ORDNANCE REEF (HI-06) FOLLOW-UP INVESTIGATION

Final Assessment Report

September 26, 2014

Distribution Statement "A" applies
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Contract No. W91ZLK-10-D-0005
Task No. 0773
CDRL No. A004/A005/A015

Submitted by

Concurrent Technologies Corporation
100 CTC Drive
Johnstown, PA 15904

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. AGENCY USE ONLY *(Leave blank)*	2. REPORT DATE September 26, 2014	3. REPORT TYPE AND DATES COVERED Final (9/30/11 – 9/29/14)

4. TITLE AND SUBTITLE
Ordnance Reef (HI-06) Follow-Up Investigation Final Assessment Report

5. FUNDING NUMBERS
Contract: W91ZLK-10-D-0005
Task: N.0773

6. AUTHOR(S)
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8. PERFORMING ORGANIZATION REPORT NUMBER

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)
NDCEE Program Office (Office of the Assistant Secretary of the Army for Installations and Environment)
5850 21st Street, Building 211
Fort Belvoir, VA 22060-5527
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10. SPONSORING/MONITORING AGENCY REPORT NUMBER
NDCEE-CR-2013-170

11 SUPPLEMENTARY NOTES

12a. DISTRIBUTION/AVAILABILITY STATEMENT
Distribution A – Approved for public release; distribution is unlimited.

12b. DISTRIBUTION CODE

13. ABSTRACT *(Maximum 200 words)*

The purpose of this project is to assess and report on the biota and sediment composition in the Ordnance Reef (HI-06) study area, to determine the potential effects of discarded military munitions (DMM) deposited off the leeward coast of Oahu following the Army's Remotely Operated Underwater Munitions Recovery System (ROUMRS) technology demonstration.

The Project Team (which includes the University of Hawaii and Environet) has prepared the attached Assessment Report for the HI-06 study area. This report summarized the activities of the University of Hawaii and Environet in gathering and analyzing biota and sediment samples from HI-06. The Project Team conducted and gathered three separate rounds of sediment samples, two rounds of biota samples, and analyzed them for munitions constituents. The results of their activities are compiled and provided in the attached Assessment Report (Appendix A) for the Ordnance Reef (HI-06) study area.

This report also includes an expanded data analysis of the data gathered during this task and compares it with the results of the ROUMRS demonstration to determine if there was any effect as a result of the demonstration.

14. SUBJECT TERMS
UH, HI-06, underwater munitions, DMM, ROUMRS.

15. NUMBER OF PAGES
217

16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
Unclassified	Unclassified	Unclassified	None

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LIST OF APPENDICES

LIST OF ACRONYMS AND ABBREVIATIONS

ARAR	applicable or relevant and appropriate requirement
BRL	Brooks Rand Laboratories
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act
COPC	Contaminant of Potential Concern
CTC	Concurrent Technologies Corporation
DMM	Discarded Military Munitions
DNT	dinitrotoluene
DoD	Department of Defense
EPA	Environmental Protection Agency
ERA	Ecological Risk Assessment
HHRA	Human Health Risk Assessment
HMX	high melting explosive (octahydro-1,3,5,7-tetranitro-1,3,5,7-tetrazocine)
HPLC	High Performance Liquid Chromatography
MC	Munitions Constituents
NDCEE	National Defense Center for Energy and Environment
NT	nitrotoluene
ODASA(ESOH)	Office of the Deputy Assistant Secretary of the Army for Environment, Safety and Occupational Health
PL	Public Law
RDX	royal demolition explosive (hexahydro-1,3,5-trinitro-1,3,5-triazine)
ROUMRS	Remotely Operated Underwater Munitions Recovery System
TBC	to-be-considered
TNB	trinitrobenzene
UWMM	Underwater Military Munitions

EXECUTIVE SUMMARY

Sea disposal was once internationally accepted as an appropriate method for disposal of conventional and chemical munitions. Following this accepted practice, the Department of Defense (DoD) sea-disposed excess, obsolete, or unserviceable munitions from at least the early 1900s through 1970. DoD policy for sea disposal was not specific in the early 1900s, but became more restrictive over time. By 1945, conventional munitions were required to be disposed at a depth of 3,000 feet. In 2006, Congress passed legislation (PL 109-364, Sec 314) requiring the Secretary of Defense to research past sea disposals and the impact of munitions on the ocean environment and those that use it, as well as of the ocean environment on the munitions.

The Office of the Deputy Assistant Secretary of the Army for Environment, Safety and Occupational Health (ODASA[ESOH]) is managing a program to collect and synthesize information on underwater military munitions (UWMM) in U.S. waters. Research and analysis are required to understand the extent of the issue and the potential risks to human health and the environment. The National Defense Center for Energy and Environment (NDCEE), operated by Concurrent Technologies Corporation (CTC), was tasked assess the change in conditions (e.g., presence of munitions constituents [MC] and concentrations) at Ordnance Reef (HI-06) following a technology demonstration during which of the munitions present at depths between approximately 30 and 120 feet were recovered. The purpose of this project is to assess and report on the biota and sediment composition in the Ordnance Reef (HI-06) study area, to determine the potential effects of discarded military munitions (DMM) deposited off the leeward coast of Oahu following the Army's Remotely Operated Underwater Munitions Recovery System (ROUMRS) technology demonstration.

The Project Team (which includes the University of Hawaii [UH] and Environet) conducted and gathered three separate rounds of sediment samples, and two rounds of biota samples, and analyzed them for munitions constituents. The results of their activities are compiled and provided in the attached Assessment Report (Appendix A) for the Ordnance Reef (HI-06) study area. The Assessment Report contains the following sections:

- Executive Summary
- Introduction
- Investigation Methods and Procedures
- Results of the Follow up Investigation
- Comparison Pre- & Post ROUMRS
- Conclusions
- References Sited

The Investigation Methods and Procedures Section discusses the stratified sampling approach, sampling procedures, mobilization, sediment sampling, seawater sampling, biological sampling, and sample numbering and labeling. In addition, equipment decontamination procedures, investigation-derived waste management, field quality assurance and quality control are also discussed.

Sample collection and handling procedures were designed to ensure that field team personnel were able to collect, label, preserve, and transport all required samples in a consistent manner to maintain sample integrity. The samples collected matched those collected for the 2009 ROUMRS study to allow a direct comparison of the results. These samples included fish, invertebrates (crab and octopus) and seaweed. A total of 108 biota samples were collected and of these, 44 were fish, 26 were octopus, 15 were crab and 23 were seaweed. A total of 99 sediment samples (clay, silt and sand but no gravel) were analyzed. TestAmerica West Sacramento analyzed all samples, with the exception of major and minor elements – aluminum, calcium, iron, magnesium, manganese, strontium and titanium- in sediment, which were analyzed by the UH laboratory, and the arsenic speciation which were conducted by Brooks Rand Laboratories (BRL). All analyses were performed using US Environmental Protection Agency or equivalent methods. High Performance Liquid Chromatography (HPLC) methods employed for this study included second column confirmation of positive detections.

