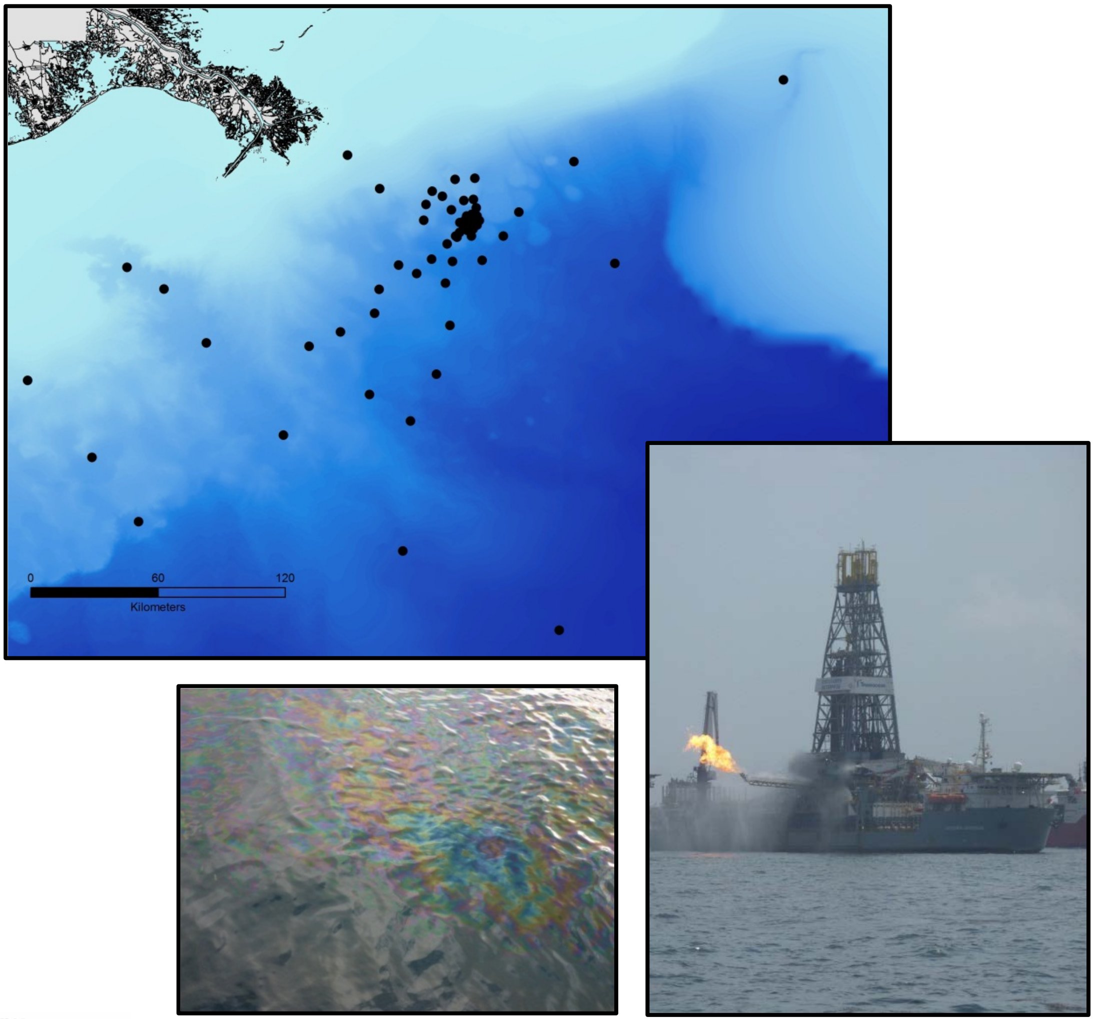
Deepwater Horizon Oil Spill: Assessment of Potential Impacts on the Deep Soft-Bottom Benthos

Interim Data Summary Report



NOAA Technical Memorandum NOS NCCOS 166
February 2013

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Citation for this report:
Montagna, P.A., J.G. Baguley, C. Cooksey, and J.L. Hyland. 2013. Deepwater Horizon Oil Spill: Assessment of Potential Impacts on the Deep Soft-Bottom Benthos. Interim Data Summary Report. NOAA Technical Memorandum NOS NCCOS 166. NOAA, National Centers for Coastal Ocean Science, Charleston, SC. 32 p.

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Deepwater Horizon Oil Spill: Assessment of Potential Impacts on the Deep Soft-Bottom Benthos

Interim Data Summary Report

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February 2013

NOAA Technical Memorandum NOS NCCOS 166

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Abstract

A study was initiated in May 2011, under the direction of the Deepwater Horizon (DWH) Natural Resource Damage Assessment (NRDA) Deepwater Benthic Communities Technical Working Group (NRDA Deep Benthic TWG), to assess potential impacts of the DWH oil spill on sediments and resident benthic fauna in deepwater (> 200 meters) areas of the Gulf. Key objectives of the study were to complete the analysis of samples from 65 priority stations sampled in September-October 2010 on two DWH Response cruises (*Gyre* and *Ocean Veritas*) and from 38 long-term monitoring sites (including a subset of 35 of the original 65) sampled on a follow-up NRDA cruise in May-June 2011. The present progress report provides a brief summary of results from the initial processing of samples from fall 2010 priority sites (plus three additional historical sites). Data on key macrofaunal, meiofaunal, and abiotic environmental variables are presented for each of these samples and additional maps are included to depict spatial patterns in these variables throughout the study region. The near-field zone within about 3 km of the wellhead, where many of the stations showed evidence of impaired benthic condition (e.g. low taxa richness, high nematode/harpacticoid-copepod ratios), also is an area that contained some of the highest concentrations of total petroleum hydrocarbons (TPH), total polycyclic aromatic hydrocarbons (total PAHs), and barium in sediments (as possible indicators of DWH discharges). There were similar co-occurrences at other sites outside this zone, especially to the southwest of the wellhead out to about 15 km. However, there also were exceptions to this pattern, for example at several farther-field sites in deeper-slope and canyon locations where there was low benthic species richness but no evidence of exposure to DWH discharges. Such cases are consistent with historical patterns of benthic distributions in relation to natural controlling factors such as depth, position within canyons, and availability of organic matter derived from surface-water primary production.

1. Introduction

The Deepwater Horizon (DWH) incident in the northern Gulf of Mexico occurred on April 20, 2010 at a water depth of 1525 meters, in Mississippi Canyon Block 252, releasing an estimated 4.9 million barrels of oil over the following three months (NOAA and USGS 2010). While oil-budget estimates suggested that a majority of the oil had been removed by cleanup operations and other natural mechanisms (NOAA and USGS 2010), there was also a possibility that large portions could have moved into offshore and deepwater sediments via several potential pathways — e.g., sinking of oil and/or dispersed oil droplets adsorbed onto suspended particles, or incorporated into copepod fecal pellets, in either surface or sub-surface layers; onshore-offshore transport of oil-laden particles; sinking of heavier oil by-products resulting from the burning of oil; or settling of oil-mud complexes resulting from the injection of drilling mud during top-kill operations (UAC 2010). In addition, drill cuttings, drill fluids, and other containment fluids commonly used during offshore oil-drilling operations (Neff et al. 1987, Neff 2005) may have been released and deposited to the bottom during the blowout event.

Such contaminants that ultimately make their way to the seafloor pose risks particularly to benthic fauna living within or in close association with bottom substrates and unable to avoid exposure due to their relatively sedentary existence. Potential losses are of concern because these fauna serve vital functional roles in the deep-sea ecosystem including sediment bioturbation and stabilization, organic matter decomposition and nutrient regeneration, and secondary production and energy flow to higher trophic levels (Danovaro et al. 2008, Thistle 2003, Gage 2003, Gray 1981, Tenore 1977). In many places, the deep-sea benthos may also represent important reservoirs of marine biodiversity (e.g., Hessler and Sanders 1967, Jumars 1976, Gage 1979, Hecker and Paul 1979, Rex 1981, Rowe et al. 1982, Grassle and Morse-Porteous 1987, Grassle and Maciolek 1992, Blake and Grassle 1994). High benthic species diversity has been reported for the Gulf of Mexico with a maximum on the mid to upper continental slope at depths between 1200 to 1600 meters (Tyler 2003; Wei and Rowe 2006; Rowe and Kennicutt II 2008, 2009; Haedrich et al. 2008; Wei et al. 2010), which coincides with depths of the DWH well site and potential zone of exposure. A recent study by Danovaro et al. (2008) provides evidence linking the loss of benthic biodiversity to an exponential decline in deep-sea ecosystem functioning.

A study was initiated in May 2011, under the direction of the DWH Natural Resource Damage Assessment (NRDA) Deepwater Benthic Communities Technical Working Group (NRDA Deep Benthic TWG), for the purpose of assessing potential impacts of the DWH oil spill on sediments and resident benthic fauna in deepwater (> 200 meters) areas of the Gulf. Key objectives of the study are aimed at completing the analysis of samples from 65 priority stations sampled in September-October 2010 on two DWH Response cruises (*Gyre* and *Ocean Veritas*) and from 38 long-term monitoring sites (including a subset of 35 of the original 65) sampled on a follow-up NRDA cruise in May-June 2011 (Fig. 1). Further details are provided in the Deep Benthic TWG Study Plan for Deepwater Sediment Sampling (approved May 2011). The present progress report provides a summary of results from the initial processing of samples from fall 2010 priority sites (as called for under the Study Plan).

