</u></b>
Table 3-5B. Pairwise tests from results of ANOSIM test of Null Hypothesis H <sub>2</sub> (biotope contrast test).....	3-49
Table 3-5C. Pairwise contrast triangle table of ANOSIM Global ‘R’ statistic values from test of Null Hypothesis H <sub>2</sub> (biotope contrast test).....	3-50
Table 3-6. Dominance rank (by numerical occurrence) of key taxa characteristic of biotope categories.....	3-51
<b><u>Chapter 4</u></b>	
<b><u>Chapter 4</u></b>	<b><u>Page</u></b>
Table 4-1. DNA sequence regions explored for utility in <i>Lophelia</i> phylogeographic analyses.....	4-37
Table 4-2. Characteristics of <i>Lophelia</i> microsatellite markers.....	4-38
Table 4-3. Levels of polymorphism and heterozygosity by locus and <i>Lophelia</i> population.....	4-39
Table 4-4. Pairwise estimates of $F_{ST}$ and chord distances between thirteen <i>Lophelia</i> populations estimated from multilocus microsatellite genotypes.....	4-41
Table 4-5. Results of analysis of molecular variance (AMOVA) among ocean regions and between populations in the Gulf of Mexico and off the southeastern U.S. coast.....	4-42
<b><u>Chapter 5</u></b>	
<b><u>Chapter 5</u></b>	<b><u>Page</u></b>
No Tables .....	---

**LIST OF TABLES (CONTINUED)**

<b><u>Chapter 6</u></b>	<b><u>Page</u></b>
Table 6-1. <i>Lophelia pertusa</i> samples collected in the Gulf of Mexico for microbiological analyses.....	6-29
Table 6-2. Summary of cultured <i>Lophelia</i> -associated bacterial isolates.....	6-32
Table 6-3. Summary of <i>Lophelia</i> -associated bacterial 16S rDNA clone libraries.....	6-34
Table 6-4. Comparison of physical and biological factors between sites VK906/862 and VK826 .....	6-35
<b><u>Chapter 5</u></b>	
No Tables .....	---
<b><u>Chapter 7</u></b>	
Table 7-1. Specimen collection location and diameter at base .....	7-12
Table 7-2. Subsample age and extrapolated specimen age .....	7-13
Table 7-3. Measured $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ isotopic abundance.....	7-14
<b><u>Chapter 8</u></b>	
Table 8-1. Data for contemporary <i>L. pertusa</i> specimens from Big Blue Reef, VK-826 (Dive 4751), aged via $^{14}\text{C}$ methodology .....	8-27
Table 8-2. Data for subfossil <i>L. pertusa</i> and a vesicomyid? bivalve embedded within aggregate carbonate reef rock from Big Blue Reef, VK-826 (Dive 4752), aged via $^{14}\text{C}$ methodology .....	8-27
Table 8-3. Stable isotope and specific gravity determinations for samples of black goethite substrate rock, and gray-white carbonate aggregate reef rock from Viosca Knoll sites .....	8-28

**LIST OF TABLES (CONTINUED)**

<b><u>Chapter 8</u></b>	<b><u>Page</u></b>
Table 8-4. Specific gravity data for live collected <i>L. pertusa</i> fronds, compact and open growth forms, and dead <i>Lophelia</i> rubble. The <i>L. pertusa</i> fronds are the same as used for comparative calyx density per unit area determinations (Table 8-5).....	8-29
Table 8-5. Comparative calyx density data for three specimens of <i>L. pertusa</i> , representing both the compact and open growth forms .....	8-30
Table 8-6. Recognizable taxa contributing to <i>Lophelia</i> reef ‘coral sand’ soft substrate on Viosca Knoll study sites (taxa identified from all submersible-collected soft substrate samples) .....	8-31

## LIST OF FIGURES

<b><u>Chapter 1</u></b>	<b><u>Page</u></b>
Figure 1-1. Location of Gulf of Mexico study sites VK-826 and VK-906/862 .....	1-31
Figure 1-2. Locations of individual submersible dive stations, VK-826, Cruises USGS-GM-2004-03 and USGS-GM-2005-04 .....	1-32
Figure 1-3. Locations of individual submersible dive stations, VK-906/862, Cruises USGS-GM-2004-03 and USGS-GM-2005-04 .....	1-33
Figure 1-4. Simrad echosounder single beam (38 kHz) acoustic false-color profile of <i>Lophelia pertusa</i> reef atop a ridge-mound on “Big Blue Reef”, northeastern sector of VK-826 study site.....	1-34
Figure 1-5. Knudsen echosounder single beam acoustic (3.5 kHz) profile of <i>Lophelia pertusa</i> coral reef, ‘Big Blue Reef’, on the flank of a ridge, northeastern sector of VK-826 study site.....	1-35
Figure 1-6. Submersible dives and surface-deployed remote sampling stations, VK-906/862, Cruise USGS-GM-2004-03, with boundaries of MMS lease blocks indicated by white grid lines and VK numbers .....	1-36
Figure 1-7. Submersible dives and surface-deployed remote sampling stations, VK-826, Cruise USGS-GM-2004-03 .....	1-37
Figure 1-8. Surface-deployed remote sampling stations, VK-906/862, Cruises USGS-GM-2005-03 and USGS-GM-2005-04 .....	1-38
Figure 1-9. Surface-deployed remote sampling stations, VK-826, Cruises USGS-GM-2005-03 and USGS-GM-2005-04 .....	1-39
Figure 1-10. Exploratory echo-sounding tracks, VK-826, Cruise USGS-GM-2005-04 ....	1-40
<b><u>Chapter 2</u></b>	<b><u>Page</u></b>
Figure 2-1. Location of two Viosca Knoll-826 submersible <i>Lophelia</i> reef study sites in the northern Gulf of Mexico, and location of comparative NOAA bottom trawl records (open rectangle).....	2-56