The Results Section focused on quantifying the effects of the summer 2011 ROUMRS technology demonstration on contaminants in the sediment and biota at Ordnance Reef (HI-06). There were three sampling events during the Follow-Up Investigation. The dates, types of sampling, and sample locations follow:

- August 2011 (sediment)
- July-August 2012 (sediment & biota)
- June 2013 (sediment & biota)

The potential fate and transport of the Contaminants of Potential Concern (COPC), and the results from analysis of the sediment and biota samples collected at Ordnance Reef (HI-06) are addressed in this report. In addition to a discussion on the occurrence and concentrations observed, a discussion of possible sources for the various analytes is presented. The final subsection discusses the hydrocasts and the resulting water column profile plots.

During this task, only three energetics were detected in biota samples (2,4-DNT, 2,6-DNT, and 1,3,5-TNB), and only in the octopus and fish. Of the 88 sediment samples collected, arsenic was detected in 75, or 85%, of the samples. Copper and lead were detected in all of the sediment samples. It should be noted though the levels of arsenic, copper and lead concentrations varied within each sample set depending on which stratum the sample was taken. Arsenic and copper were detected in all biota samples; however, lead was not detected in the crab or octopus samples but was detected in approximately half of the seaweed samples.

The Comparison of Pre- and Post-ROUMRS Section provides a comparison of sample analysis of the Ordnance Reef (HI-06) prior to the ROUMRS sampling in addition to sampling conducted one year after ROUMRS sampling. Samples were taken on both sediment and biota and analyzed for calcium, magnesium, strontium, 2,4-DNT, arsenic, cobalt, nickel, lead, zinc, 2,4-DNT, chromium and copper. Arsenic was significantly higher in post-ROUMRS crabs but significantly lower in post-ROUMRS octopus. There was also significantly lower zinc in the post-ROUMRS octopus. Post-ROUMRS copper and zinc were significantly higher in fish but so were chromium, and strontium. Post-ROUMRS arsenic, lead, and vanadium were significantly lower. Boxplots are included in the appendix showing post- and pre-ROUMRS data.

The Conclusions Section includes the overall findings and comparison of the sampling analyses. This section provides a summary of the both testing rounds and findings. Overall, no significant differences were identified between pre- and post-ROUMRS sediment and biota data. However, it is difficult to say that these differences resulted from the ROUMRS technology demonstration and, in fact, the data suggest that there were other, unknown factors that may have contributed to these differences. While the sediment data did not explain the differences, it was apparent that sediment data are at least more consistent than biota data.

APPENDIX A

University of Hawaii Assessment Report
(Contact DTIC for the entire Appendix A which is on a CD)

UH FUI Report
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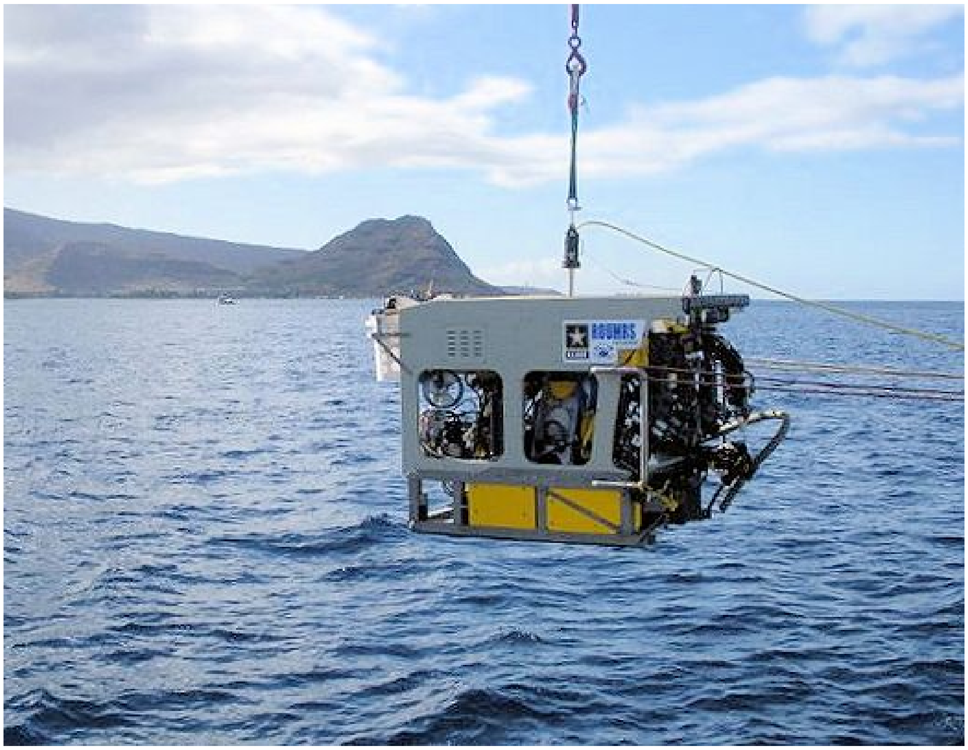

FINAL
Follow-Up Investigation
Assessment Report

UNIVERSITY of HAWAI'I
MĀNOA

September 2014

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FINAL
Follow-Up Investigation Assessment Report

Ordnance Reef (HI-06)

Wai‘anae, O‘ahu, Hawai‘i

Prepared for:
Concurrent Technologies Corporation

Prepared by:
UH

Contract No.: W91ZLK-10-D-0005 Task 0773

Prepared By:

UNIVERSITY of HAWAI‘I
MĀNOA

September 2014

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List of Acronyms and Symbols