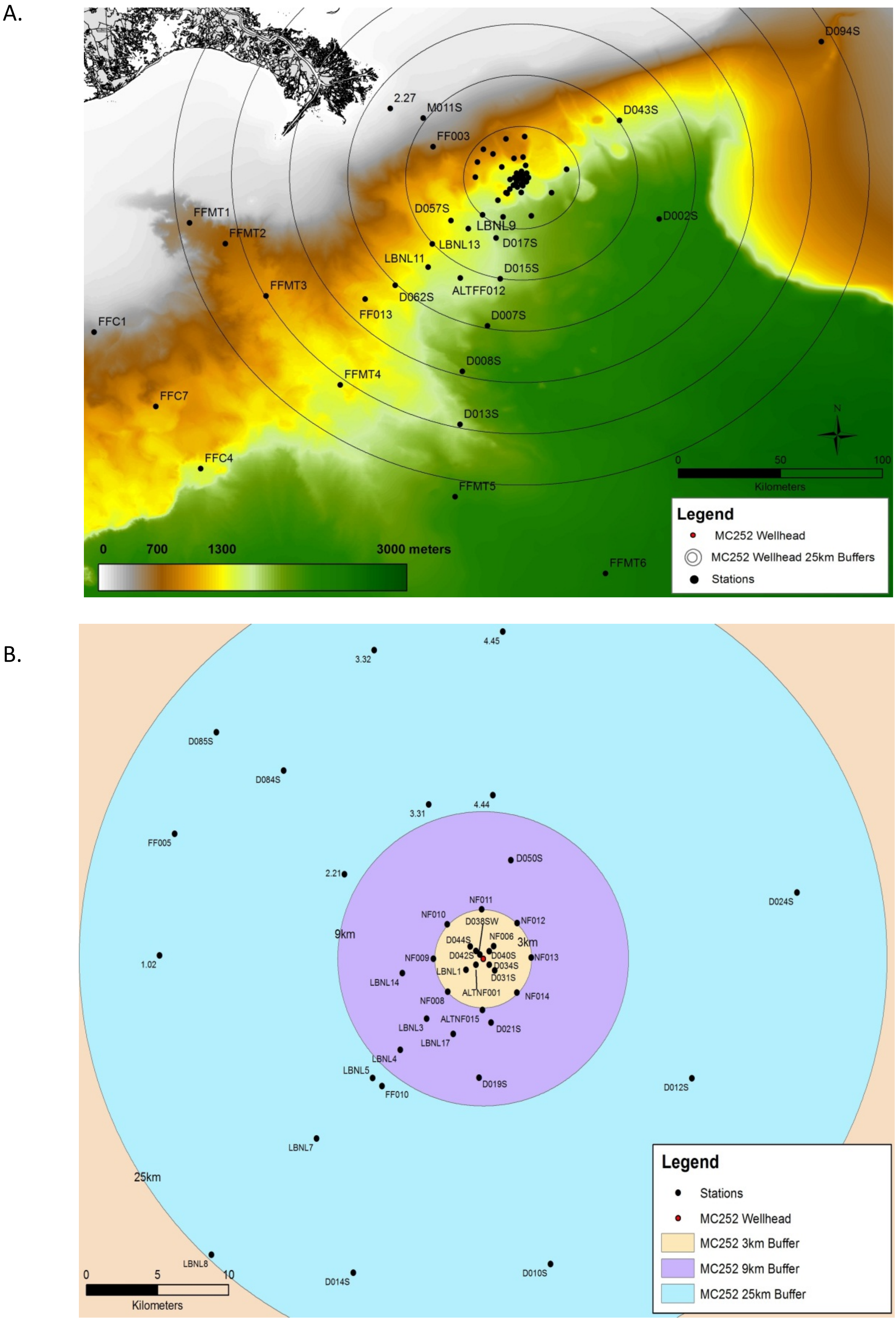

Fig. 1. Map of study area and sampling sites: (A) All sampling sites (concentric rings are 25 km apart); (B) Sites < 25km of MC252; Station NF006 = NF006MOD elsewhere in report.

2. Methods

The data presented here are from sediment samples collected on prior Response cruises conducted from September 16 – October 19, 2010 on the *R/V Gyre* and from September 24 – October 30, 2010 on the *R/V Ocean Veritas*. Both cruises collected sediment samples for analysis of oil and other drilling-related contaminants, benthic communities, and toxicity (not presented here) at near-field sites around the wellhead and additional far-field sites under known surface-water slick areas, beneath subsurface dispersed oil, and at historic sampling sites with pre-spill benthic data — i.e., Deep Gulf of Mexico Benthos Program (DGoMB) sites (Rowe and Kennicutt 2008, 2009). Also on both cruises, a multi-corer system (OSIL 2012) was used to collect benthic samples (Fig. 2). This is a unique system designed to collect undisturbed samples of seabed sediment and overlying water with minimal risk of a bow-wave effect that might otherwise displace surface sediment and any associated drilling contaminants. While benthic samples were obtained during these cruises from a total of 169 sites, the data here are represented by a subset of 68 stations including 65 priority sites identified in the Study Plan (May 2011, Objective 2) and three additional historical sites (FFC1, FFMT2, FFMT6 = DGoMB sites C1, MT2, and MT6 respectively). Of the 65 priority sites, 17 are from near-field locations within 3 km of the wellhead, in an area where OSAT (2010) data showed sediments containing hydrocarbons consistent with MC252 oil and at concentrations in excess of EPA aquatic life benchmarks; 23 are from additional mid-field sites within 25 km of the wellhead; 15 are from far-field sites > 25 km of the wellhead within suggested paths of oil movement based on subsurface trajectory modeling results (UAC 2010); two are from far-field sites > 25 km NW of the wellhead; and eight are pre-spill DGoMB sites (D002S, D094S, FFC4, FFC7, FFMT1, FFMT3, FFMT4, and FFMT5 = DGoMB sites S37, S35, C4, C7, MT1, MT3, MT4, and MT5 respectively) (Fig. 1).

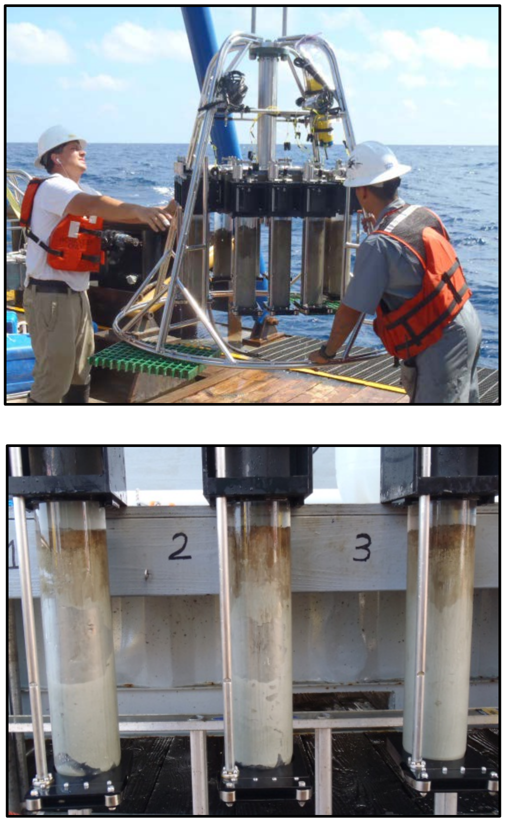

Fig. 2. OSIL multi-corer system (top) and close-up view of sediment core tubes (bottom).

Methods for the collection and analysis of benthic samples are described in the Deep Benthic TWG Study Plan (NRDA Deep Benthic TWG 2011) and are consistent with standard techniques in marine benthic ecology (e.g., Elefteriou and McIntyre 2005). Briefly, macrofaunal samples were collected and processed in the following manner: (1) three sediment cores (0.01 m^2 each) were collected from a single multi-core drop at most stations (i.e., all but eight of the 68 stations, where only 1 - 2 cores were obtained to support other sampling requirements, see Table 1 and corresponding footnote); (2) each core was extruded into two vertical sections (0 – 5 cm and 5 –

10 cm); (3) resulting samples were preserved in the field in 4% buffered formalin with Rose Bengal, sieved in the laboratory on a 0.3-mm mesh screen, and transferred to 70% ethanol; and (4) animals in each of the above samples were sorted from remaining sediment and debris under a dissecting microscope, counted, and identified typically to the family level.

Meiofaunal samples were collected and processed in the following manner: (1) one sediment core (0.01 m^2) was collected from a single multi-core drop at all but two of the 68 stations (ALTFF012 and D013S, where part or all of the samples were lost during transit from the field to the lab); (2) each core was extruded into two vertical sections (0 – 1 cm and 1 – 3 cm) and sub-sampled using a 0.0024 m^2 corer; (3) resulting samples were treated in the field with 7% $MgCl_2$ as an initial relaxant, fixed in a solution of 4% buffered formalin with Rose Bengal, and sieved subsequently in the laboratory on a 0.045-mm mesh screen; and (4) after sieving, animals in each of the above samples were extracted from remaining sediment and debris using isopycnic centrifugation in Ludox HS-40 (Burgess 2001), counted, and identified to major taxonomic groups (order level or higher, though harpacticoid copepods will be identified to family level at a later date). Specimens were identified to family or higher taxonomic levels in order to reduce processing time and because many of these deep-sea fauna have not been described previously to the species level. Also, using data from higher taxonomic levels in benthic studies has been shown to depict patterns similar to those using species-level data (Heip et al. 1988, Warwick 1988, Montagna and Harper 1996) and is a much faster process.

Data on abiotic environmental variables (e.g., chemical contaminants in sediments, grain size, total organic carbon, site locations, and water depth) were downloaded from the Environmental Response Management Application (ERMA) Gulf Response website (<http://gomex.erma.noaa.gov>). These data correspond to samples collected and processed under initial DWH Response efforts as described in the OSAT (2010) report. The contaminant data focus on concentrations of total petroleum hydrocarbons (TPH), total polycyclic aromatic hydrocarbons (total PAH), and selected metals (barium, chromium, lead, and zinc). Metals were analyzed by Lancaster Laboratories using EPA Method 6010C (inductively coupled plasma-atomic emission spectrometry). TPH was analyzed by either Lancaster Laboratories or Battelle, depending on the sample, using EPA Method 8015 (non-halogenated organics by gas chromatography). PAHs were measured by Battelle using EPA Method 8270-SIM (semi-volatile organic compounds by gas chromatography/mass spectrometry with selective ion monitoring); total PAH values were calculated by Battelle as the sum of individual PAHs listed in Appendix I.

Though processed separately, vertical sections of the same core and replicate cores from the same multi-core drop were combined mathematically for data-analysis purposes in the present report. Data from different vertical sections of the same core were collapsed into a single common species list for the individual core. Data from replicate cores from the same multi-core drop (applies to macrofauna only) were averaged and reported as per-station means. Results are presented using simple tables to document key macrofaunal, meiofaunal, and abiotic environmental variables for each of the various samples processed to date (Tables 1, 2, and 3 respectively) and additional maps to illustrate spatial distributions of selected variables throughout the study region (Figs. 3-8). Bathymetric contours in the figure maps are based on estimated seafloor topography for the Gulf of Mexico as presented in the ERMA database and derived from the SRTM30_PLUS V6.0 global bathymetry grid developed by Scripps Institution of Oceanography. Because the contours are approximations, Table 3 should be consulted for actual measured station depths.