**LIST OF FIGURES (CONTINUED)**

<b><u>Chapter 2</u></b>	<b><u>Page</u></b>
<p>Figure 2-2. Bathymetric chart (10-m isobaths) of Viosca Knoll-826 <i>Lophelia</i> reef study site, showing tracks of 12 USGS submersible dives undertaken in 2004-2005: A = “Big Blue Reef” on northeastern sector of overall feature; B = 100 m deep depression; C = main knoll on southwestern sector of feature (with <i>Lophelia</i>).....</p>	2-57
<p>Figure 2-3. Bathymetric chart (10-m isobaths) of Viosca Knoll-906/862 <i>Lophelia</i> reef study site, showing tracks of eight USGS submersible dives undertaken in 2004-2005: A = area of live-bottom development, including <i>Lophelia</i> coral; B = area visited on one exploratory dive.....</p>	2-58
<p>Figure 2-4. Knudsen echosounder single beam acoustic (3.5 kHz) profile of <i>Lophelia pertusa</i> coral reef, Big Blue Reef, on flank of a ridge, northeastern sector of VK-826 study site.....</p>	2-59
<p>Figure 2-5. Examples of Viosca Knoll biotopes: A) ‘Open’ biotope, 528 m; B) ‘Open’ biotope, 547 m, with the hake <i>Laemonema goodebeanorum</i> and tube-dwelling cerianthid anemones; C) ‘Plate’ biotope, 316 m, with <i>Lophelia pertusa</i> hard coral and <i>Leiopathes</i> black coral bushes; D) ‘Plate’ biotope, 312 m, with <i>Epinephelus niveatus</i> snowy grouper .....</p>	2-60
<p>Figure 2-6. Examples of Viosca Knoll biotopes: A) ‘Rock’ biotope, 312 m, with <i>Hyperoglyphe perciformis</i> barrelfish; B) ‘Rock’ biotope, 320 m, supporting a diverse assemblage of sessile invertebrates, <i>Epinephelus niveatus</i> beneath; C) ‘Thicket’ biotope, 465 m, with a monoculture of <i>Lophelia pertusa</i>; D) ‘Rubble’ biotope, rare on Viosca Knoll, 467 m, with <i>Laemonema goodebeanorum</i> .....</p>	2-61

**LIST OF FIGURES (CONTINUED)**

<b><u>Chapter 3</u></b>	<b><u>Page</u></b>
Figure 3-1. Location of two Viosca Knoll 826 submersible <i>Lophelia</i> reef study Sites in the northern Gulf of Mexico, and location of comparative NOAA bottom trawl records (open rectangle).....	3-56
Figure 3-2. Bathymetric chart (10-m isobaths) of Viosca Knoll 826 <i>Lophelia</i> reef study site, showing tracks of 12 USGS submersible dives undertaken in 2004-2005: A = “Big Blue Reef” on northeastern sector of overall feature; B = 100 m deep depression; C = main knoll on southwestern sector of feature (with <i>Lophelia</i> ).....	3-57
Figure 3-3. Bathymetric chart (10-m isobaths) of Viosca Knoll 906/862 <i>Lophelia</i> reef study site, showing tracks of eight USGS submersible dives undertaken in 2004-2005: A = area of live-bottom development, including <i>Lophelia</i> coral; B = area visited on one exploratory dive.....	3-58
Figure 3-4. Measurements of common invertebrates used to scale frame grab image field of view for CPCe analyses: A) Orange-lipped white anemone, stalk base diameter: N = 41 individuals, mean diameter = 2.202 cm ±SD (0.236 cm), median = 2.212 cm. Error bars on individual histobars indicate methodological standard error; B) <i>Lophelia pertusa</i> coral, calyx length = distance between adjacent branching nodes: N = 50 measurements, mean = 2.048 cm ±SD (0.247 cm).....	3-59
Figure 3-5. Frequency plot (in intervals of 5,000 cm <sup>2</sup> ) of the area of the field of view in 459 video frame grab images analyzed in this study .....	3-60
Figure 3-6. Computer screen grab to display a typical Viosca Knoll frame grab in the process of megafaunal invertebrate occurrence scoring via projection of a grid of 60 open boxes (10 columns by 6 rows) using Coral Point Count (CPCe).....	3-61

**LIST OF FIGURES (CONTINUED)**

<b><u>Chapter 3</u></b>	<b><u>Page</u></b>
Figure 3-7. Four Viosca Knoll digital images categorized as representing typical ‘Open’ soft-bottom biotope.....	3-62
Figure 3-8. Four Viosca Knoll digital images categorized as representing typical ‘Plate’ hard-bottom biotope.....	3-64
Figure 3-9. Four Viosca Knoll digital images categorized as representing typical ‘Plate/Chemo’ hard-bottom biotope. ....	3-65
Figure 3-10. Four Viosca Knoll digital images categorized as representing typical ‘Rock’ hard-substrate biotope.....	3-66
Figure 3-11. Four Viosca Knoll digital images categorized as representing typical <i>Lophelia</i> coral ‘Rubble’ biotope.	
Figure 3-12. Four Viosca Knoll digital images categorized as representing typical ‘Thicket’ <i>Lophelia</i> coral biotope .....	3-67
Figure 3-13. Four Viosca Knoll digital images displaying examples of high-diversity megafaunal invertebrate oases, which form primarily on plate and rock hardpan goethite substrate biotopes .....	3-68
Figure 3-14. ANOSIM results of sampling site differentiation hypothesis test VK-826 versus VK-906/862) accomplished from Primer 6 .....	3-69
Figure 3-15. ANOSIM results of biotope differentiation hypothesis test (VK-826 versus VK- 906/862) accomplished from Primer 6 .....	3-70
Figure 3-16. Species richness rarefaction curves (solid lines) and 95% CIs (dotted or dashed lines) for Viosca Knoll empirically-defined biotopes. ....	3-71
Figure 3-17. Species richness rarefaction curves (solid lines) without 95% CIs for Viosca Knoll empirically-defined biotopes.....	3-72
Figure 3-18. Species richness rarefaction curves (solid lines) without 95% CIs for Viosca Knoll empirically-defined biotopes .....	3-73
Figure 3-19. Primer 6-produced sampling SITE CLUSTERGRAM from Coral Point Count (CPCe) analysis of 459 digital still frame grabs .....	3-74