ADCP	acoustic Doppler current profiler
Am	amino
ATSDR	Agency for Toxic Substances and Disease Registry
C&C	City and County
CAMIP	Coral Avoidance and Minimization of Injury Plan
CEC	cation exchange capacity
CERCLA	Comprehensive Environmental Response, Compensation, & Liability Act
cm	centimeter
COC	chain-of-custody
CON	control
COPC	constituent of potential concern
COPEC	constituent of potential ecological concern
CTD	conductivity, temperature, depth
CTL	critical tissue level
DL	detection limit
DMM	discarded military munitions
DNB	dinitrobenzene
DNT	dinitrotoluene
DO	dissolved oxygen
DoD	Department of Defense
DOH	State of Hawaiʻi Department of Health
DQO	data quality objective
ERA	ecological risk assessment
ft	feet
FDA	U.S. Food and Drug Administration
FSP	Field Sampling Plan
GIS	geographic information system
g/mL	grams per milliliter
GPS	global positioning system
HELCOM	Helsinki Commission
HHRA	human health risk assessment
HMX	high melting explosive (octahydro-1,3,5,7-tetranitro-1,3,5,7-tetrazocine)
HPLC	high performance liquid chromatography
ICP-MS	inductively coupled plasma - mass spectrometry
ICP-OES	inductively coupled plasma - optical emission spectrometry
ID	identification
IDW	investigation-derived waste
in	inch
kg	kilograms
km	kilometers
K_{oc}	organic carbon partition coefficient
K_{ow}	octanol-water partition coefficient
lbs/gal	pounds per gallon

LCS	laboratory control sample
LCSD	laboratory control sample duplicate
m	meters
MB	method blank
MC	munitions constituents
MDL	method detection limit
mi	statute miles
mg	milligram
mg/kg	milligrams per kilogram
mm	millimeter
m/s	meters per second
MS	matrix spike
MSD	matrix spike duplicate
NM	nautical mile
NMDS	nonmetric multidimensional scaling
NOAA	National Oceanic and Atmospheric Administration
NPDES	National Pollutant Discharge Elimination System
NPS	non-point source
NRDC	Natural Resources Defense Council
NT	nitrotoluene
ORCC	Ordnance Reef Coordinating Council
ORP	oxidation-reduction potential
PCA	principal component analysis
pH	hydrogen potential
ppm	parts per million
ppt	parts per thousand
psi	pounds per square inch
QA	quality assurance
QC	quality control
QAPP	Quality Assurance Project Plan
RDX	royal demolition explosive (hexahydro-1,3,5-trinitro-1,3,5-triazine)
RI	Remedial Investigation
RL	reporting limit
ROUMRS	Remotely Operated Underwater Munitions Recovery System
SAA	small arms ammunition
SBE	Sea-Bird Electronics
SCAR	Special Operations Forces Combat Assault Rifle
SCUBA	self-contained underwater breathing apparatus
SONAR	sound navigation and ranging
SW	solid waste
TNB	trinitrobenzene
TNT	trinitrotoluene
UH	University of Hawai'i
U.S.	United States
USACE	U.S. Army Corps of Engineers
USACHPPM	U.S. Army Center for Health Promotion and Preventive Medicine (now Public Health Command)
USATCES	U.S. Army Technical Center for Explosives Safety

USEPA	U.S. Environmental Protection Agency
UXO	unexploded ordnance
WWTP	wastewater treatment plant
µg/g	micrograms per gram
µg/L	micrograms per liter
µm	micrometer
°C	degrees Celsius
°F	degrees Fahrenheit
%	percent

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Executive Summary

The University of Hawai‘i (UH) was contracted by the National Defense Center for Energy and Environment (NDCEE), operated by Concurrent Technologies Corporation (CTC), to assess the change in conditions (e.g., presence of munitions constituents [MC] and concentrations) at Department of Defense (DoD) sea disposal site Hawai‘i 6 (HI-06) (locally known as Ordnance Reef) following a technology demonstration during which 74 of the medium and large munitions and an estimated 2,300 small arms ammunition present were recovered. Ordnance Reef is off the Wai‘anae Coast of O‘ahu, Hawai‘i (hereafter referred to as Ordnance Reef [HI-06]). This study follows the Comprehensive Environmental Response, Compensation, and Liability Act's (CERCLA) process, even though Ordnance Reef (HI-06) is not subject to CERCLA, as CERCLA offers a recognized framework for investigation and evaluation of sites. The purpose of this Follow-Up Investigation is to assess and report on changes to the biota and sediment composition in the Ordnance Reef (HI-06) study area following the recovery of discarded military munitions (DMM) during the Army's Remotely Operated Underwater Munitions Recovery System (ROUMRS) technology demonstration. Ordnance Reef (HI-06) covers an area approximately 1 nautical mile (NM) in length by 0.5 NM in width and lies in approximately 33 to 230 feet (ft) (10 to 70 meters (m)) of water. It is directly offshore of several O‘ahu communities (e.g., Wai‘anae, Nānākuli, Mā‘ili) that rely on the area for recreation, subsistence, and perpetuation of local culture.

This study approached the investigation in the same manner as the prior site assessment (UH, 2014), sampling sediment and biota in four strata (DMM, control [CON], non-point source [NPS], and wastewater treatment plant [WWT]), and thus allowed us to meet the objective of being able to compare pre- and post-ROUMRS conditions. This investigation also addressed the concerns previously identified through discussion with regulators and the Ordnance Reef Coordinating Council (ORCC). The input from the regulators and ORCC brought a wealth of local knowledge and fishing expertise to the study team and was brought to bear on this study.

The primary focus of sample site selection was to target the collection of biota and sediment samples in close proximity to the munitions recovered during the Ordnance Reef (HI-06) ROUMRS technology demonstration in order to assess the possible impacts from the recovery of these munitions at Ordnance Reef (HI-06). Considering the anticipated difficulties of finding specific biota at DMM recovery sites and the other sampling sites within the four strata (CON, NPS, WWT), the Wai‘anae fishermen who were contracted to collect biota were remarkably successful in collecting biota samples near designated DMM. Sampling during and one week after the ROUMRS technology demonstration, about one year later, and finally nearly two years later, UH collected a total of 88 sediment samples from the four strata and a total of 108 biota samples consisting of limu (seaweed), crab, octopus, and fish. In addition to analyzing these samples for elements (munitions related and unrelated) and energetics, we also determined generally toxic inorganic versus nontoxic organic arsenic. Using a variety of sophisticated statistical techniques we were able to look for patterns in complex data, quantify the relationships between analytes, and compare pre- and post-ROUMRS data.

In the analysis of both pre- and post-ROUMRS sediment data using the nonparametric ordination technique nonmetric multidimensional scaling (NMDS), four elements (copper, lead, zinc, and magnesium) were clearly associated with munitions, in addition to the energetics. We surmised that brass shell casings were the source of much of the copper and zinc, small arms ammunition slugs with lead, and tracer rounds with magnesium. Arsenic, on the other hand, was more closely associated with the terrestrial elements (e.g., aluminum, chromium, iron), possibly because the source may be terrestrial runoff. Nonparametric Kendall's tau correlation analysis not only confirmed the element associations but quantified the strength of the relationship between analytes as well. Not surprisingly, copper, zinc, and lead were generally higher in the DMM stratum, whereas arsenic and the terrestrial elements were higher in the CON stratum.