3. Summary of Results from 2010 Response Samples

3.1 Macrofauna

- Most stations were dominated (two most abundant taxa) by polycheate worms including Acrocirridae, Capitellidae, Cirratulidae, Cossuridae, Dorvilleidae, Lumbrineridae, Maldanidae, Opheliidae, Paraonidae, Spionidae, and Syllidae (Table 1). Less frequently occurring dominants included amphipod (Ampeliscidae) and ostracod (Myodocopida, Podocopida) crustaceans; bivalve, gastropod, and aplacophoran molluscs; and nemerteans.
- Macrofaunal richness (# taxa), H' diversity ($\log_e$), and density (# individuals m^{-2}) averaged 21 station^{-1}, 2.53 station^{-1}, and 8987 m^{-2} respectively and ranged from 4 – 39 station^{-1}, 0.86 – 3.30 station^{-1}, and 1172 – 21084 m^{-2} respectively across the various stations.
- Lowest values of macrofaunal richness (lower 25th percentile of values, red dots in Fig. 3) occurred at stations close to the DWH wellhead, namely eight stations within about 1.5 km in various directions (D042S, D038SW, LBNL1, ALTNF001, D031S, D034S, NF006MOD, D040S) and one station (LBNL3) located 5 km to the southwest, in addition to several farther-field sites — i.e., Station LBNL9 located 34 km to the southwest, Station FFMT1 at the head of Mississippi Canyon, Station 2.27 on the outer shelf 60 km to the northwest of the wellhead, and five other stations at deeper mid- to lower-slope locations (FFMT4, D013S, FFMT5, FFMT6, D002S). There also was a high concentration of stations with intermediate values (lower 25th to 50th percentile, yellow dots) particularly around 3 km from the wellhead in various directions and further away to the southwest.

3.2 Meiofauna

- The dominant (two most abundant) meiofaunal taxa at all stations consisted of either harpacticoid copepods, nematodes, or unidentified nauplii (Table 2). Other subdominant taxa at many of the stations (data not shown) included kinorhynchs, polychaetes, ostracods, and bivalves.
- Numbers of meiofaunal taxa, H' diversity ($\log_e$), and density (# individuals m^{-2}) averaged 9 core^{-1}, 0.60 core^{-1}, and 2,425,513 m^{-2} respectively and ranged from 4 – 13 core^{-1}, 0.09 – 1.25 core^{-1}, and 204,137 – 8,654,967 m^{-2} respectively across the various stations.
- Similar to the macrofaunal pattern, lowest values of meiofaunal richness (lower 25th percentile of values, red dots in Fig. 4) tended to occur at stations relatively close to the DWH wellhead and to the southwest — including nine stations within about 1.5 km in various directions (D042S, D038SW, LBNL1, ALTNF001, D031S, D034S, NF006MOD, D040S, D044S), one station (4.44) 10 km to the north, and 10 stations from 3 – 37 km to the southwest (NF009, LBNL17, LBNL4, LBNL5, FF010, LBNL7, D014S, D057S, LBNL9, D017S) — in addition to several farther-field sites at the head of Mississippi Canyon (FFMT1) and in deeper mid- to lower-slope locations (FFC4, FFMT5, FFMT6, D007S).

- Stations with the highest ratios of nematode to adult harpacticoid copepod abundances (N/H) also tended to be at sites nearest to the wellhead, including 10 stations within 3 km in various directions (LBNL1, ALTNF001, D040S, NF006MOD, D031S, NF008, NF009, NF010, NF011, NF012) and four additional sites within 10 km to the north (2.21, D050S) and southwest (LBNL3, LBNL5) (Table 2, Figs. 5 and 6). Prior studies (Montagna et al. 1987, Shirayama and Ohta 1990) have noted higher nematode to harpacticoid ratios in oil-contaminated sediments compared to lesser or uncontaminated sites due to an increase in the relative abundance of pollution-tolerant nematodes and a decrease of the more sensitive harpacticoids.

3.3 Abiotic Environmental Variables

- Locations (latitude, longitude) and key abiotic environmental variables — water depth, total organic carbon (TOC) and % silt-clay content of sediment, and concentrations of total petroleum hydrocarbons (TPH), total polycyclic aromatic hydrocarbons (Total PAH) and selected metals (barium, chromium, lead, and zinc) in sediments — are listed in Table 3 for each of the sampling sites.
- With the exception of one site on the outer shelf (Station 2.27 at 76 m), depths ranged from 211 – 2767 m and averaged 1394 m. Sediments throughout the study region consisted predominantly of muds with high silt-clay content (averaging 96.3% and ranging from 69.4% – 99.2%). While three stations (D043S, D044S, M011S) had sediment TOC levels below the detection limits, TOC levels at most stations were moderate to high — averaging 14,246 ppm (1.4%) and ranging up to 32,600 ppm (3.2%).
- Concentrations of TPHs in sediments ranged from 0 – 5,023,004 μg/kg (Table 3). Highest concentrations (upper 25th percentile of values = 183,286 – 5,023,004 μg/kg; red dots in Fig. 7) tended to occur at stations nearest to the DWH wellhead, i.e. at 13 stations within about 3 km in various directions (D042S, D038SW, LBNL1, ALTNF001, D031S, D034S, NF006MOD, D040S, D044S, NF009, NF011, NF013, ALTNF015) and at three stations from 8-10 km to the southwest (LBNL4, LBNL5, FF010).
- Concentrations of total PAHs in sediments ranged from 28 – 47,559 μg/kg (Table 3). Similar to TPHs, highest concentrations (upper 25th percentile of values = 1,612 – 47,559 μg/kg; results not plotted) tended to occur at stations nearest to the DWH wellhead, i.e. at 12 stations within about 3 km in various directions (D042S, D038SW, LBNL1, ALTNF001, D031S, NF006MOD, D040S, D044S, NF009, NF011, NF013, ALTNF015) and at two stations 10 km to the southwest (LBNL5, FF010).
- Metals known to occur at elevated levels on the seafloor in association with offshore drilling operations often include chromium, lead, zinc, and especially barium (Neff et al. 1987, Neff 2005). In the present study, concentrations of barium in sediments ranged from 126 – 12,700 μg/g (Table 3). Highest concentrations (upper 25th percentile of values = 863 – 12,700 μg/g; red dots in Fig. 8) also tended to occur at stations nearest to the DWH wellhead — i.e. at eight stations within about 1.5 km in various directions (D042S, D038SW, LBNL1, ALTNF001, D031S, D034S, D040S, D044S) and at four stations from 3-15 km to the southwest (NF008, ALTNF015, D021S, LBNL7) — in addition to four other farther-field sites located from 50-200 km to the southwest (D015S, ALTFF12, FFMT3, FFC1).
- The near-field zone within about 3 km of the wellhead, where many of the stations showed evidence of impaired benthic condition (e.g. low taxa richness, high N/H ratios),

also is an area that contained some of the highest concentrations of TPH, total PAHs and Ba in sediments (as possible indicators of DWH discharges). There were similar co-occurrences at other sites outside this zone, especially to the southwest of the wellhead out to about 15 km (e.g., LBNL4, LBNL5, LBNL7, FF010). However, there also were exceptions to this pattern, for example at several farther-field sites in deeper-slope and canyon locations (e.g., FFMT1, FFMT4, FFMT5, FFMT6, FFC4, D013S, D007S, D002S) where there was low benthic infaunal richness but no evidence of exposure to DWH discharges. Such cases are consistent with historical patterns of benthic distributions in relation to natural controlling factors such as depth, position within canyons, and availability of organic matter derived from surface-water primary production (Rowe and Kennicutt 2008, 2009; Wei and Rowe 2006, Wei et al. 2010).

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5. Acknowledgments

This work is part of an ongoing study conducted under the direction of the Deepwater Horizon (DWH) Natural Resource Damage Assessment, Deepwater Benthic Communities Technical Working Group. Benthic samples discussed in this report were collected during the Response phase of the incident, under direction of the Unified Area Command (UAC), on cruises aboard the *R/V Gyre* (September 16 – October 19, 2010) and *R/V Ocean Veritas* (September 24 – October 30, 2010). Our appreciation is extended to members of the ship and science crews for their contributions to these initial field efforts. We especially thank Ian Hartwell (NOAA, Silver Spring MD) and Rick Kalke (Harte Research Institute, Texas A&M University-Corpus Christi) for their participation as Chief Scientists on the *R/V Ocean Veritas* and *Gyre* cruises respectively. Also, many people from the Harte Research Institute/Texas A&M participated in the collection and analysis of these samples: Sandra Arismendez and Rick Kalke collected sediment samples on the *R/V Gyre* cruise; Chien-Yi Hsiang, David Franklin, Elani K. Morgan, Robert Gutierrez, and Travis Washburn washed, sorted, and counted macrofauna samples; Rick Kalke, Adelaide Rhodes, Larry Hyde, and Michael Reuscher performed taxonomic identifications; and Carrol Simanek and Leslie Adams helped to digitize and proof-read the data base. Funds for the analysis and reporting of these samples were provided through the NOAA, National Ocean Service, Office of Response and Restoration.