**LIST OF FIGURES (CONTINUED)**

<b><u>Chapter 3</u></b>	<b><u>Page</u></b>
Figure 3-20. Primer 6-produced BIOTOPE CLUSTERGRAM from Coral Point Count (CPCe) analysis of 419 digital still frame grabs .....	3-75
Figure 3-21. A) 2-D, nonmetric multidimensional scaling (MDS) ordination plot using Primer 6 from data categorized by SAMPLE SITE (DEPTH HORIZON). Data in matrix was first standardized by sample total from the original CPCe raw data matrix of species occurrences across all samples (images), N = 459. B) 2-D Shepard plot from the same data matrix .....	3-76
Figure 3-22. A) 3-D, nonmetric multidimensional scaling (MDS) ordination plot using Primer 6 from data categorized by SAMPLE SITE (DEPTH HORIZON); B) 3-D Shepard plot from the same data matrix .....	3-77
Figure 3-23. A) 2-D, nonmetric multidimensional scaling (MDS) ordination plot using Primer 6 from data categorized into EMPIRICALLY-DEFINED BIOTOPES, with SIMPROF SAMPLE CLUSTERS (as per Figure 3-20) overlaid at slack level = 30 .....	3-78
Figure 3-24. Primer 6-produced megafaunal invertebrate SPECIES CLUSTERGRAM from Coral Point Count (CPCe) analysis of 459 digital still frame grabs .....	3-79
Figure 3-25. A) 2-D, nonmetric multidimensional scaling (MDS) ordination plot using Primer 6 from SPECIES OCCURRENCE DATA, with SIMPROF species clusters (Figure 3-24) overlaid at slack level = 30 .....	3-80
Figure 3-26. A) 2-D Shepard plot to accompany Figure 3-25, stress statistic = 0.03; B) 3-D Shepard plot for same data matrix (3-D MDS plot not shown), stress statistic = 0.01 .....	3-81
Figure 3-27. Comparative proportion of unpopulated substrate (percentage of ‘No Invertebrate’ scores in CPCe raw data matrix) among the five empirical biotope categories .....	3-82

## LIST OF FIGURES (CONTINUED)

<b><u>Chapter 4</u></b>	<b><u>Page</u></b>
Figure 4-1. Map of <i>Lophelia</i> collection sites in the Gulf of Mexico and off the southeastern U.S. coast .....	4-44
Figure 4-2. Phylogenetic hypothesis of relationships among corals based on maximum parsimony analysis of mitochondrial 16S sequence data .....	4-45
Figure 4-3. Phylogenetic hypothesis of relationships among corals based on Bayesian analysis of mitochondrial 16S sequence data.....	4-46
Figure 4-4. Phylogenetic hypothesis of relationships among ‘robust’ corals based on maximum parsimony analysis of mitochondrial 16S sequence data .....	4-47
Figure 4-5. Phylogenetic hypothesis of relationships among Complex corals based on maximum parsimony analysis of mitochondrial 16S sequence data .....	4-48
Figure 4-6. Phylogenetic hypothesis of relationships among ‘robust’ corals based on maximum parsimony analysis of nuclear internal transcribed spacer sequence data .....	4-49
Figure 4-7. Phylogenetic hypothesis of relationships among ‘complex’ corals based on maximum parsimony analysis of nuclear internal transcribed spacer sequence data .....	4-50
Figure 4-8. Allelic patterns across <i>Lophelia</i> populations .....	4-51
Figure 4-9. Neighbor-joining phylogram describing relationships among <i>Lophelia</i> populations.....	4-52
Figure 4-10. Mantel test results illustrating significant correlations between geographic distance and genetic distance for A) all <i>Lophelia</i> populations surveyed, B) Gulf of Mexico and southeastern U.S. <i>Lophelia</i> populations.....	4-53
Figure 4-11. Mantel test results illustrating insignificant correlations between geographic and genetic distance for A) southeastern U.S. <i>Lophelia</i> populations B) Gulf of Mexico. <i>Lophelia</i> populations .....	4-54

## LIST OF FIGURES (CONTINUED)

<b><u>Chapter 5</u></b>	<b><u>Page</u></b>
Figure 5-1. <i>Lophelia pertusa</i> branching .....	5-17
Figure 5-2. An alignment of <i>Lophelia pertusa</i> <i>pox 3</i> with similar <i>Gsx/cnox2</i> genes from other species .....	5-18
Figure 5-3. An alignment of an <i>engrailed</i> -like gene from <i>Lophelia pertusa</i> with similar genes from other species .....	5-18
Figure 5-4. Alignment of <i>Lophelia pertusa</i> calcium L-type channel amino acid sequence with that from <i>Stylophora pistillata</i> .....	5-19
Figure 5-5. An alignment of a <i>DM</i> -containing gene from <i>Lophelia pertusa</i> with similar genes in other species .....	5-20
Figure 5-6. Comparison of <i>Hox/paraHox</i> expression levels in budding and unitary polyps.....	5-21
Figure 5-7. Expression of a <i>Lophelia pertusa</i> <i>DM</i> -containing gene .....	5-22
<b><u>Chapter 6</u></b>	<b><u>Page</u></b>
Figure 6-1. The tree of life, based on the 16S ribosomal RNA (rRNA) gene .....	6-37
Figure 6-2. 2004 and 2005 submersible dive tracks at Viosca Knoll 906/862, with the microbial ecology dives (4746 in 2004, 4873 in 2005) highlighted in red .....	6-38
Figure 6-3. 2004 and 2005 submersible dive tracks at Viosca Knoll 826.....	6-39
Figure 6-4. The ‘Kellogg Sampler’. This specially designed box is used to collect discrete <i>Lophelia</i> samples for coral microbial ecology experiments.....	6-40
Figure 6-5. Denaturing gel gradient electrophoresis (DGGE) of <i>Lophelia</i> bacterial communities .....	6-41
Figure 6-6. Comparison of bacterial 16S clone libraries between the two sites.....	6-42

