# 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**
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**Florida Integrated Science Center-Gainesville, Florida**
**Coastal Ecology and Conservation Research Group**

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

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

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Mark D. Myers, Director

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## CONTRIBUTORS

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## 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.

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## 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 ($m^2$) |
| acre | 0.4047 | hectare (ha) |
| acre | 0.4047 | square hectometer ($hm^2$) |
| acre | 0.004047 | square kilometer ($km^2$) |
| square foot ($ft^2$) | 929.0 | square centimeter ($cm^2$) |
| square foot ($ft^2$) | 0.09290 | square meter ($m^2$) |
| square inch ($in^2$) | 6.452 | square centimeter ($cm^2$) |
| section (640 acres or 1 square mile) | 259.0 | square hectometer ($hm^2$) |
| square mile ($mi^2$) | 259.0 | hectare (ha) |
| square mile ($mi^2$) | 2.590 | square kilometer ($km^2$) |
| | Volume | |
| barrel (bbl), (petroleum, 1 barrel=42 gal) | 0.1590 | cubic meter ($m^3$) |
| 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 ($m^3$) |
| gallon (gal) | 3.785 | cubic decimeter ($dm^3$) |
| million gallons (Mgal) | 3,785 | cubic meter ($m^3$) |
| cubic inch ($in^3$) | 16.39 | cubic centimeter ($cm^3$) |
| cubic inch ($in^3$) | 0.01639 | cubic decimeter ($dm^3$) |
| cubic inch ($in^3$) | 0.01639 | liter (L) |
| cubic foot ($ft^3$) | 28.32 | cubic decimeter ($dm^3$) |

| | | |
|---|---|---|
| cubic foot ($ft^3$) | 0.02832 | cubic meter ($m^3$) |
| cubic yard ($yd^3$) | 0.7646 | cubic meter ($m^3$) |
| cubic mile ($mi^3$) | 4.168 | cubic kilometer ($km^3$) |
| acre-foot (acre-ft) | 1,233 | cubic meter ($m^3$) |
| acre-foot (acre-ft) | 0.001233 | cubic hectometer ($hm^3$) |
| | Flow rate | |
| acre-foot per day (acre-ft/d) | 0.01427 | cubic meter per second ($m^3/s$) |
| acre-foot per year (acre-ft/yr) | 1,233 | cubic meter per year ($m^3/yr$) |
| acre-foot per year (acre-ft/yr) | 0.001233 | cubic hectometer per year ($hm^3/yr$) |
| 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 ($ft^3/s$) | 0.02832 | cubic meter per second ($m^3/s$) |
| cubic foot per second per square mile [($ft^3/s$)/$mi^2$] | 0.01093 | cubic meter per second per square kilometer [($m^3/s$)/$km^2$] |
| cubic foot per day ($ft^3/d$) | 0.02832 | cubic meter per day ($m^3/d$) |
| gallon per minute (gal/min) | 0.06309 | liter per second (L/s) |
| gallon per day (gal/d) | 0.003785 | cubic meter per day ($m^3/d$) |
| gallon per day per square mile [(gal/d)/$mi^2$] | 0.001461 | cubic meter per day per square kilometer [($m^3/d$)/$km^2$] |
| million gallons per day (Mgal/d) | 0.04381 | cubic meter per second ($m^3/s$) |
| million gallons per day per square mile [(Mgal/d)/$mi^2$] | 1,461 | cubic meter per day per square kilometer [($m^3/d$)/$km^2$] |
| 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) |

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CONVERSION FACTORS (continued)

| | | |
|---|---|---|
| ton per day per square mile [(ton/d)/$mi^2$] | 0.3503 | megagram per day per square kilometer [(Mg/d)/$km^2$] |
| 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 60ºF (in Hg) | 3.377 | kilopascal (kPa) |
| pound-force per square inch (lbf/$in^2$) | 6.895 | kilopascal (kPa) |
| pound per square foot (lb/$ft^2$) | 0.04788 | kilopascal (kPa) |
| pound per square inch (lb/$in^2$) | 6.895 | kilopascal (kPa) |
| | Density | |
| pound per cubic foot (lb/$ft^3$) | 16.02 | kilogram per cubic meter (kg/$m^3$) |
| pound per cubic foot (lb/$ft^3$) | 0.01602 | gram per cubic centimeter (g/$cm^3$) |
| | 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 ($ft^2$/d) | 0.09290 | meter squared per day ($m^2$/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] |

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

°F=(1.8×°C)+32

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

°C=(°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*

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### 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*

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### 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 indentified 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.

## 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.

## 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 $Ca^{2+}$ 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.

## 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 210Pb 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 $^{15}N$ 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 $^{13}C$ and $^{18}O$ 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 Wisconsonian 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.