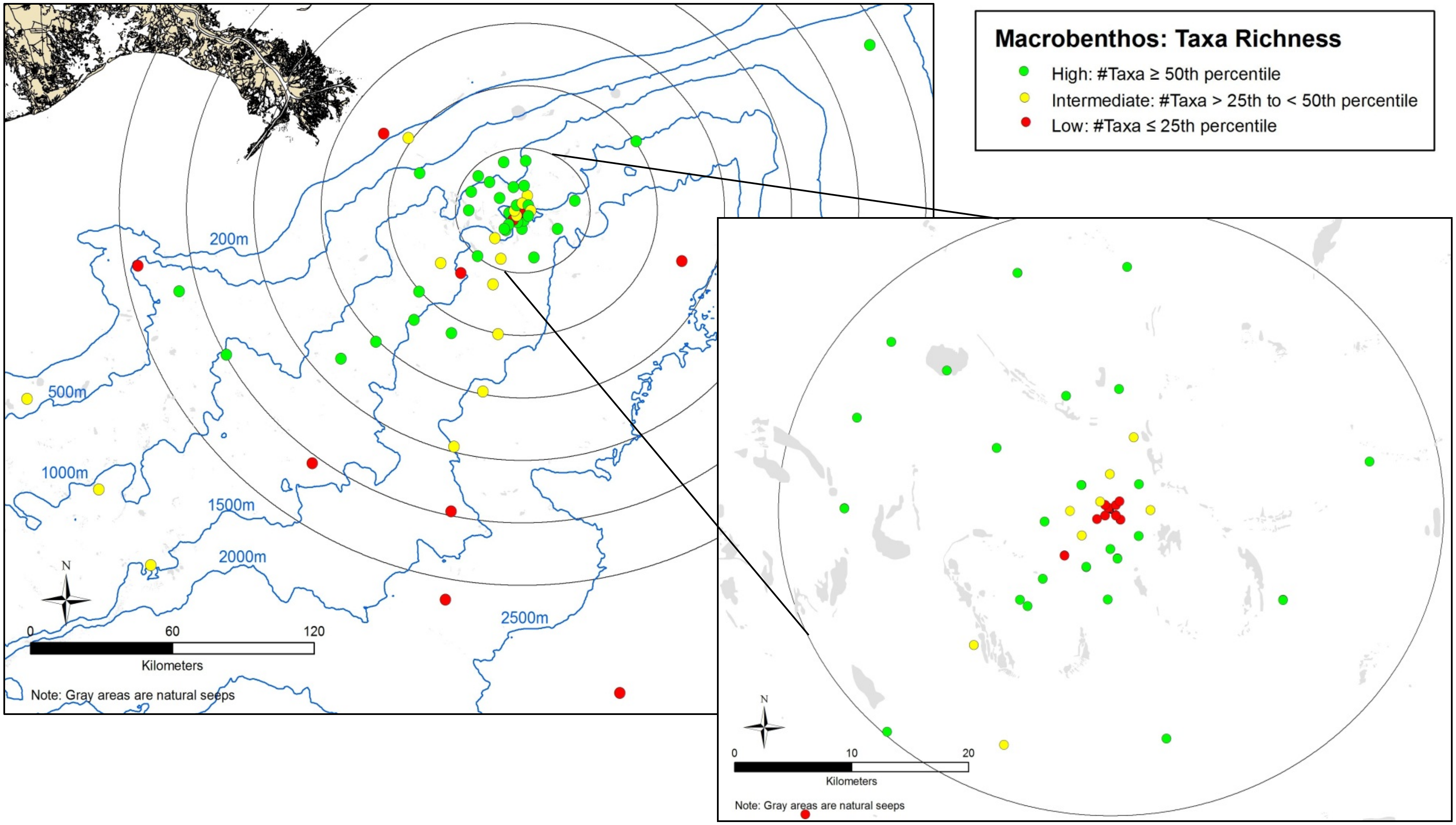

Fig. 3. Spatial comparison of different ranges (high, intermediate, and low) of macrofaunal taxa richness in relation to the DWH wellhead. Concentric rings are 25 km apart.

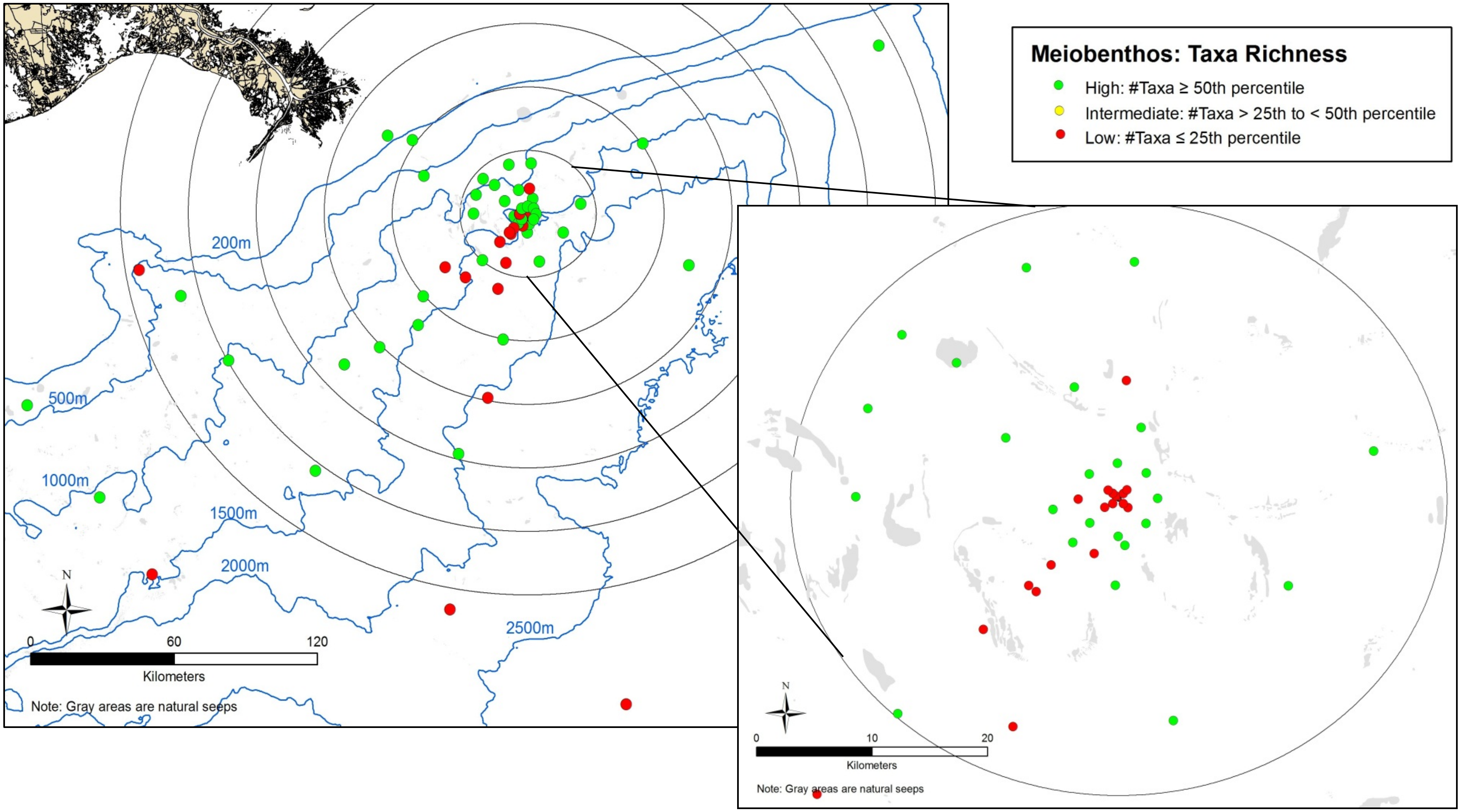

Fig. 4. Spatial comparison of different ranges (high, intermediate, and low) of meiofaunal taxa richness in relation to the DWH wellhead. Concentric rings are 25 km apart.

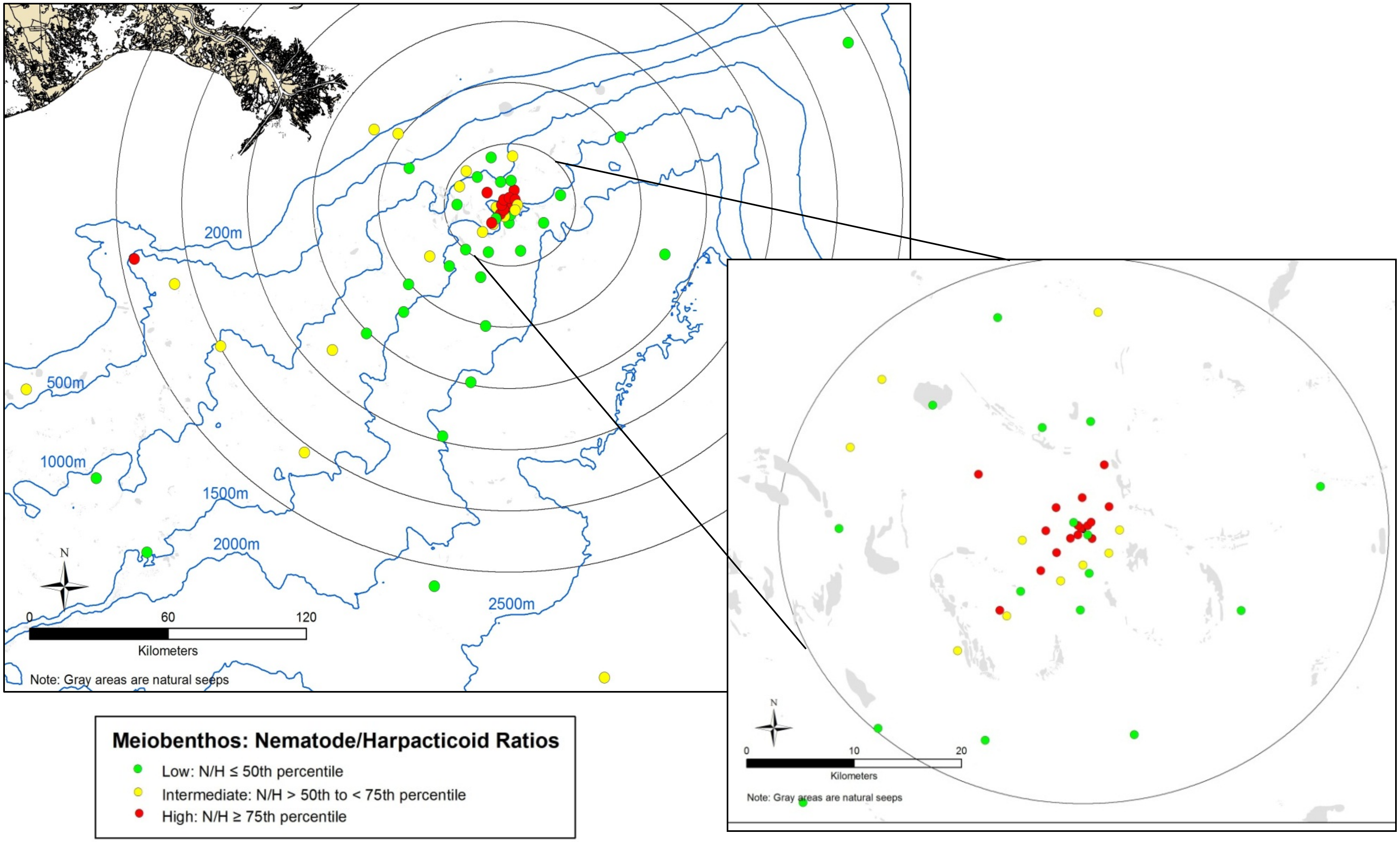

Fig. 5. Spatial comparison of different ranges (high, intermediate, and low) of meiofaunal nematode/harpacticoid ratios in relation to the DWH wellhead. Concentric rings are 25 km apart.