**LIST OF FIGURES (CONTINUED)**

<b><u>Chapter 7</u></b>	<b><u>Page</u></b>
Figure 7-1. Location of antipatharian collection sites on southeastern U.S. continental slope at Jacksonville lithoherms, Stetson Bank, and Viosca Knoll .....	7-16
Figure 7-2. Video frame grab of black coral colony observed at 561 m at Jacksonville lithoherm site .....	7-17
Figure 7-3. Cross section of specimen A8601 after KOH treatment.....	7-18
Figure 7-4. Cross section of specimen A8601 under light microscope.....	7-19
<b><u>Chapter 8</u></b>	
<b><u>Chapter 8</u></b>	<b><u>Page</u></b>
Figure 8-1. A single, largely-unbranched, 38 mm-long frond of the open growth form of <i>Lophelia pertusa</i> , sampled from Viosca Knoll, USGS-2004-05, Dive 4751 .....	8-35
Figure 8-2. <i>Leiopathes glabberima?</i> (orange-red living tissue) black coral from Cruise 2005-Dive 4876 (image JSL1_4876_066) .....	8-36
Figure 8-3. <i>Leiopathes</i> sp. (white living tissue) black coral attached to a plate of black goethite substrate rock, collected together during Cruise 2005-04, Dive 4876, VK-906/862 (image JSL1_4876_079).....	8-37
Figure 8-4. A - Specimen of plate-like black goethite substrate rock upon which a 2-m tall <i>Leiopathes</i> sp. black coral was attached; B - Close-up of attachment scar (ca 15 diameter) left when the black coral was removed with a saw .....	8-38

**LIST OF FIGURES (CONTINUED)**

<b><u>Chapter 8</u></b>	<b><u>Page</u></b>
<p>Figure 8-5. Authigenic carbonate/biogenic aggregate basal reef rock, Cruise 2004-03, Dive 4752, VK-826, with subfossil biotic inclusions:            A - Whole rock, inset illustrating broken bases of living <i>L. pertusa</i> coral using rock as substrate; B - Close-up to show methanogenic pores;            C - Subfossil <i>L. pertusa</i> embedded in rock matrix; D - Subfossil bivalve (vent clam?) embedded in rock matrix .....</p>	8-39
<p>Figure 8-6. Specimen of plate-like black goethite substrate rock from Cruise 2005-04, Dive 4876, VK-906/862 (same as in Figure 8-3): A - Pitted and eroded edge of plate; B - Freshly exposed section through plate where sample was taken for gravimetric and x-ray diffraction analyses;            C - Enlargement to denote sub-mm laminated/layered pattern of mineral deposition.....</p>	8-40
<p>Figure 8-7A. Calcium carbonate aggregate reef rock from Cruise 2005-04, Dive 4879, comprised predominantly of highly eroded <i>L. pertusa</i> coral, with carbonate from other biotic sources included, and semiconsolidated sediment trapped within interstices.....</p>	8-41
<p>Figure 8-7B&amp;C. Close-ups of calcium carbonate aggregate reef rock from Cruise 005-04, Dive 4879: B - Heavily eroded and cemented <i>L. pertusa</i> reef matrix (branches and calices) in the above-substrate portion of the rock; C - Eroded coral calices at the distal below-substrate end of the rock.....</p>	8-42
<p>Figure 8-8. Layout image of black goethite substrate rock from Cruise 2005-04, Dive 4875, VK-826: A - Whole specimen as collected; B- Highly eroded and pitted reverse surface (with eroded serpulid tube); C - Freshly exposed section where sample was taken .....</p>	8-43

**LIST OF FIGURES (CONTINUED)**

<b><u>Chapter 8</u></b>	<b><u>Page</u></b>
Figure 8-9. Goethite coated carbonate-interior rock from Viosca Knoll collected by JSL (image DSCN 5349): A - Whole specimen as collected; B – Freshly exposed section where sample was taken; C – Enlargement to illustrate distinct separation between carbonate core and irregularly-layered goethite crust (arrow).....	8-44
Figure 8-10A. Open growth form of <i>L. pertusa</i> , characterized by elongate branches with limited lateral branching and inter-branch anastomosing, a by loose, open matrix.....	8-45
Figure 8-10B. Compact growth form of <i>L. pertusa</i> , characterized by extensive lateral branching and inter-branch anastomosing, and by dense matrix.....	8-45
Figure 8-11A. A frond of the open, loosely branching growth form of <i>L. pertusa</i> used for gravimetric and coral calyx per unit area determinations.....	8-46
Figure 8-11B. A frond of the compact, densely branches growth form of <i>L. pertusa</i> used for gravimetric and coral calyx per unit area determinations.....	8-46
Figure 8-12. Viosca Knoll sand sample from Dive 2004-4747 (image DSCN 5212). Identifiable reef-derived biotic components: A – <i>L. pertusa</i> coral, B – <i>Cidaris rugosa</i> pencil urchin spines, C – encrusting sponge, D- eroded bivalve fragment, E – broken gastropod shells, F- serpulid worm. Water-column derived biotic component: G – pteropod test. Abiotic component: H – fragment of black goethite rock.....	8-47
Figure 8-13. Biotic components of Viosca Knoll sand sample from Dive 2004-4747 (images B1-10, 8, 5, 11): A -Keyhole limpet; B -Heteropod test; C -Serpulid annelid worm tube; D -- <i>eratoisis flexibilis</i> bamboo coral, pteropod test.....	8-48
Figure 8-14. Micrograph of a thin section through an individual <i>L. pertusa</i> calyx, appearing to show 1-2 marginal growth rings .....	8-49

**LIST OF FIGURES (CONTINUED)**

<b><u>Chapter 8</u></b>	<b><u>Page</u></b>
Figure 8-15. Sea level (m) stands versus geological time (kyr before present) to provide a temporal frame of reference for the potential age of Gulf of Mexico <i>Lophelia</i> reefs (adapted and modified from Aharon, 1983) .....	8-50
Figure 8-16. Subbottom (1.2-4.8 kc) echo-sounder profile of Blake Plateau <i>Lophelia</i> biogenic reef mounds (> 40 m thick) lying unconformably on the essentially horizontal sedimentary plane of the plateau – the strong linear acoustic reflector (adapted after Stetson et al. 1962) .....	8-50
Figure 8-17A. Single-beam echo-sounder profile through a portion of Big Blue Reef on Viosca Knoll-826, displaying the underlying geology of ridges and valleys, and a well-developed <i>Lophelia</i> reef, appearing as a thin veneer, returning a weak acoustic signal from an echo-sounder tuned to subbottom profiling.....	8-51
Figure 8-17B. Single-beam false-color acoustic profile of Big Blue Reef, a well-developed, high-profile living <i>Lophelia</i> reef sitting unconformably atop a geological ridge on a portion of the VK-826 study site, 450 m, from an echo-sounder tuned as a fish-finder.....	8-51
Figure 8-18. Two small, mound-like features in the northeastern Gulf of Mexico, off Florida and lying east of Viosca Knoll, unexplored potential <i>Lophelia</i> reef sites, identified from a NOAA composite bathymetric map provided by the Naval Research Laboratory, modified by USGS (courtesy of Bill Teague).....	8-52