NMDS analysis of the biota data revealed that there was a clear pattern in the data by organism type; however, only the limu data showed a possible pattern associated with strata. We did see that crab and octopus clustered somewhat together, whereas the fish and limu formed distinct and separate clusters. Not only did the crab and octopus cluster together but they also clustered with copper which is not surprising given that their blood contains copper-based hemocyanin. Arsenic and zinc were highest in crabs and lead was consistently detected in limu. A consistent and strong correlation existed between copper and zinc for all organisms (Kendall's tau > 0.4) presumably because of the presence of copper- and/or zinc-based enzymes. With the exception of limu, toxic inorganic arsenic was not detected in organisms.

Using another nonparametric test analogous to the generalized Wilcoxon test, we compared pre- and post-ROUMRS sediment data from both the DMM and CON strata. We found that most analytes were significantly lower (at a statistical significance level $\alpha = 0.5$) in the post-ROUMRS data; there were exceptions (e.g., calcium). While it would be tempting to say that this decrease was the result of recovering the DMM, the fact that analytes not associated with DMM were also lower as were post-ROUMRS data from the CON stratum, suggests that there may be other factors that caused the observed difference. There also was no clear pattern in the biota data with some post-ROUMRS analytes higher and others lower depending on the organism.

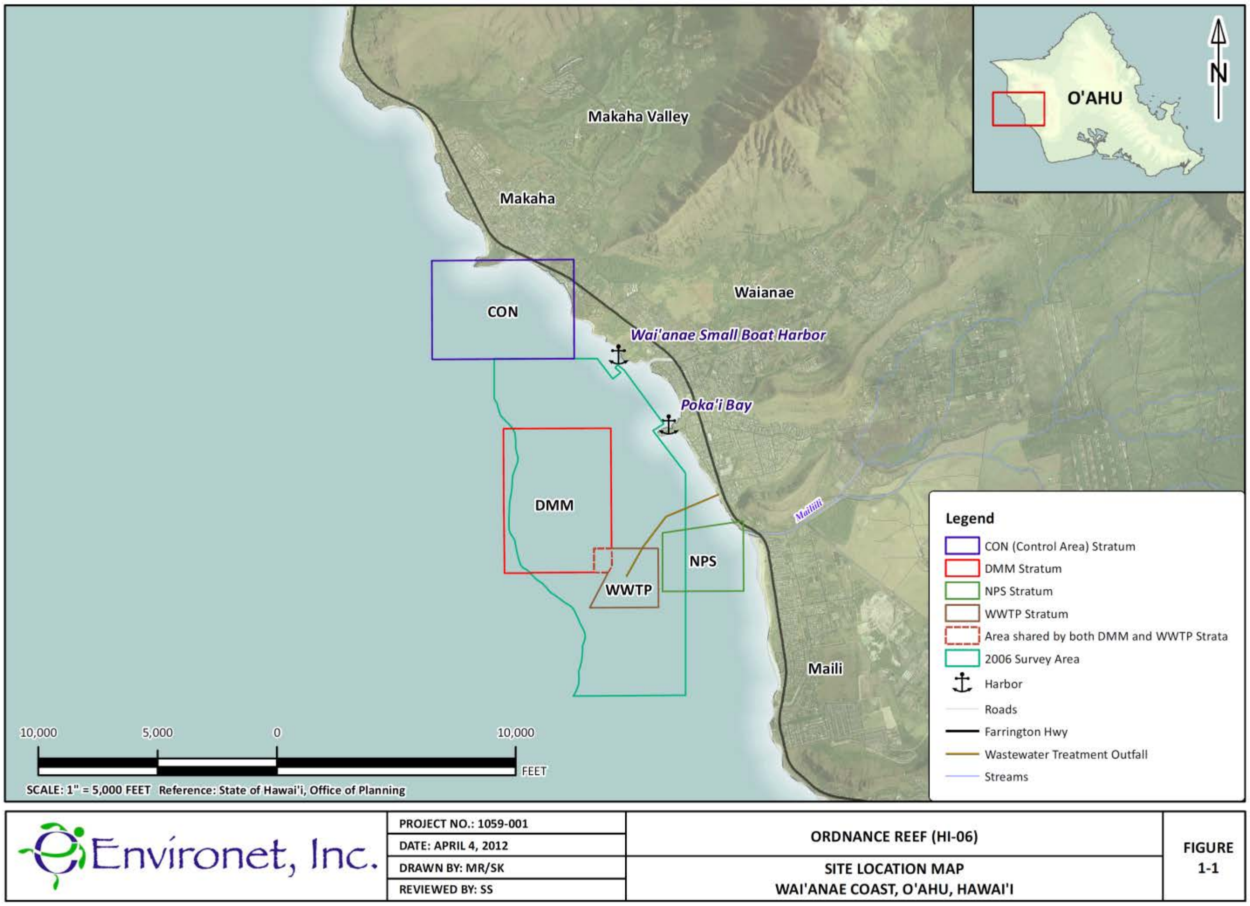
We compared the NMDS plots for the pre- and post-ROUMRS sediment data and the correlations between analytes from post-ROUMRS data seem to be somewhat less. Interpretation of the meaning of this, at this point, is purely conjecture without additional investigation. Given that the munitions were on the seafloor and, hence, in contact with the sediments for decades, it is possible that the chemicals that made up the casings, explosives, and propellants had reached pseudo-equilibrium with their environment. It is possible that in recovering some of the DMM, this equilibrium was disturbed and, as a result, the correlations are no longer as strong as they were in the pre-ROUMRS data. Proving this hypothesis would require further testing. There could be a number of other reasons why pre- and post-ROUMRS sediment data differ.