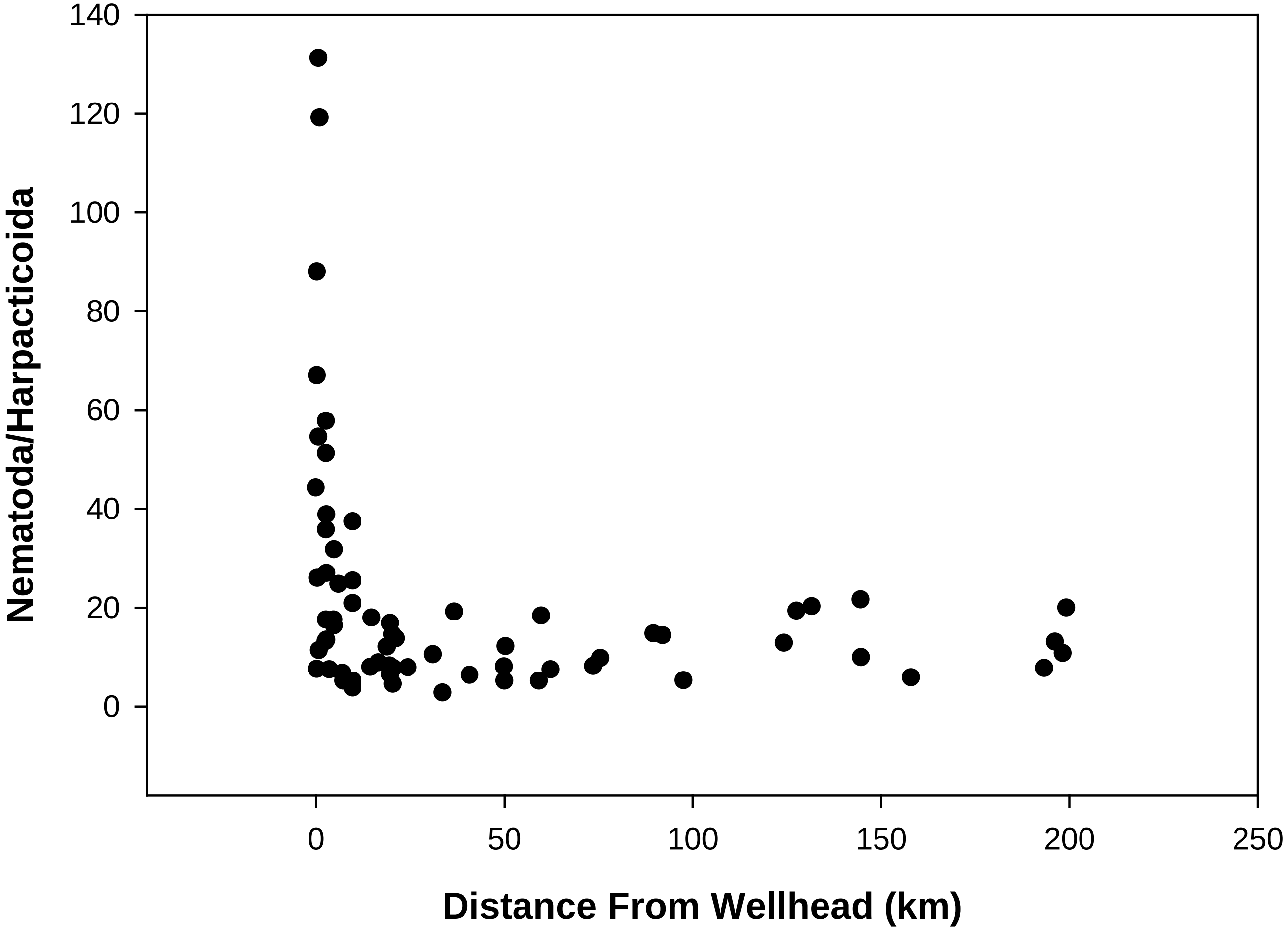

Fig. 6. The ratio of nematode to harpacticoid copepod abundance in relation to distance from the wellhead (km). Ratios increase notably at distances < about 10 km from the DWH wellhead.

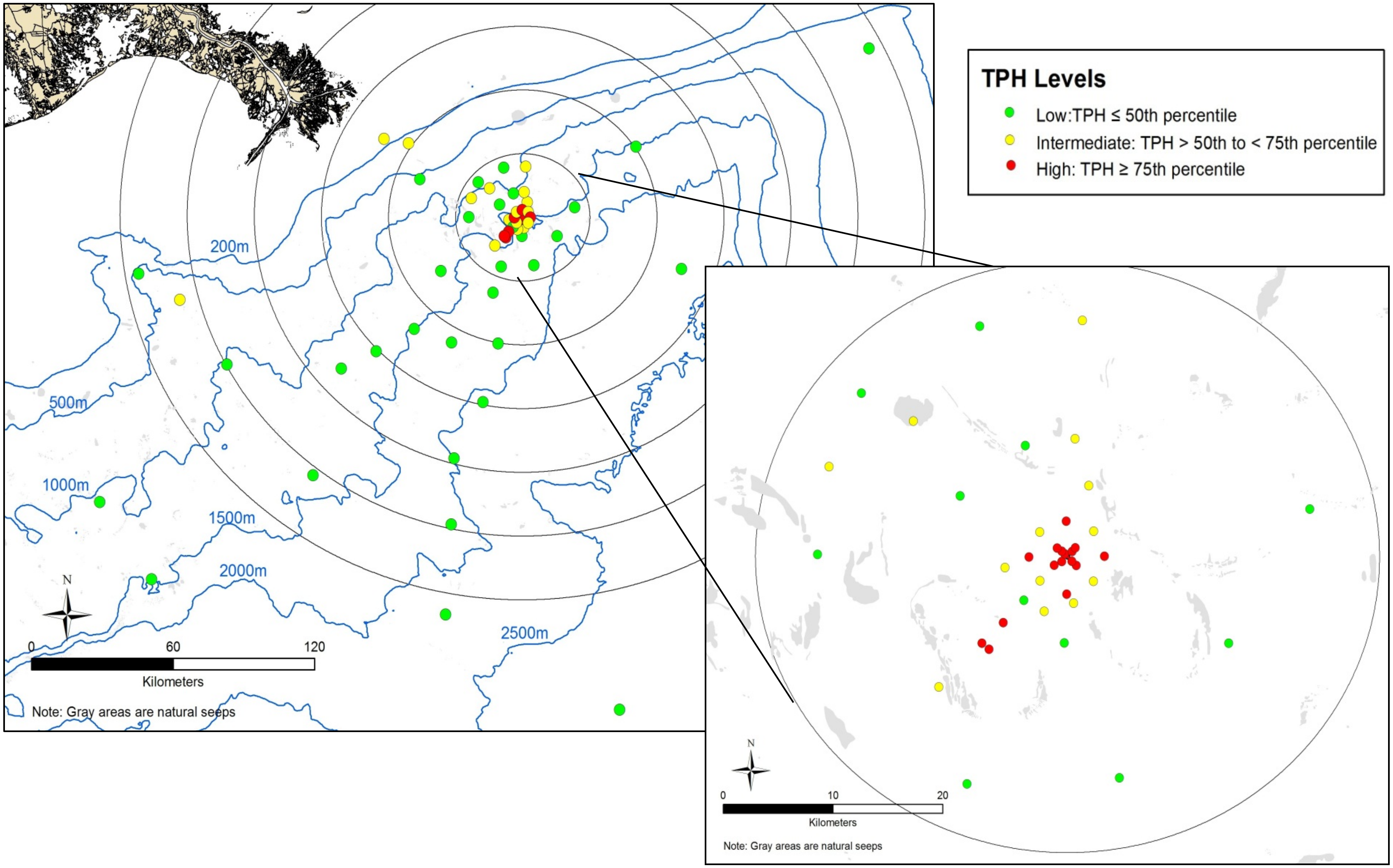

Fig. 7. Spatial comparison of different ranges (high, intermediate, and low) of sediment TPH in relation to the DWH wellhead. Concentric rings are 25 km apart. TPH range = 0 – 5,023,004 μg/kg; 50th percentile = 56,296 μg/kg; 75th percentile = 181,879 μg/kg.