**LIST OF APPENDICES**

<b><u>Chapter 1</u></b>	<b><u>Page</u></b>
No Appendices.....	---

<b><u>Chapter 2</u></b>	<b><u>Page</u></b>
No Appendices.....	---

<b><u>Chapter 3</u></b>	<b><u>Page</u></b>
Appendix 3-I. ‘EstimateS’ EXPECTED NUMBER OF SPECIES (Sobs = Mao Tau statistic) and 95% confidence intervals determined from multiple random draws upon pooled sample data for each empirically-defined biotope group.....	84
Appendix 3-II. Multivariate determined sampling SITE CLUSTER GROUPS AND SUBGROUPS by alphabetical designation, with list of component images (N <sub>T</sub> = 419) and original empirical biotope designations.....	96
Appendix 3-III. Multivariate determined BIOTOPE CLUSTER GROUPS AND SUBGROUPS by numeric designation, with list of component images (N <sub>T</sub> = 419) and original empirical biotope designations.....	106
Appendix 3-IV. SPECIES CLUSTER GROUP composition.....	116

<b><u>Chapter 4</u></b>	<b><u>Page</u></b>
Appendix 4-I. Species included in phylogenetic analyses, including taxonomic classification, sample source (when available), sequence authors, and Genbank accession numbers.....	56
Appendix 4-II. On-deck photographs of coral species used in genetic analyses.....	70

**LIST OF APPENDICES (CONTINUED)**

**Chapter 5** **Page**

No Appendices .....---

**Chapter 6** **Page**

No Appendices .....---

**Chapter 7** **Page**

No Appendices .....---

**Chapter 8** **Page**

No Appendices .....---

## CONVERSION FACTORS

Multiply	By	To obtain
Length		
inch (in.)	2.54	centimeter (cm)
inch (in.)	25.4	millimeter (mm)
foot (ft)	0.3048	meter (m)
mile (mi)	1.609	kilometer (km)
mile, nautical (nmi)	1.852	kilometer (km)
yard (yd)	0.9144	meter (m)
Area		
acre	4,047	square meter (m <sup>2</sup> )
acre	0.4047	hectare (ha)
acre	0.4047	square hectometer (hm <sup>2</sup> )
acre	0.004047	square kilometer (km <sup>2</sup> )
square foot (ft <sup>2</sup> )	929.0	square centimeter (cm <sup>2</sup> )
square foot (ft <sup>2</sup> )	0.09290	square meter (m <sup>2</sup> )
square inch (in <sup>2</sup> )	6.452	square centimeter (cm <sup>2</sup> )
section (640 acres or 1 square mile)	259.0	square hectometer (hm <sup>2</sup> )
square mile (mi <sup>2</sup> )	259.0	hectare (ha)
square mile (mi <sup>2</sup> )	2.590	square kilometer (km <sup>2</sup> )
Volume		
barrel (bbl), (petroleum, 1 barrel=42 gal)	0.1590	cubic meter (m <sup>3</sup> )
ounce, fluid (fl. oz)	0.02957	liter (L)
pint (pt)	0.4732	liter (L)
quart (qt)	0.9464	liter (L)
gallon (gal)	3.785	liter (L)
gallon (gal)	0.003785	cubic meter (m <sup>3</sup> )
gallon (gal)	3.785	cubic decimeter (dm <sup>3</sup> )
million gallons (Mgal)	3,785	cubic meter (m <sup>3</sup> )
cubic inch (in <sup>3</sup> )	16.39	cubic centimeter (cm <sup>3</sup> )
cubic inch (in <sup>3</sup> )	0.01639	cubic decimeter (dm <sup>3</sup> )
cubic inch (in <sup>3</sup> )	0.01639	liter (L)
cubic foot (ft <sup>3</sup> )	28.32	cubic decimeter (dm <sup>3</sup> )

CONVERSION FACTORS (continued)

cubic foot (ft <sup>3</sup> )	0.02832	cubic meter (m <sup>3</sup> )
cubic yard (yd <sup>3</sup> )	0.7646	cubic meter (m <sup>3</sup> )
cubic mile (mi <sup>3</sup> )	4.168	cubic kilometer (km <sup>3</sup> )
acre-foot (acre-ft)	1,233	cubic meter (m <sup>3</sup> )
acre-foot (acre-ft)	0.001233	cubic hectometer (hm <sup>3</sup> )
Flow rate		
acre-foot per day (acre-ft/d)	0.01427	cubic meter per second (m <sup>3</sup> /s)
acre-foot per year (acre-ft/yr)	1,233	cubic meter per year (m <sup>3</sup> /yr)
acre-foot per year (acre-ft/yr)	0.001233	cubic hectometer per year (hm <sup>3</sup> /yr)
foot per second (ft/s)	0.3048	meter per second (m/s)
foot per minute (ft/min)	0.3048	meter per minute (m/min)
foot per hour (ft/hr)	0.3048	meter per hour (m/hr)
foot per day (ft/d)	0.3048	meter per day (m/d)
foot per year (ft/yr)	0.3048	meter per year (m/yr)
cubic foot per second (ft <sup>3</sup> /s)	0.02832	cubic meter per second (m <sup>3</sup> /s)
cubic foot per second per square mile [(ft <sup>3</sup> /s)/mi <sup>2</sup> ]	0.01093	cubic meter per second per square kilometer [(m <sup>3</sup> /s)/km <sup>2</sup> ]
cubic foot per day (ft <sup>3</sup> /d)	0.02832	cubic meter per day (m <sup>3</sup> /d)
gallon per minute (gal/min)	0.06309	liter per second (L/s)
gallon per day (gal/d)	0.003785	cubic meter per day (m <sup>3</sup> /d)
gallon per day per square mile [(gal/d)/mi <sup>2</sup> ]	0.001461	cubic meter per day per square kilometer [(m <sup>3</sup> /d)/km <sup>2</sup> ]
million gallons per day (Mgal/d)	0.04381	cubic meter per second (m <sup>3</sup> /s)
million gallons per day per square mile [(Mgal/d)/mi <sup>2</sup> ]	1,461	cubic meter per day per square kilometer [(m <sup>3</sup> /d)/km <sup>2</sup> ]
inch per hour (in/h)	0.0254	meter per hour (m/h)
inch per year (in/yr)	25.4	millimeter per year (mm/yr)
mile per hour (mi/h)	1.609	kilometer per hour (km/h)
Mass		
ounce, avoirdupois (oz)	28.35	gram (g)
pound, avoirdupois (lb)	0.4536	kilogram (kg)
ton, short (2,000 lb)	0.9072	megagram (Mg)
ton, long (2,240 lb)	1.016	megagram (Mg)
ton per day (ton/d)	0.9072	metric ton per day
ton per day (ton/d)	0.9072	megagram per day (Mg/d)