Section 1
Introduction

This document presents the results of a Follow-Up Investigation by the University of Hawai‘i (UH) at the Department of Defense (DoD) sea disposal site Hawai‘i 6 (HI-06) (locally known as Ordnance Reef), which is off the Wai‘anae Coast of O‘ahu, Hawai‘i (hereafter referred to as Ordnance Reef [HI-06]). This investigation was contracted to Concurrent Technologies Corporation (CTC) under contract W91ZLK-10-D-0005, Task 0773. The Follow-Up Investigation was conducted by researchers from the UH Oceanography Department to determine quantitatively if conditions at Ordnance Reef (HI-06) changed as a result of the Army’s Remotely Operated Underwater Munitions Recovery System (ROUMRS) technology demonstration, which took place during the summer of 2011, and to evaluate any further changes over a period of two years after the demonstration. The ROUMRS project demonstrated technology for the removal and disposal of previously at-sea discarded military munitions (DMM). The Office of the Deputy Assistant Secretary of the Army for Environment, Safety and Occupational Health (ODASA-ESOH), through the DoD’s National Defense Center for Energy and Environment (NDCEE), contracted CTC to carry out the investigation and CTC sub-contracted UH to perform the investigation. The Army found the methods of sampling and analysis used for investigations under the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) to be useful to assist in carrying out studies at Ordnance Reef (HI-06). The use of these methods and processes does not indicate this is a CERCLA response action or that the requirements of CERCLA or its implementing regulations are applicable to these studies or to the Army at this site. Throughout this report, terminology is occasionally used that is associated with CERCLA Remedial Investigations (RI) and concepts that are discussed in guidance that pertains to CERCLA response actions, however the use of these terms and concepts is a matter of convenience to the Army and does not indicate there are any requirements under CERCLA or its implementing regulations or guidance that apply to this project.

Ordnance Reef (HI-06) covers an area approximately 1 nautical mile (NM) in length by 0.5 NM in width and lies in approximately 33 to 230 feet (ft) (10 to 70 meters [m]) of water. The nearest communities are Wai‘anae, approximately 3 miles (mi) (5 kilometers [km]) to the northeast, and Mā‘ili, approximately 5 mi (8 km) to the southeast. The geographic boundaries of the National Oceanic and Atmospheric Administration (NOAA) 2006 survey (Figure 1-1) encompassed an area approximately 3 by 1.5 NM (3,814 acres [1,543 hectares]) which includes a fish haven and the Wai‘anae wastewater treatment plant (WWTP) outfall area. This study occurred in much the same area as 2009 UH Ordnance Reef (OR) Study (UH, 2014) (Figure 1-1).

Figure 1-1: Ordnance Reef study area located on the leeward side of O‘ahu, Hawai‘i.



This study was confined to depths shallower than typically used by SCUBA (self-contained underwater breathing apparatus) divers (120 ft, or approximately 37 m). Depths beyond 120 ft are not accessible to most ocean users, and were thus not considered applicable for this study, which focused on potential threats to human health. Much of the fishing at Ordnance Reef (HI-06) is conducted at these depths and the ability of local fishermen to collect biota in close proximity to the munitions recovery sites was important in the experimental design.

1.1 Purpose

The Follow-Up Investigation’s primary objective was to:

> Evaluate whether the recovery of water disposed military munitions from Ordnance Reef (HI-06) during the Army’s ROUMRS technology demonstration had any impact on the concentrations of munitions constituents (MC) present in the environment. This was accomplished by comparing post-demonstration sampling results to those collected during NOAA’s and UH’s earlier investigations.

Specific study components to accomplish the primary objective included:

- Collection of a sufficient number of samples of sediment and biota from Ordnance Reef (HI-06) immediately following the ROUMRS technology demonstration as well as a period between 6 months and two years after the demonstration, and analyzing samples for MC[1] to determine if conditions changed.
- The analytical suite matched that of the 2009 UH OR Study of the area. The analytical laboratories involved participate in the National Environmental Laboratory Accreditation Program (NELAP) and are accredited for these analyses. UH generated screening level data (non-NELAP), primarily major and some minor elements, at the Principal Investigator’s laboratory, which supported various statistical analyses including ordination techniques in order to identify the potential sources of study sample (sediments, biota) constituents.
- Carrying out three rounds of sampling. The first round of Follow-Up Investigation sampling (FUI1 – sediment only) occurred during and within a week after the completion of the ROUMRS technology demonstration. The second Follow-Up Investigation sampling effort (FUI2 – sediments and biota) occurred about 11 months following the first round of sampling to assess if conditions observed during the first sampling round had further evolved. Finally, a third round of Follow-Up Investigation sampling (FUI3 – sediments and biota) was conducted 22 months after the ROUMRS demonstration in order to determine what long-term changes, if any, had occurred.
- Comparing the concentrations of MC in sediment and biota samples collected subsequent to the ROUMRS technology demonstration to those observed in the corresponding media prior to the technology demonstration. The comparison was based on data acquired by UH during the 2009 UH OR Study. The strata sampled during this Follow-Up Investigation included the DMM and CON (control) areas; although small numbers of samples were also collected at the WWT and NPS areas of the prior study.
- Collecting biota samples (i.e., Kona crab, octopus [he‘e], seaweed [limu kohu] and goatfish [weke]) using traditional local methods. Samples were preserved, prepared, and analyzed in the same fashion as was done during the 2009 UH OR Study (UH, 2014).
- Measuring the oceanographic conditions in the water column of the Ordnance Reef (HI-06) area through *in situ* measurements of temperature, salinity, dissolved oxygen, turbidity and chlorophyll fluorescence in the water column. These measurements occurred at times corresponding with sampling of sediments and/or biota during the latter two sampling events described above. No water column measurements were conducted during the first sampling event due to an instrument malfunction.
- Analysis of sediment and biota for elemental concentrations following: 1) the methods described by USEPA (e.g., SW-846); 2) modifications to the USEPA Methods used during the 2009 UH OR Study; or 3) comparable standard methods.

[1] **Munitions Constituents (MC)**. Any materials originating from unexploded ordnance (UXO), discarded military munitions (DMM), or other military munitions, including explosive and non-explosive materials, and emission, degradation, or breakdown elements of such ordnance or munitions. (10 U.S.C. 2710(e)(3)).

The methods were selected to ensure comparability of data between the current data collection effort and the results of analysis of biota and sediments from the 2009 UH OR Study (UH, 2014). Validation of analytical data packages followed accepted industry practice (USEPA level IV validation). Documentation of analytical data was sufficient to support a subsequent risk assessment, if such were deemed necessary.

- Analysis of blanks, field duplicates, matrix spike and matrix spike duplicates, in addition to the laboratory quality assurance/quality control (QA/QC) specified by the analytical methods.
- Comparison of conditions in the marine environment of Ordnance Reef (HI-06) following the ROUMRS technology demonstration to the conditions documented prior to the demonstration project. UH compared the DMM stratum (i.e., the area where DMM were present) to a reference (control, CON) stratum unimpacted by DMM through sampling and analysis of the same biota and the collection and analysis of sediment samples.
- Performance of nonparametric ordination analysis using nonmetric multidimensional scaling (NMDS) and Kendall’s tau correlation analysis on the data and using available information to determine whether any constituents detected are attributable to DMM, or whether they are attributable to other sources.
- Carrying out of additional statistical analyses to fully describe and compare the results of this Follow-Up investigation with the 2009 UH OR Study (UH, 2014).
- Carrying out all aspects of the study in a transparent manner and informing communities of the findings.
- Photographs were taken throughout the investigation to document typical field activities.
- Preparation of this summary report comparing post-ROUMRS technology demonstration conditions to those extant at the end of the field sampling operations of the 2009 UH OR Study.