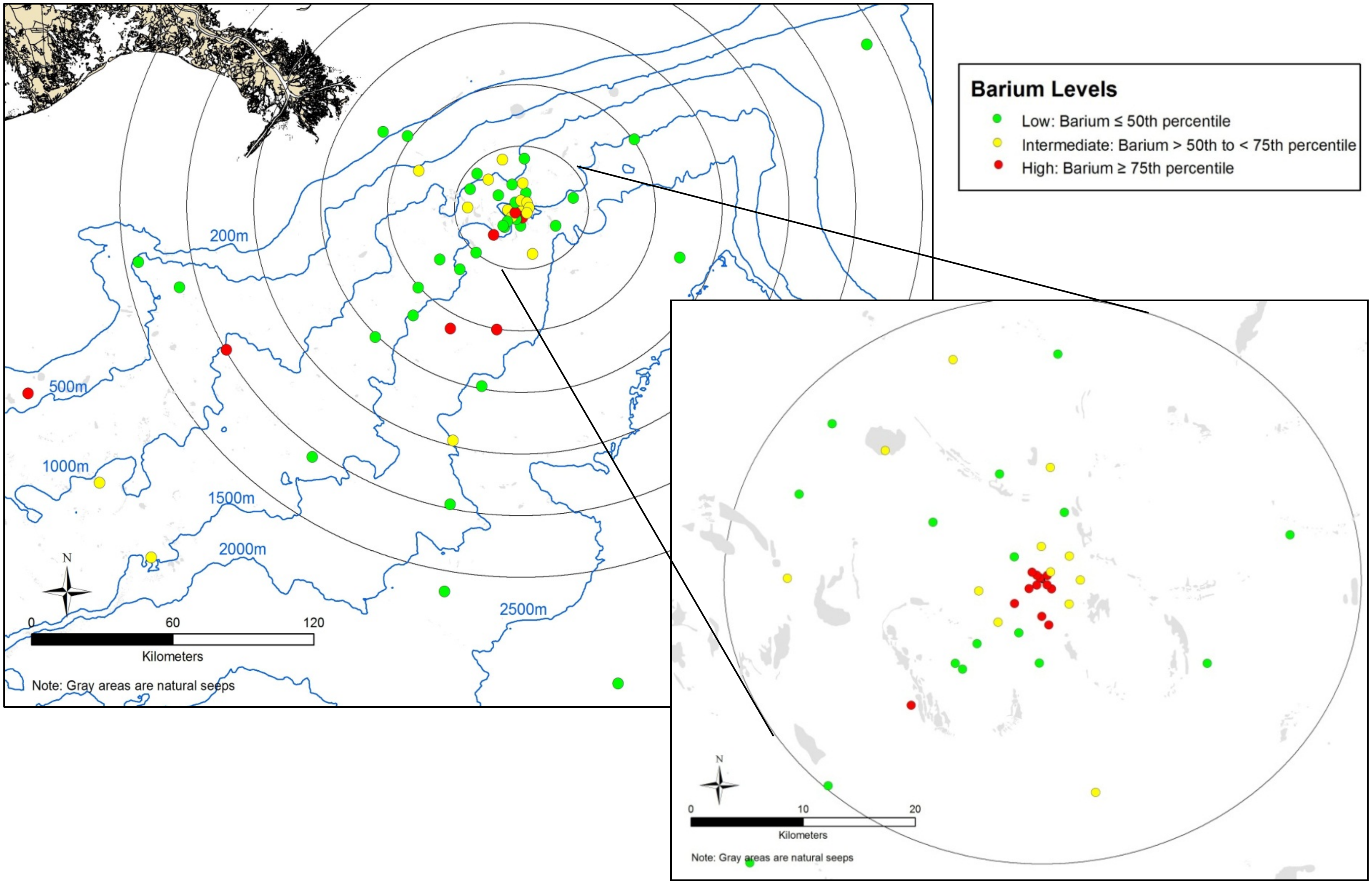

Fig. 8. Spatial comparison of different ranges (high, intermediate, and low) of sediment barium levels in relation to the DWH wellhead. Concentric rings are 25 km apart. Barium range = 126 – 12,700 µg/g; 50th percentile = 455µg/g; 75th percentile = 825 µg/g.

Table 1. Key macrofaunal variables by station. Dominant taxa = two most abundant at a station. H' calculated with natural logarithms. STD = standard deviations.

Station	Dominant Taxa	# of Cores[1]	# Taxa per Station		H'		Density m^{-2}	
			Mean	STD	Mean	STD	Mean	STD
1.02	Cirratulidae Spionidae	3	31.3	6.7	3.01	0.23	14,600	4,555
2.21	Paraonidae Cirratulidae	3	25.7	6.0	2.74	0.28	16,776	9,808
2.27	Cossuridae Spionidae	3	11.0	1.0	1.83	0.07	12,717	1,888
3.31	Spionidae Podocopida	3	38.7	4.2	3.30	0.16	11,692	527
3.32	Spionidae Aplacophora	3	26.7	5.7	2.94	0.15	13,513	8,273
4.44	Spionidae Cirratulidae	3	31.7	5.5	3.00	0.22	13,931	2,825
4.45	Aplacophora Podocopida	2	38.5	9.2	3.18	0.39	16,129	2,044
ALTFF012	Maldanidae Capitellidae	3	23.7	2.9	2.61	0.14	9,580	1,888
ALTNF001	Dorvilleidae Paraonidae	3	8.7	2.1	1.63	0.25	3,514	1,197
ALTNF015	Maldanidae Dorvilleidae	3	23.0	1.0	2.62	0.20	11,798	1,479
D002S	Spionidae Paraonidae	3	12.7	2.5	2.32	0.22	2,931	313
D007S	Spionidae Acrocirridae	3	17.7	4.0	2.65	0.23	3,765	1,328
D008S	Spionidae Acrocirridae	3	18.7	1.5	2.80	0.06	3,682	507
D010S	Spionidae Maldanidae	3	23.3	2.5	2.87	0.08	5,983	1,006
D012S	Spionidae Maldanidae	3	24.3	3.5	2.83	0.13	7,614	817
D013S	Spionidae Nemertea	3	14.0	6.2	2.38	0.56	2,803	959
D014S	Maldanidae Dorvilleidae	3	18.7	3.1	2.40	0.20	8,367	767
D015S	Capitellidae Bivalvia	3	18.3	3.8	2.56	0.29	5,690	3,605
D017S	Maldanidae Spionidae	3	19.7	7.5	2.42	0.52	6,903	2,843
D019S	Bivalvia Paraonidae	3	25.7	4.9	2.82	0.15	9,413	2,837

Station	Dominant Taxa	# of Cores[1]	# Taxa per Station		H'		Density m^{-2}	
			Mean	STD	Mean	STD	Mean	STD
D021S	Capitellidae Maldanidae	3	26.7	5.8	2.84	0.20	9,915	1,327
D024S	Maldanidae Capitellidae	3	23.0	1.7	2.84	0.15	8,200	735
D031S	Dorvilleidae Paraonidae	3	9.0	0.0	1.48	0.08	4,225	192
D034S	Paraonidae Maldanidae	3	7.7	1.5	1.82	0.16	1,966	384
D038SW	Dorvilleidae Capitellidae	3	8.7	0.6	0.86	0.15	8,534	1,274
D040S	Dorvilleidae Paraonidae	3	4.3	2.5	0.93	0.62	2,259	1,087
D042S	Dorvilleidae Paraonidae	3	13.7	2.3	2.12	0.50	7,154	2,752
D043S	Spionidae Paraonidae	2	25.5	6.4	2.72	0.24	10,730	2,219
D044S	Dorvilleidae Paraonidae	3	18.0	3.0	2.41	0.16	10,710	2,807
D050S	Paraonidae Maldanidae	3	22.0	2.7	2.69	0.12	10,796	2,326
D057S	Dorvilleidae Paraonidae	3	20.7	4.0	2.43	0.16	10,249	2,362
D062S	Paraonidae Maldanidae	3	22.7	2.5	2.81	0.10	7,530	2,803
D084S	Aplacophora Spionidae	2	27.5	2.1	2.87	0.01	9,798	1,077
D085S	Gastropoda Myodocopida	3	30.0	2.7	2.94	0.09	14,851	2,492
D094S	Spionidae Capitellidae	3	25.0	3.6	2.95	0.20	7,907	1,322
FF003	Cossuridae Spionidae	3	26.3	3.2	2.59	0.23	21,084	6,072
FF005	Cirratulidae Aplacophora	3	27.7	8.3	2.84	0.25	12,468	4,154
FF010	Paraonidae Maldanidae	3	26.0	1.7	2.74	0.10	12,853	959
FF013	Spionidae Capitellidae	3	24.3	4.7	2.83	0.28	7,195	2,250
FFC1	Spionidae Paraonidae	3	21.3	0.6	2.77	0.10	5,899	784
FFC4	Spionidae Paraonidae	3	19.7	4.0	2.63	0.19	4,769	996
FFC7	Spionidae	3	18.7	5.0	2.52	0.41	4,183	1,045

Station	Dominant Taxa	# of Cores[1]	# Taxa per Station		H'		Density m^{-2}	
			Mean	STD	Mean	STD	Mean	STD
	Syllidae							
FFMT1	Ampeliscidae	1	11.0	.	2.08	.	3,263	.
	Paraonidae							
FFMT2	Paraonidae	3	32.0	5.0	2.95	0.30	13,139	4,513
	Spionidae							
FFMT3	Spionidae	3	27.3	3.5	2.96	0.04	7,656	1,602
	Opheliidae							
FFMT4	Spionidae	3	14.7	2.1	2.31	0.15	4,184	441
	Paraonidae							
FFMT5	Spionidae	3	8.0	1.0	2.03	0.18	1,172	72
	Bivalvia							
FFMT6	Bivalvia	3	9.0	2.7	2.09	0.36	1,381	126
	Paraonidae							
LBNL1	Dorvilleidae	3	13.7	2.5	1.86	0.18	8,660	1,972
	Capitellidae							
LBNL11	Maldanidae	3	28.0	4.4	2.90	0.13	10,292	1,744
	Spionidae							
LBNL13	Paraonidae	2	25.0	1.4	2.81	0.05	12,805	5,320
	Capitellidae							
LBNL14	Paraonidae	2	26.5	6.4	2.72	0.30	13,868	1,686
	Dorvilleidae							
LBNL17	Maldanidae	3	31.7	3.1	2.85	0.14	15,228	1,815
	Paraonidae							
LBNL3	Maldanidae	3	13.7	3.2	2.20	0.18	6,401	2,999
	Paraonidae							
LBNL4	Maldanidae	3	25.0	8.2	2.74	0.36	11,086	4,387
	Spionidae							
LBNL5	Dorvilleidae	3	24.7	1.2	2.80	0.07	11,588	1,946
	Paraonidae							
LBNL7	Dorvilleidae	3	21.7	0.6	2.61	0.21	8,618	2,160
	Capitellidae							
LBNL8	Maldanidae	3	24.0	3.6	2.67	0.13	9,329	817
	Capitellidae							
LBNL9	Aplacophora	2	15.5	9.2	2.17	0.56	7,848	4,177
	Dorvilleidae							
M011S	Cirratulidae	3	19.3	6.7	2.31	0.26	16,315	3,986
	Lumbrineridae							
NF006MOD	Dorvilleidae	3	9.7	2.9	1.66	0.53	3,765	664
	Paraonidae							
NF008	Maldanidae	3	20.0	2.7	2.55	0.07	8,367	1,341
	Capitellidae							
NF009	Paraonidae	3	20.0	2.7	2.57	0.15	7,739	1,125
	Capitellidae							

Station	Dominant Taxa	# of Cores[1]	# Taxa per Station		H'		Density m^{-2}	
			Mean	STD	Mean	STD	Mean	STD
NF010	Maldanidae Paraonidae	3	23.0	4.6	2.78	0.23	10,376	1,811
NF011	Maldanidae Paraonidae	3	22.3	5.7	2.71	0.29	11,839	4,422
NF012	Maldanidae Paraonidae	3	24.3	3.8	2.77	0.26	11,295	1,660
NF013	Maldanidae Capitellidae	3	19.0	1.0	2.52	0.13	7,781	2,141
NF014	Maldanidae Capitellidae	3	23.0	3.6	2.76	0.12	10,041	2,424

[1] Note: At eight stations, the multi-corer did not obtain a sufficient number of acceptable cores to meet sampling requirements of all variables. In these cases, 1 - 2 of the 3 replicate cores intended for macrofaunal analysis were used to provide sediment needed for other required variables.