CONVERSION FACTORS (continued)

ton per day per square mile [(ton/d)/mi <sup>2</sup> ]	0.3503	megagram per day per square kilometer [(Mg/d)/km <sup>2</sup> ]
ton per year (ton/yr)	0.9072	megagram per year (Mg/yr)
ton per year (ton/yr)	0.9072	metric ton per year
Pressure		
atmosphere, standard (atm)	101.3	kilopascal (kPa)
bar	100	kilopascal (kPa)
inch of mercury at 60°F (in Hg)	3.377	kilopascal (kPa)
pound-force per square inch (lbf/in <sup>2</sup> )	6.895	kilopascal (kPa)
pound per square foot (lb/ft <sup>2</sup> )	0.04788	kilopascal (kPa)
pound per square inch (lb/in <sup>2</sup> )	6.895	kilopascal (kPa)
Density		
pound per cubic foot (lb/ft <sup>3</sup> )	16.02	kilogram per cubic meter (kg/m <sup>3</sup> )
pound per cubic foot (lb/ft <sup>3</sup> )	0.01602	gram per cubic centimeter (g/cm <sup>3</sup> )
Energy		
kilowatthour (kWh)	3,600,000	joule (J)
Radioactivity		
picocurie per liter (pCi/L)	0.037	becquerel per liter (Bq/L)
Specific capacity		
gallon per minute per foot [(gal/min)/ft]	0.2070	liter per second per meter [(L/s)/m]
Hydraulic conductivity		
foot per day (ft/d)	0.3048	meter per day (m/d)
Hydraulic gradient		
foot per mile (ft/mi)	0.1894	meter per kilometer (m/km)
Transmissivity*		
foot squared per day (ft <sup>2</sup> /d)	0.09290	meter squared per day (m <sup>2</sup> /d)
Application rate		
pounds per acre per year [(lb/acre)/yr]	1.121	kilograms per hectare per year [(kg/ha)/yr]
Leakance		
foot per day per foot [(ft/d)/ft]	1	meter per day per meter
inch per year per foot [(in/yr)/ft]	83.33	millimeter per year per meter [(mm/yr)/m]

### CONVERSION FACTORS (continued)

Temperature in degrees Celsius (°C) may be converted to degrees Fahrenheit (°F) as follows:

$$^{\circ}\text{F}=(1.8\times^{\circ}\text{C})+32$$

Temperature in degrees Fahrenheit (°F) may be converted to degrees Celsius (°C) as follows:

$$^{\circ}\text{C}=(^{\circ}\text{F}-32)/1.8$$

Vertical coordinate information is referenced to the insert datum name (and abbreviation) here for instance, “North American Vertical Datum of 1988 (NAVD 88).”

Horizontal coordinate information is referenced to the insert datum name (and abbreviation) here for instance, “North American Datum of 1983 (NAD 83).”

Altitude, as used in this report, refers to distance above the vertical datum.

## COMPENDIUM OF ABSTRACTS: CHAPTER 1 (INTRODUCTION - No Abstract)

## COMPENDIUM OF ABSTRACTS: CHAPTER 2

### DEMERSAL FISHES ASSOCIATED WITH *LOPHELIA PERTUSA* CORAL AND ASSOCIATED BIOTOPES ON THE CONTINENTAL SLOPE, NORTHERN GULF OF MEXICO

*Kenneth J. Sulak, R. Allen Brooks, Kirsten E. Luke, April D. Norem,  
Michael T. Randall, Andrew J. Quaid, George E. Yeargin, Jana M. Miller,  
William M. Harden, John H. Caruso, and Steve W. Ross*

#### ABSTRACT

The demersal fish fauna of *Lophelia pertusa* coral reefs and associated hard-bottom biotopes was investigated at two depth horizons in the northern Gulf of Mexico using a manned submersible and remote sampling. The Viosca Knoll fauna consisted of at least 54 demersal fish species, 38 of which were documented by submersible video. On the 325 m horizon, dominant taxa determined from frame-by-frame video analysis included Stromateidae, Serranidae, Trachichthyidae, Congridae, Scorpaenidae and Gadiformes. On the 500 m horizon, large mobile visual macrocarnivores of families Stromateidae and Serranidae dropped out, while a zeiform microcarnivore assumed importance on reef 'Thicket' biotope, and the open-slope taxa Macrouridae and Squalidae gained in importance. The most consistent faunal groups at both depths included sit-and-wait and hover-and-wait strategists (Scorpaenidae, Congridae, Trachichthyidae), along with generalized mesocarnivores (Gadiformes). The specialized microcarnivore, *Grammicolepis brachiusculus*, appears to be highly associated with *Lophelia* reefs. Coral 'Thicket' biotope was extensively developed on the 500 m site, but fish abundance was low, only 95 fish/hectare. In contrast to *Lophelia* reefs from the eastern North Atlantic, coral 'Rubble' biotope was essentially absent. This study represents the first quantitative analysis of fishes associated with *Lophelia* reefs in the Gulf of Mexico, and generally in the western North Atlantic.