The study team’s planning considered other possible environmental impacts to the area such as the Wai‘anae WWTP outfall at the southeast corner of the survey area, and areas of coastal non-point source (NPS) discharge via channels/canals (Figure 1-1). The sampling approach was thus designed in a stratified manner to attempt to separate out these potential sources of contamination from those attributable to DMM (refer to Section 2.1 for a more detailed discussion).

1.2 Limitations of this Study

The goal of this study was solely to identify changes in MC concentrations that could be attributable to the ROUMRS technology demonstration. If necessary, the data from this investigation could be used to support a risk assessment. A risk assessment, however, is beyond the scope of this investigation.

1.3 Site Description

1.3.1 Site Background

During a benthic survey of the Waiʻanae WWTP ocean outfall in 1992, the City and County (C&C) of Honolulu, Department of Wastewater Management's oceanographic team discovered DMM between about 0.25 and 0.5 NM (0.5 and 1 km) northwest of the existing municipal sewage outfall's diffuser. The C&C's oceanographic team also discovered DMM south of the WWTP outfall and just west of the State of Hawaiʻi-designated fish haven.

At the request of the U.S. Army Corps of Engineers (USACE), the Explosive Ordnance Disposal Detachment MIDPAC (UIC-32082) from Pearl Harbor, Hawaiʻi, conducted a diver survey to determine the various amounts and types of munitions in Pōkaʻī Bay on the western coast of Oʻahu, Hawaiʻi in July 2002. The search area was divided into three sections. The largest section was 1 NM by 1 NM (2 km by 2 km) with depths ranging from approximately 15 to 700 ft (5 to 213 m). The deepest area of the section was not searched. The second section was the inner area of Pōkaʻī Bay. This area was primarily searched by snorkelers. The third section was added to the survey in an attempt to find the boundary of the DMM disposal area. It was limited in size to the area with depths accessible with standard SCUBA diving equipment (an area approximately 1,500 by 900 ft (457 by 274 m) with a depth range of 60 to 130 ft (18 to 40 m). This was deemed sufficient for a general evaluation of the overall search area. Bounce dives were conducted on the deepest section just outside of the third section to try to determine the extent of the DMM disposal area. Observed DMM were reported and marked using a global positioning system (GPS).

The first summary of DMM found at Ordnance Reef (HI-06) was generated from the 2002 survey which is provided below in Table 1-1. The DMM observed included clipped .50 caliber rounds, 2-in Special Operations Forces Combat Assault Rifle (SCAR) munitions, 105-millimeter (mm) shells, 155-mm shells, mines, mortars, naval artillery projectiles, and other munitions. Most of the munitions found were described as live and unfired (i.e., DMM). The locations and approximate depths of the underwater military munitions at Ordnance Reef (HI-06) were documented during USACE's 2002 and NOAA's 2006 surveys. Based on these surveys, the Army estimated that approximately 2,000 munitions were present within the site boundaries at 160 ft (49 m) or shallower (DoD, 2010). Munitions are also present at depths beyond those surveyed.

Table 1-1: Summary of military munitions documented at Ordnance Reef (HI-06) – 2002.

Munitions Description	Approximate Quantity
.50 caliber cartridges	200
100-lb old style fragmentation bomb recon from surface, not diver-verified	1
90-mm mortar	1
105-mm cartridge case	1
105-mm projectiles	150
155-mm projectiles	75
20-mm cartridges	1,040
25-mm cartridges	250
Closed ammunition boxes (2 feet X 2 feet X 2 feet)	30
Bottom mine	1
Depth charge	1
Tubes (4 feet X 3 inches in diameter)	70
has? (2 feet X 3 inches in diameter)	1
High concentration of 6-inch projectiles	
Large pile of munitions – counted by divers before ascent	45
3- to 6-inch Naval gun ammunition	35
5-inch Naval gun ammunition	5
5- to 8-inch Naval gun ammunition	90
6- to 8-inch Naval gun ammunition	
8-inch projectiles	45
Naval gun ammunition various sizes	65
Approximate Quantity	**2,106**

All quantities are estimated and identifications are considered tentative based on the 2002 report. These quantities were used for initial planning purposes only.

In NOAA's 2011 Coral Avoidance and Minimization of Injury Plan (CAMIP, NOAA [2011]) for the Army's ROUMRS technology demonstration, NOAA provided the most comprehensive survey of munitions at Ordnance Reef (HI-06). NOAA photographed, visually identified, and assigned munitions to three general categories: 1) small arms ammunition (SAA), 2) small to medium caliber munitions (munitions above .50 caliber to and including 105 mm), and 3) large caliber and other munitions (munitions larger than 105 mm, bombs, rockets, etc.). NOAA reported that 64% of the munitions at Ordnance Reef (HI-06) are SAA (NOAA, 2011). The estimate of the total number of munitions present is much higher than the 2002 estimate because (a) NOAA's divers were using mixed-gas (nitrox), allowing more time underwater, and (b) NOAA had access to the previous surveys, allowing it to focus on areas where munitions were concentrated. In addition, NOAA attempted to count individual munitions, including SAA, rather than count them as clusters or groupings of munitions as was done previously. Prior surveys did not attempt to estimate the number of SAA and addressed clusters and groupings collectively. Table 1-2 summarizes munitions documented by NOAA during their 2010 survey. NOAA estimated that 21,199 DMM lie within three designated Ordnance Reef (HI-06) technology demonstration work areas.

Table 1-2: Summary of military munitions documented at Ordnance Reef (HI-06) – 2010

	Small Arms Ammunition	Small to Medium Caliber Munitions[a]	Large Caliber and Other Munitions[b]
Work Area A	14	0	0
Work Area B	229	1,464	0
Work Area C	12,557	6,061	874
Total	**12,800**	**7,525**	**874**

Notes:
Reference: NOAA, 2011
[a] Munitions above .50 caliber to 105-millimeter
[b] Munitions larger than 105-millimeter, bombs, rockets, etc.

The munitions present at Ordnance Reef (HI-06) appear to be DMM, not unexploded ordnance[2] (UXO). As such, they are considered less hazardous, because they have not been through their arming sequence. Records detailing the disposal of munitions at this location have not been uncovered despite extensive research efforts. It is presumed that the munitions date from the activities associated with the ending of World War II.