Table 2. Key meiofaunal variables by station (1 core per station). Dominant taxa = two most abundant at a station; H' calculated with natural logarithms; N/H = nematode/harpacticoid ratio. Note: There are no meiofauna data for Stations ALTFF012 and D013S.

Station	Dominant Taxa	# of Taxa	H'	Density m^{-2}			N/H
				All Fauna	Nematodes	Harpacticoids	
1.02	Nematodes Harpacticoids	10	0.77	909565	714267	114906	6.2
2.21	Nematodes Harpacticoids	13	0.38	6625808	6095474	241597	25.2
2.27	Nematodes Nauplii	10	0.65	4820989	4085676	225182	18.1
3.31	Nematodes Harpacticoids	9	0.96	2300639	1523237	438999	3.5
3.32	Nematodes Harpacticoids	9	0.83	824122	612410	142264	4.3
4.44	Nematodes Harpacticoids	8	0.85	1428114	1041307	211713	4.9
4.45	Nematodes Harpacticoids	13	0.43	2362512	2142381	128795	16.6
ALTNF001	Nematodes Harpacticoids	6	0.10	4049058	3984660	45457	87.7
ALTNF015	Nematodes; Nauplii	9	0.63	1883107	1562802	118694	13.2
D002S	Nematodes Harpacticoids	9	0.80	366183	282003	39144	7.2
D007S	Nematodes Nauplii	8	0.79	590102	457097	58084	7.9
D008S	Nematodes Nauplii	11	1.00	485298	330827	66502	5
D010S	Nematodes Nauplii	10	0.73	1485356	1185675	100174	11.8
D012S	Nematodes Nauplii	10	0.86	1598578	1176416	151945	7.7
D014S	Nematodes Nauplii	8	0.86	1186096	876735	117010	7.5
D015S	Nematodes Harpacticoids	10	0.68	772772	626720	80392	7.8
D017S	Nematodes Nauplii	8	0.76	822439	648186	63135	10.3

Station	Dominant Taxa	# of Taxa	H'	Density m^{-2}			N/H
				All Fauna	Nematodes	Harpacticoids	
D019S	Nematodes Harpacticoids	9	0.83	1511031	1130537	174253	6.5
D021S	Nematodes Nauplii	9	0.78	1763150	1346880	188142	7.2
D024S	Nematodes Nauplii	11	0.78	1476096	1135167	141422	8
D031S	Nematodes Harpacticoids	6	0.14	1711379	1667185	30726	54.3
D034S	Nematodes Harpacticoids	6	0.76	204137	160784	21887	7.3
D038SW	Nematodes Harpacticoids	4	0.16	859478	833382	18941	44
D040S	Nematodes Harpacticoids	5	0.12	2237084	2189101	32830	66.7
D042S	Nematodes Harpacticoids	4	0.28	2638622	2478259	96386	25.7
D043S	Nematodes Nauplii	11	0.72	2321264	1853644	156154	11.9
D044S	Nematodes Nauplii	8	0.59	1760625	1478622	133004	11.1
D050S	Nematodes Harpacticoids	10	0.31	6658217	6216693	254224	24.5
D057S	Nematodes Harpacticoids	8	0.34	3868913	3569232	188984	18.9
D062S	Nematodes Harpacticoids	9	0.64	1276169	1066982	112380	9.5
D084S	Nematodes Nauplii	12	0.75	2365458	1869638	216764	8.6
D085S	Nematodes Harpacticoids	10	0.58	2282962	1952555	144790	13.5
D094S	Nematodes Nauplii	11	0.80	848114	652395	66923	9.7
FF003	Nematodes Harpacticoids	12	0.90	3627316	2662193	436052	6.1
FF005	Nematodes Nauplii	12	0.59	2246764	1913411	133425	14.3
FF010	Nematodes Harpacticoids	8	0.40	2277069	2070407	100595	20.6
FF013	Nematodes Nauplii	11	0.59	2254340	1930247	133425	14.5

Station	Dominant Taxa	# of Taxa	H'	Density m^{-2}			N/H
				All Fauna	Nematodes	Harpacticoids	
FFC1	Nematodes Nauplii	9	0.69	3050262	2522875	128375	19.7
FFC4	Nematodes Nauplii	7	0.73	637243	508447	48404	10.5
FFC7	Nematodes Nauplii	11	0.94	905356	641031	85864	7.5
FFMT1	Nematodes Nauplii	6	0.60	356923	306836	14311	21.4
FFMT2	Nematodes Nauplii	9	0.49	3507360	3107084	155312	20
FFMT3	Nematodes Nauplii	11	0.70	1575850	1293005	102700	12.6
FFMT4	Nematodes Nauplii	9	0.59	719318	617460	32409	19.1
FFMT5	Nematodes Nauplii	7	0.96	345980	227707	40827	5.6
FFMT6	Nematodes Nauplii	6	0.67	220131	177199	13890	12.8
LBNL1	Nematodes Harpacticoids	6	0.11	8654967	8504705	71553	118.9
LBNL11	Nematodes Harpacticoids	10	0.89	842221	597678	120798	4.9
LBNL13	Nematodes Harpacticoids	11	0.93	2187838	1556909	318621	4.9
LBNL14	Nematodes Nauplii	11	0.55	3901322	3325952	206662	16.1
LBNL17	Nematodes Nauplii	8	0.58	2397446	2014007	116589	17.3
LBNL3	Nematodes Harpacticoids	10	0.31	3469058	3244297	103121	31.5
LBNL4	Nematodes Nauplii	8	1.01	2814137	1610784	329144	4.9
LBNL5	Nematodes Harpacticoid	8	0.30	2932831	2754791	74078	37.2
LBNL7	Nematodes Nauplii	8	0.47	2890320	2562439	144790	17.7
LBNL8	Nematodes Nauplii	11	0.75	3258187	2526663	334616	7.6
LBNL9	Nematodes Nauplii	7	1.25	2760683	1250494	499187	2.5

Station	**Dominant Taxa**	**# of Taxa**	**H'**	**Density m^{-2}**			**N/H**
				All Fauna	**Nematodes**	**Harpacticoids**	
M011S	Nematodes Harpacticoids	13	0.55	4581917	3956881	281582	14.1
NF006MOD	Nematodes Harpacticoids	7	0.09	3246402	3197998	24412	131
NF008	Nematodes Nauplii	9	0.32	4699349	4375676	123324	35.5
NF009	Nematodes Harpacticoids	6	0.30	4363049	4088202	153208	26.7
NF010	Nematodes Harpacticoids	11	0.23	4778478	4569711	118273	38.6
NF011	Nematodes Harpacticoids	9	0.20	4395880	4229203	82917	51
NF012	Nematodes Harpacticoids	9	0.18	4975880	4816780	83759	57.5
NF013	Nematodes Nauplii	10	0.52	2337258	2048941	118694	17.3
NF014	Nematodes Nauplii	10	0.63	2579275	2161322	167097	12.9

Table 3. Key abiotic variables by station. Total PAH = total polynuclear aromatic hydrocarbons, TPH = total petroleum hydrocarbons, TOC = total organic carbon. Data for Total PAH, TPH, % silt-clay, TOC, and metals were downloaded from the ERMA Gulf Response website (<http://gomex.erma.noaa.gov>). NA = not available.

Station	Latitude (deg. N)	Longitude (deg. W)	Depth (m)	Dist. Well (km)	Dist. Seep (km)	Total PAH (ppb)	TPH (ppb)	Silt-Clay (%)	TOC (ppm)	Ba (ppm)	Cr (ppm)	Pb (ppm)	Zn (ppm)
1.02	28.740044	-88.570589	1129	20.0	1.22	NA	0	97.7	18,700	729	44.2	36.2	107
2.21	28.784596	-88.453714	1367	10.0	4.76	NA	0	97.6	9,670	284	35.9	32.3	84.6
2.27	29.015963	-88.893449	76	60.1	14.5	NA	67,000	98.4	15,100	194	36.4	32.8	96.2
3.31	28.823065	-88.400480	976	10.0	0.43	NA	34,000	90.2	15,900	323	28.6	31.7	66.8
3.32	28.913845	-88.437757	854	20.7	4.73	NA	0	97.2	19,600	482	35.9	34.6	80.8
4.44	28.828141	-88.359791	755	10.0	1.15	NA	71,000	95.4	27,400	710	34.9	44	91.5
4.45	28.918182	-88.353596	755	20.0	1.60	NA	65,000	97.1	29,400	420	38.2	27.5	94.9
ALTFF012	28.297308	-88.636311	1738	55.7	8.82	67.5	8,168	96.1	15,200	1,700	38.9	24.9	100
ALTNF001	28.734789	-88.370533	1543	0.58	3.95	46,714	9,190,621	97.4	11,000	6,680	30	34.9	76.3
ALTNF015	28.709925	-88.366436	1607	3.13	2.40	13,676	1,959,533	96.7	14,500	985	41.5	36.1	99.7
D002S	28.557089	-87.760689	2389	62.6	13.7	51.2	25,985	97.2	12,800	255	35.9	18.3	85.5
D007S	28.086583	-88.516989	2052	73.9	16.0	78.5	10233.24	94.2	18,600	165	11.6	31.7	26.8
D008S	27.887417	-88.626806	1606	97.9	9.11	82.5	5,472	93.5	19,200	571	36.2	37	89
D010S	28.570086	-88.323350	1884	19.1	8.42	208	30,508	97.2	19,100	626	29.3	24.2	70.5
D012S	28.672442	-88.233931	1819	14.9	1.50	114	14,470	96.9	18,700	440	31.6	24.3	76.5
D013S	27.654381	-88.637922	1766	123	11.8	346	2,797	74.4	17,700	275	23.4	20.9	56.3
D014S	28.565414	-88.448072	1760	20.8	5.57	83.4	10,598	98.5	NA	NA	NA	NA	NA
D015S	28.293817	-88.460031	1576	50.2	5.32	91.7	8,967	97.6	21,800	905	37.2	26.2	93.5
D017S	28.473367	-88.478325	1712	31.4	6.00	126	16,263	96.4	NA	NA	NA	NA	NA
D019S	28.672706	-88.368517	1656	7.27	2.39	222	46,647	97.9	13,200	395	38.3	26.5	94.4
D021S	28.703044	-88.360953	1618	3.93	1.50	291	59,731	98.1	8,300	1,270	39.9	21.3	87.4
D024S	28.774570	-88.167545	1697	19.8	1.11	221	47,070	98.3	18,100	357	32.1	25	81.2
D031S	28.731703	-88.358731	1508	1.01	2.76	31,880	3,667,840	93.2	4,970	6,550	42.4	24.5	95.3
D034S	28.734822	-88.362208	1544	0.52	3.22	912	898,052	98.4	10,300	3,350	42.2	25.9	102