### COMPENDIUM OF ABSTRACTS: CHAPTER 3

#### QUANTITATIVE DEFINITION OF VIOSCA KNOLL BIOTOPES AVAILABLE TO FISHES OF THE CONTINENTAL SLOPE, 325-500 M, NORTHERN GULF OF MEXICO

*Kenneth J. Sulak, April D. Norem, Kirsten E. Luke, Michael T. Randall,  
and Jana M. Miller*

#### ABSTRACT

The megafaunal invertebrate fauna of *Lophelia pertusa* coral reefs and associated hard-bottom biotopes was investigated at two depth horizons (325m and 500m depth) on Viosca Knoll in the northern Gulf of Mexico using a manned submersible. Megafaunal invertebrates were quantified by occurrence from high-quality digital video frame grabs using Coral Point Count software. Megafaunal invertebrate assemblages identified by Primer v6 multivariate analyses of the occurrence data were used to characterize and differentiate key biotopes used by demersal fishes associated with *Lophelia* coral and comparative biotopes. Multivariate analyses fundamentally supported the a priori empirical classification of biotopes on Viosca Knoll, including *Lophelia* coral ‘Thicket’, ‘Rock’, ‘Plate’, ‘Plate/Chemo’ and ‘Open’. In striking contrast to *Lophelia* reefs in the northeastern Atlantic and off the southeastern U.S. East Coast, coral ‘Rubble’ biotope was essentially absent in this study. *Lophelia* coral ‘Thicket’ biotope was extensively developed on the 500 m site. *Lophelia* occurred only sporadically and as individual colonies on the 325 m site. Mixed species oases comprised of *Lophelia*, black corals, sponges and other taxa occurred primarily on the shallower site. In places clusters of individuals of a single species inhabited broad expanses of ‘Plate’ and ‘Rock’ biotope. Among hard-substrate and structured biotopes, species richness was highest for ‘Rock’ biotope, and lowest on *Lophelia* ‘Thicket’. Thus, contrary to expectations, *Lophelia* biotope in the northern Gulf of Mexico does not support a richer invertebrate megafaunal assemblage than that found on comparative hard-substrate or soft-substrate biotopes. In striking contrast to *Lophelia* reefs in the northeastern Atlantic and off the southeastern U.S. East Coast, coral ‘Rubble’ biotope was essentially absent in this study. The height and slope of the rarefaction curve for ‘Open’ biotope suggested that this inadequately sampled biotope probably supports the highest megafaunal invertebrate species richness, also contrary to expectations. This study represents the first statistically robust

quantitative analysis of biotopes available to fishes associated with *Lophelia* reefs in the Gulf of Mexico, and generally in the western North Atlantic.

## COMPENDIUM OF ABSTRACTS: CHAPTER 4

### MOLECULAR ASSESSMENT OF DEEP-SEA SCLERACTINIAN CORAL BIODIVERSITY AND POPULATION STRUCTURE OF *LOPHELIA PERTUSA* IN THE GULF OF MEXICO

*Cheryl L. Morrison, Robin L. Johnson, Tim L. King, Steve W. Ross, Martha S. Nizinski*

#### ABSTRACT

Geographic patterns of genetic diversity in *Lophelia pertusa* were examined by quantifying genetic diversity present in populations, and assessing levels of genetic differentiation within the Gulf of Mexico (5 sampling locations, <1-290 km apart). Patterns of differentiation observed within Gulf *Lophelia* were compared to *Lophelia* populations from the Southeastern U.S. continental slope (6 sampling locations, 18-990 km apart) and with Europe (5400-7900 km away from sampled U.S. populations). A suite of nine microsatellite markers for Gulf of Mexico *Lophelia* were developed; 190 individuals have been genotyped. The microsatellite markers were highly variable, ranging from 11-53 alleles per locus with an average of 27.4 alleles per locus. Eighteen (9%) individuals with identical multi-locus genotypes were identified as clones. Populations of *Lophelia* harbored substantial genetic diversity. The majority of populations had unique alleles indicative of little gene flow. Pairwise chord distances were high among all populations (0.42 – 0.62), and regional groupings of populations resulted from a neighbor-joining clustering analysis. North versus south areas of Viosca Knoll 826, the most intensively sampled area, had fixation index estimates significantly greater than zero, suggesting little larval mixing. Comparisons of all Gulf *Lophelia* populations with the shallowest site, VK862, produced significant fixation indices. Quantitative estimates of hierarchical gene diversity (AMOVA) indicated significant population structure at every level: between the three regions examined; between Gulf and southeastern U.S. regions; and within the Gulf and southeastern U.S. regions. Mantel tests identified significant correlations between geographic and genetic distance (an isolation-by-distance pattern) at larger spatial scales, but not within regions. Thus, dispersal of *Lophelia* larvae is generally localized, with occasional long distance dispersal occurring such that some genetic cohesion is retained regionally within the Gulf and Southeastern U.S. Genetic differentiation observed between these regions suggests more

restricted gene flow than expected, suggesting that the most effective management plan for *Lophelia* may be regional reserve networks.

Gulf of Mexico deep-sea scleractinian coral biodiversity was put into a phylogenetic framework by comparison of 16S mitochondrial DNA sequences. Four basal lineages were revealed, including the ‘complex’ and ‘robust’ corals, the genus *Anthemiphyllia*, plus several species belonging to the family Caryophylliidae. The latter basal coral lineage appears diverse since three Gulf species grouped within this clade. Members of the family Caryophylliidae were not monophyletic, but appeared in six clades; the majority of which were in the ‘robust’ coral group. The high estimate of genetic distance reported previously between *Lophelia* in different oceanic regions was not supported.

## COMPENDIUM OF ABSTRACTS: CHAPTER 5

### EXPRESSED GENES OF THE DEEPWATER CORAL, *LOPHELIA PERTUSA*

*William B. Schill*

#### ABSTRACT

While some functional genomic studies have been conducted on shallow-water corals, these kinds of studies on deep-water corals are virtually absent and little or nothing is known about how deep-water organisms such as *Lophelia pertusa* perform the basic life functions of growth, differentiation, and reproduction. A suite of assays that could be used to measure and assess the physiological status of these life functions in key coral species would be a useful management tool. Utilizing polymerase chain reaction, the expression of several gene families was investigated to study the molecular mechanisms functioning in *Lophelia* that are known from studies of other metazoan species to be associated with vegetative growth, division, gamete development, and skeletal biomineralization. Four, previously unknown expressed genes were discovered from the deep-sea coral, *Lophelia pertusa*. Expression of these genes were compared in budding (presumably immature) and unitary (presumably mature) polyps. Two members of the *Hox/paraHox* gene family, thought to be associated with segmentation and neuronal development were found to have elevated expression in budding polyps. An L-type calcium channel gene associated with the importation of  $\text{Ca}^{2+}$  into calcioblastic cells was also more highly expressed in budding as opposed to unitary polyps. In contrast, a *DM*-containing gene, a member of a family of genes notably associated with sexual development and gamete differentiation, was strongly expressed in both budding and unitary polyps. Interestingly, the samples analyzed were taken at a time thought to be the approximate spawning period for *Lophelia pertusa* in the Gulf of Mexico.