1.3.1.1 Previous Environmental Investigations and Data Gaps

From May 2006 to June 2006, NOAA and UH conducted a screening-level survey of Ordnance Reef (HI-06) to determine the environmental implications of the DMM (NOAA, 2007). Side scan sound navigation and ranging (SONAR) was used to survey 71 linear NM (131 linear km) at depths ranging from about 23 to 300 ft (7 to 91 m) and discrete samples of sediments (96) and fish (49) were analyzed for major, minor, and trace elements and energetics. Based on available documentation, NOAA's study team identified the following compounds as their target analytes: energetic compounds – trinitrotoluene (TNT), royal demolition explosive (hexahydro-1,3,5-trinitro-1,3,5-triazine) (RDX), and metalloid or metal target compounds – arsenic (metalloid), copper, and lead. The analytical suite, however, included a large number of elements selected based on their potential to identify individual source contribution and included arsenic, calcium, cadmium, cobalt, copper, chromium, iron, magnesium, nickel, lead, strontium, uranium, vanadium, and zinc. To represent a "worst-case" scenario, whole fish homogenized samples were analyzed. All fish samples and a portion of the sediment samples were analyzed for a standard list of 13 energetic related compounds including RDX and TNT. The trace metal enrichment of the sediment samples from Ordnance Reef (HI-06) was found to be low, suggesting that little contamination is derived from DMM. The survey did find high levels of metals in sediments near the Wai‘anae WWTP outfall, and in areas of natural drainage off the island. Dinitrotoluene (DNT) was the only explosive-related compound found in the sediment, and only in four of the 96 samples. No energetics were found in the fish samples. The observations of NOAA's 2006 survey suggested that the DMM in the area are not a risk to human health (NOAA, 2007).

In subsequent independent reviews of NOAA's report (NOAA, 2007), the Agency for Toxic Substances and Disease Registry (ATSDR) and the U.S. Army Center for Health Promotion and

[2] **Unexploded Ordnance (UXO)**. Military munitions that (A) have been primed, fuzed, armed, or otherwise prepared for action; (B) have been fired, dropped, launched, projected, or placed in such a manner as to constitute a hazard to operations, installations, personnel, or material; and (C) remain unexploded whether by malfunction, design, or any other cause. (10 U.S.C. 101(e)(5)(A) through (C)))

Preventive Medicine (USACHPPM, now known as the U.S. Army Public Health Command) concurred that, based on the data collected, there were no indications that the presence of the DMM posed a threat to human health or the environment (ATSDR, 2007; USACHPPM, 2007).

The USACHPPM health risk evaluation also included an ecological evaluation, and noted that no overt signs of stress or ecological impact were evident at Ordnance Reef (HI-06). Based on this observation, USACHPPM stated that a full ecological risk assessment (ERA) would not be necessary at Ordnance Reef (HI-06) (USACHPPM, 2007).

A risk assessment of the explosive safety considerations due to DMM at Ordnance Reef (HI-06) was conducted by U.S. Army Technical Center for Explosives Safety (USATCES, 2007) following NOAA’s 2006 survey. The USATCES risk assessment summarized various levels of explosives risk for activities categories assumed to take place in the area. A summary of risks was as follows: risk associated with removal of munitions (extremely high); recreation, commercial and miscellaneous risk (high); shipping/boating risk (moderate); and fishing and emergency services risk (low). Based on the results of this assessment, USATCES recommended a public education program on the hazards associated with DMM and UXO, restricting some activities from Ordnance Reef (HI-06) waters, and leaving the munitions where they currently lie. The explosives risks are all associated with activities that would disturb the munitions. Over a period of several years, USACE provided the public education recommended, and undertook a number of efforts to distribute information to the public (public outreach materials are at www.denix.osd.mil/uxo).

Although NOAA’s 2006 survey (NOAA, 2007) did not identify significant threats to human health or the environment, several data gaps were identified by resource agencies and the public. The 2009 UH OR Study (UH, 2014) focused on the following data gaps:

- A lack of seasonal sampling (NOAA’s 2006 survey only collected samples during the summer season, and thus did not involve sampling during the high wave action winter months).
- Inclusion of additional analytes, specifically nitroglycerin and ammonium picrate (as picric acid).
- Analysis of fish fillet samples, to be more representative of the diet of the Wai‘anae community (the previous survey looked solely at homogenized whole fish, and the community felt that this did not accurately represent local consumption habits).
- Collection of human food-item biota, such as goatfish (weke), octopus (he‘e), Kona crab, and seaweed (limu). NOAA’s 2006 survey collected fish species that were not felt to represent the local diet, and this was identified as a data gap by the people of the Wai‘anae community.
- Application of a modified analytical method for energetics in biological tissue samples, as opposed to the use of the standard USEPA Method 8330, which was designed for soil and water. The study team identified a commercial laboratory, TestAmerica West Sacramento, which was equipped to conduct a series of method detection limit (MDL) studies and to modify the USEPA Method 8330 for tissue analysis. To ensure the applicability of the analytical method for this study, the MDL study was performed on biota types collected from O‘ahu: fish, crab, octopus, and seaweed.

- To determine whether metals and trace elements detected in samples collected from Ordnance Reef (HI-06) are attributable to land-based sources as opposed to munitions casings, all elemental concentrations were evaluated based on partitioning into their principal components (i.e., primary sources). This statistically based evaluation method is an ordination technique known as principal components analysis (PCA).
- The Health Risk Evaluation completed by USACHPPM (2007) noted that the reported arsenic levels were a source of uncertainty, because arsenic was not speciated into inorganic and organic forms. The 2009 UH OR Study included speciation of arsenic to minimize this uncertainty.
- The ATSDR health consultation (ATSDR, 2007) determined that, although fish tissue analyses of some inorganic compounds were reported as non-detect values in NOAA's 2006 survey, the laboratory detection limits were higher than the health-based comparison values used to determine adverse health effects. Low-level amounts of these compounds may have been present in fish samples collected during NOAA's 2006 survey, but not detected by the laboratory. Regardless, because these compounds were not detected in NOAA's 2006 survey (NOAA, 2007), they are not considered constituents of potential concern (COPCs).