Station	Latitude (deg. N)	Longitude (deg. W)	Depth (m)	Dist. Well (km)	Dist. Seep (km)	Total PAH (ppb)	TPH (ppb)	Silt-Clay (%)	TOC (ppm)	Ba (ppm)	Cr (ppm)	Pb (ppm)	Zn (ppm)
D038SW	28.740483	-88.368058	1509	0.33	4.04	16,707	1,909,053	95.4	7,440	2,860	37.1	16.9	92.1
D040S	28.742303	-88.362169	1517	0.59	3.68	47,559	5,023,004	92.4	12,200	12,700	24.6	23.9	73.2
D042S	28.742525	-88.370500	1502	0.66	4.36	18,692	589,865	95.2	15,900	1,890	35.8	19.2	144
D043S	28.989167	-87.934643	1492	50.6	7.83	49.5	0	97.4	0	380	32.4	19.9	78.8
D044S	28.744919	-88.374242	1493	1.11	4.60	11,809	1,358,119	98.5	0	1,650	32.8	16.3	85.8
D050S	28.792450	-88.348483	1432	6.27	0.59	722	113,190	97.9	32,600	283	29.7	23.1	80.7
D057S	28.549282	-88.677556	1364	37.0	1.81	NA	28,000	98.4	14,600	265	33.8	33.7	92.3
D062S	28.265647	-88.923322	1303	75.8	3.07	154	21,813	98.9	8,260	351	38.2	26.1	99.3
D084S	28.841695	-88.492019	931	16.9	1.56	325	59,032	97.7	18,200	535	30	25.2	77.7
D085S	28.862904	-88.534614	842	21.6	2.87	433	53,691	98.1	20,600	413	28	21.4	73.7
D094S	29.335197	-87.046351	668	145	94.4	38.8	0	95.5	28,000	184	27.5	23.5	60.3
FF003	28.873950	-88.756894	493	41.1	0.57	218	40,088	98.6	19,600	580	42	27.7	104
FF005	28.807000	-88.561000	1003	20.6	4.46	1,006	168,874	98	9,520	405	33.3	29.2	87.9
FF010	28.668000	-88.430000	1356	10.0	2.46	2,436	334,903	98.2	7,640	315	35.9	37.8	88
FF013	28.204852	-89.056013	1213	89.9	5.46	NA	NA	NA	NA	NA	NA	NA	NA
FFC1	28.059642	-90.249119	325	200	5.72	NA	NA	98.6	24,900	1,940	45.8	24.5	102
FFC4	27.460422	-89.779464	1456	199	6.57	91.8	2,090	95.3	26,200	468	34.6	20.4	74.6
FFC7	27.733039	-89.976969	1015	194	0.47	133	6,758	95.5	21,800	644	37.8	23.4	84.5
FFMT1	28.539636	-89.828800	211	145	9.68	218	12,855	98.9	9,590	440	43	35.6	111
FFMT2	28.447919	-89.671883	684	132	3.12	328	64,524	92.4	13,800	364	30.2	35.1	77.2
FFMT3	28.218692	-89.491714	1002	125	6.68	135	11,090	99.2	14,100	986	41.4	24.9	94.1
FFMT4	27.828322	-89.164775	1405	128	0.77	51.7	0	95.3	18,200	442	35.6	18	82.4
FFMT5	27.336322	-88.659344	2259	158	10.8	59.7	0	97.5	12,400	154	41.6	17.6	101
FFMT6	26.999739	-87.996706	2767	197	51.2	28.2	0	69.4	13,000	126	24.9	10.9	51.6
LBNL1	28.732000	-88.376800	1578	1.26	4.42	5,688	2,108,199	97.2	6,100	4,110	34.8	32	92.1
LBNL11	28.345175	-88.778517	1438	59.5	0.36	117	10,583	99	8,880	349	43.5	23	106
LBNL13	28.447056	-88.759342	1286	50.3	5.61	NA	NA	99	5,240	314	36.1	18.3	90.7
LBNL14	28.730175	-88.416986	1535	5.07	3.22	1,169	180,496	98.3	7,380	553	39.2	24	90.9

Station	**Latitude (deg. N)**	**Longitude (deg. W)**	**Depth (m)**	**Dist. Well (km)**	**Dist. Seep (km)**	**Total PAH (ppb)**	**TPH (ppb)**	**Silt-Clay (%)**	**TOC (ppm)**	**Ba (ppm)**	**Cr (ppm)**	**Pb (ppm)**	**Zn (ppm)**
LBNL17	28.696767	-88.384875	1595	4.96	3.42	273	77,822	95.9	11,800	395	38.2	32.5	92.2
LBNL3	28.705231	-88.401672	1585	5.06	2.44	389	44,635	98	13,700	702	47.6	24.1	101
LBNL4	28.688081	-88.418439	1422	7.57	0.08	849	183,286	97.9	9,830	439	38.6	25.6	90.5
LBNL5	28.672508	-88.435906	1350	10.0	1.91	2,057	358,203	98.3	12,600	394	39.8	36.7	103
LBNL7	28.639167	-88.471294	1577	15.1	0.51	376	65,019	97.7	11,700	863	40.1	37.9	97.6
LBNL8	28.575208	-88.537842	1578	24.7	2.08	NA	NA	96.9	NA	405	37	20.3	85.9
LBNL9	28.514144	-88.600569	1516	33.9	5.06	NA	NA	98.6	5,810	317	36.1	23.4	89.1
M011S	29.000375	-88.800019	211	51.4	6.97	240	59,184	98.8	0	248	32.3	23.8	88.4
NF006MOD	28.745081	-88.359400	1517	1.00	3.34	22,871	3,095,416	94.1	11,300	789	34.1	37.3	87.5
NF008	28.720005	-88.388440	1585	2.98	4.50	419	102,545	97.4	16,300	1,100	46	29.5	115
NF009	28.738219	-88.397370	1489	3.08	5.10	2,391	288,689	NA	NA	NA	NA	NA	NA
NF010	28.757164	-88.388669	1439	3.07	4.92	786	148,133	98.3	14,300	323	43.8	31.9	109
NF011	28.765306	-88.366883	1449	3.02	3.17	1,612	257,925	96.7	17,400	586	45	29.6	114
NF012	28.757853	-88.344461	1520	3.04	1.37	370	64,260	97.7	11,500	627	42.4	33.4	103
NF013	28.738786	-88.335619	1567	2.97	1.38	1934	185,182	98.5	9,280	490	36.8	32.4	89.1
NF014	28.719603	-88.344700	1579	2.93	1.09	894	128,207	97.9	16,600	666	45.6	33.1	110

Appendix I. List of analytes included in the calculation of Total PAH values as presented in the ERMA Gulf Response website (<http://gomex.erma.noaa.gov>). CAS# = Chemical Abstract Service Registry Number.

Analyte	CAS#
Naphthalene	91-20-3
C1-Naphthalenes	NPHC1
C2-Naphthalenes	NPHC2
C3-Naphthalenes	NPHC3
C4-Naphthalenes	NPHC4
Biphenyl	92-52-4
Dibenzofuran	132-64-9
Acenaphthylene	208-96-8
Acenaphthene	83-32-9
Fluorene	86-73-7
C1-Fluorenes	FLC1
C2-Fluorenes	FLC2
C3-Fluorenes	FLC3
Anthracene	120-12-7
Phenanthrene	85-01-8
C1-Phenanthrenes/Anthracenes	PHEN/ANTHC1
C2-Phenanthrenes/Anthracenes	PHEN/ANTHC2
C3-Phenanthrenes/Anthracenes	PHEN/ANTHC3
C4-Phenanthrenes/Anthracenes	PHEN/ANTHC4
Dibenzothiophene	132-65-0
C1-Dibenzothiophenes	30995-64-3
C2-Dibenzothiophenes	DBTC2
C3-Dibenzothiophenes	DBTC3
C4-Dibenzothiophenes	DBTC4
Fluoranthene	206-44-0
Pyrene	129-00-0
C1-Fluoranthenes/Pyrenes	E17148362
C2-Fluoranthenes/Pyrenes	FLUOR/PYRC2
C3-Fluoranthenes/Pyrenes	FLUOR/PYRC3
Benz(a)anthracene	56-55-3
Chrysene	218-01-9
C1-Chrysenes	CRYSC1
C2-Chrysenes	CRYSC2
C3-Chrysenes	CRYSC3
C4-Chrysenes	CRYSC4
Benzo(b)fluoranthene	205-99-2
Benzo(k)fluoranthene	207-08-9
Benzo(e)pyrene	192-97-2
Benzo(a)pyrene	50-32-8
Perylene	198-55-0
Indeno(1,2,3-cd)pyrene	193-39-5
Dibenz(a,h)anthracene	53-70-3
Benzo(g,h,i)perylene	191-24-2
DI(Propylene Glycol)ButylEther	29911-28-2
DPnB-Peak1	29911-28-2-PK1
DPnB-Peak2	29911-28-2-PK2

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