## COMPENDIUM OF ABSTRACTS: CHAPTER 6

### MICROBIAL ECOLOGY OF *LOPHELIA PERTUSA* IN THE NORTHERN GULF OF MEXICO

*Christina A. Kellogg*

#### ABSTRACT

Microbes, including bacteria, archaea and fungi, are recognized to be an important part of the total biology of shallow-water corals. Deep-sea corals have a fundamentally different ecology due to their adaptation to cold, dark, high-pressure environments, and as such have novel microbiota. The goal of this study was to characterize the microbial associates of *Lophelia pertusa* in the Gulf of Mexico. This is the first study to include both culture-based and molecular data on deep-sea coral-associated bacterial communities. It is also the first study to collect the coral samples in individual insulated containers and to preserve coral samples at depth in an effort to maintain *in situ* microbial diversity by minimizing contamination and thermal shock.

There are a few links between *Lophelia*-associated bacteria and bacteria from shallow-water corals and deep-sea octocorals, but both cultured isolates and clone libraries revealed many novel bacteria associated with *Lophelia*. There are many bacteria and clone sequences that are similar to symbionts of fish, squid, and methane seep clams. In particular, there is a sequence, VKLP1, present in all *Lophelia* colonies analyzed to date (n=6), which is related to a sulfide-oxidizing gill symbiont of a seep clam. This microbe may be a *Lophelia*-specific bacterium and links the coral to cold seep communities. Molecular analysis of bacterial diversity showed a marked difference between the two sites, Visoca Knoll 906/862 and Visoca Knoll 826. The 16S rRNA bacterial clone libraries from VK826 were dominated by a variety of unknown *Firmicutes*. The dissimilarity between the dominant members of the bacterial communities at these two sites may be evidence of diseased *Lophelia* or thermal stress at one site, or may indicate biogeographical differences.

There was no overlap between the bacteria identified in this study and those from a recent study of *Lophelia* in the Mediterranean. This may indicate biogeographical differences, however, it is more likely due to the significant methodological differences in collection, extraction, and

analysis of the *Lophelia* samples. No archaea have been detected to date, however, a fungus similar to marine species of *Paecilomyces* and *Acremonium* was found.

## COMPENDIUM OF ABSTRACTS: CHAPTER 7

### DEEPWATER ANTIPATHARIANS: PROXIES OF ENVIRONMENTAL CHANGE

*B. Williams, M. J. Risk, S. W. Ross, and K. J. Sulak*

#### ABSTRACT

Deepwater (307–697 m) antipatharian (black coral) specimens were collected from the southeastern continental slope of the United States and the north-central Gulf of Mexico. The sclerochronology of the specimens indicates that skeletal growth takes place by formation of concentric coeval layers. We used  $^{210}\text{Pb}$  to estimate radial growth rate of two specimens, and to establish that they were several centuries old. Bands were delaminated in KOH and analyzed for carbon and nitrogen stable isotopes. Carbon values ranged from -16.4‰ to -15.7‰; the oldest specimen displayed the largest range in values. Nitrogen values ranged from 7.7‰ to 8.6‰. Two specimens from the same location and depth had similar  $^{15}\text{N}$  signatures, indicating good reproducibility between specimens.



## COMPENDIUM OF ABSTRACTS: CHAPTER 8

### ORIGINS, COMPOSITION, AGE, AND STRUCTURAL DIVERSIFICATION OF VIOSCA KNOLL *LOPHELIA* CORAL REEFS AND SUBSTRATE – A SYNOPSIS OF PRELIMINARY RESULTS

*Kenneth J. Sulak*

#### ABSTRACT

Incidental collections of live *Lophelia pertusa* fronds, coral rubble, rocks and reef sands during 2004-2005 submersible investigations of *Lophelia* reefs on Viosca Knoll, northern Gulf of Mexico, enabled an opportunistic group of primarily geological analyses to proceed. Radiometric ages of living coral and dead sub-fossil coral were obtained. One substrate rock was analyzed for mineralogy via x-ray diffraction and for stable  $^{13}\text{C}$  and  $^{18}\text{O}$  isotopic signatures. Gravimetric analyses of specific gravity were undertaken for fresh coral, coral rubble, and rocks. Reef sand collected was analyzed to identify major biotic contributors. Results suggest an age of <400 yrs for contemporary Viosca Knoll *Lophelia* reefs, and of 25.0-26.0 ky for the overall *Lophelia* ecosystem in the northern Gulf of Mexico. This indicates that reefs flourished during the low sea-level stand of the Pleistocene Wisconsinian Glaciation. From the young age of contemporary reefs, relative to the much greater age of sub-fossil *Lophelia*, it may be hypothesized that reef-building has occurred episodically over geological time, a concept raised by Paull et al. (2000), but not further elaborated. Results of analysis of one black substrate rock revealed unexpected goethite mineralogy, whereas methanogenic carbonates had been anticipated in the area of methane seeps. The atypical rock substrate mineralogy, and the exclusive occurrence of well-developed *Lophelia* reefs on Viosca Knoll suggest a uniquely favorable environmental context for reef development on this feature, relative to other similar slope-depth features further to the west. The absence of coral mounds and of extensive rubble fields indicates a distinct difference in the development of *Lophelia* reefs and associated biotopes in the northern Gulf of Mexico, relative to reefs off the southeastern U.S. East Coast, and in the northeastern Atlantic. Soft substrates found on Viosca Knoll may be characterized as biogenic reef sands, comprised predominantly of eroded calcium carbonate shells, spines, and skeletons. Thus, *Lophelia* reefs do create a unique sedimentary regime very different from that of the surrounding abiogenic fine sediment of the open slope.