To address community and regulatory agency concerns regarding NOAA's 2006 survey and sampling design (NOAA, 2007), the primary focus of 2009 site selection was to target the collection of biota and sediment samples in close proximity to specific DMM. The Army consulted with the U.S. Environmental Protection Agency in making decisions on prioritization of sample sites. Considering the anticipated difficulties of finding specific biota at DMM and other sites, the Wai‘anae fishermen were remarkably successful in collecting biota samples near DMM items in 2009. Biota and sediment samples were successfully collected near all of the DMM types (SAA, 20-mm rounds, 105-mm projectiles, and 6-inch and 8-inch Naval rounds). Sample sites were selected to reflect anticipated worst-case conditions (i.e., sites likely to have the highest concentrations of contaminants present) at Ordnance Reef (HI-06). The Follow-Up Investigation used the same sampling approach and techniques.

The 2009 UH OR Study involved an extensive effort to evaluate the applicability of the previously developed USEPA Method 8330 (applicable to soil and groundwater) for Hawai‘i-specific biota types, and modify them as necessary to allow reliable analysis of the munitions COPCs in these matrices. This effort was a multi-year undertaking that involved close coordination between UH, Environet, USEPA, and the commercial laboratory selected to perform the MDL study (TestAmerica). Results of the MDL study led to a modified Method 8330 that is sufficient to analyze quantitatively the majority of energetics in marine biota. UH also applied the modified method during this Follow-Up Investigation.

There were no detections of phthalates/pyrene or energetics in any of the seawater samples collected during the 2009 UH OR Study. This is unsurprising considering the rapid dilution that would be anticipated for any COPC released into seawater at Ordnance Reef (HI-06).

Two energetic compounds were detected in sediments in 2009: 2,4-DNT (dinitrotoluene) and 2,6-DNT. These are the same two compounds detected during NOAA's 2006 survey (NOAA, 2007). Concentrations detected in 2009 were much lower than those detected in 2006, and occurred in primarily the DMM stratum, although at least one detection also occurred in the WWT stratum. There was no clear and consistent correlation evident between the concentration of energetic compounds and the distance from the target DMM. Neither compound was present at concentrations exceeding project action limits. Because of the low concentrations of these two energetics detected during the 2009 UH OR Study, and because it is unlikely people will come into regular contact with sediments, energetics in sediment were not considered to pose a human health risk. Nevertheless, sediments were collected and analyzed during the Follow-Up Investigation as a conservative measure and to help identify the sources of COPCs.

Several energetic compounds were detected in biota samples collected from Ordnance Reef (HI-06) during the 2009 UH OR Study: 2,4-DNT, HMX or octogen (octahydro-1,3,5,7-tetranitro-1,3,5,7-tetrazocine), 2-NT (2-nitrotoluene), 4-NT (4-nitrotoluene), RDX, tetryl and 1,3,5-TNB (1,3,5-trinitrobenzene). Detections occurred primarily in fish samples; although one octopus and one crab also contained at least one energetic compound (values were estimated). These data were carefully considered in both the human health risk assessment (HHRA) and the ERA included in UH (2014).

On average, samples collected from the DMM stratum showed higher abundances of copper and lead than those collected from the other strata, while concentrations of arsenic were higher in sediments from the CON stratum than from other strata. Although there is community concern with respect to arsenic, this element is not abundant in conventional munitions and it was not expected that arsenic would be enriched in sediments from the DMM stratum. The finding of arsenic in sediments from the CON stratum indicates that this element is derived from land-based input through runoff. As with energetics, there was no clear and consistent correlation evident between the concentration of metals in sediment and the distance from the target DMM.

In general, metals were detected at similar levels in all biota from all strata. Notable exceptions to this finding were copper and zinc, which were considerably enriched in seaweed collected in the DMM stratum. Concentrations of arsenic in biota were remarkably similar across the various strata. Furthermore, the overwhelming majority (approximately 99%) of arsenic was present in the less toxic organic form in crab, octopus, and fish. Metals in biota were carefully considered in both the HHRA and the ERA.

PCA is an exploratory ordination technique useful for finding patterns of variance and elemental associations both within and between large and diverse data sets. There was considerable variation in concentrations of metals (COPC) detected in sediments and biota for the four strata. PCA was applied to elemental composition data to evaluate elemental associations and variations that could indicate individual sources of the metals.

The PCA sediment results demonstrated that there are three principal factors describing sediment metal variations and associations. Factor 1 (vanadium, chromium, cobalt, nickel, arsenic, barium, aluminum, iron, manganese, and titanium) represent metals which do not have considerable anthropogenic contributions and whose concentrations are likely derived from weathering terrigenous sources such as volcanic minerals, which are mainly aluminosilicate minerals, iron oxyhydroxides, and hydrous aluminum oxides. Arsenic, as one of the three metalloid or metal COPC, was grouped into this first factor and therefore arsenic occurrence was considered to be derived from terrestrial anthropogenic contributions. Comparing the four strata, the CON stratum is most strongly influenced by weathering of terrigenous sources. Factor 2 (zinc, copper, and lead) represented anthropogenic enrichments of these metals and the DMM stratum sediment composition and variability was representative of enrichment of copper, a COPC, from the deterioration and transport of military munitions (zinc and copper are present in brass). Factor 3 (calcium and strontium) represented the influence of marine biogenic sediments (e.g., sediments formed from corals). The WWT and nonpoint source (NPS) strata showed stronger variability and composition controls by marine biogenic sediments compared to the DMM and CON strata.

It is important to note that marine carbonates dominate the sediment composition for Ordnance Reef (HI-06) and thus all four strata. Therefore, carbonate sediments contribute relatively little to the variance of the compositional data set as analyzed by PCA. With this in mind, the small contribution of DMM derived material (at the DMM stratum) or terrigenous material (at the CON stratum) actually contributes to a larger variability in composition of the sediments.

Supplemental carcinogenic risk characterization estimates for the “high-end” seafood consumer in the DMM and NPS strata, using the 2009 UH OR Study data (UH, 2014), were within the regulatory risk range, while carcinogenic risks at the WWT and CON strata were below the USEPA and Hawaii Department of Health (DOH) point of departure of 1E-06. Non-carcinogenic hazards for the “high-end” seafood consumer exceeded the regulatory level of concern at the DMM and WWT strata. Under the “average” seafood consumer scenario, carcinogenic risk was 4E-06 at the DMM stratum (within the USEPA and DOH regulatory risk range but near the point of departure risk values of 1E-06). All other strata exhibited risk below the USEPA and DOH point of departure. Non-carcinogenic hazards did not exceed the regulatory level of concern at any stratum. Refer to the HHRA (UH, 2014) for a full discussion of the site risks.

In summary, the risk associated with consumption of seafood from the DMM stratum, based on the 2009 UH OR Study findings (UH, 2014), was similar to those of other strata within Ordnance Reef (HI-06) except for the “high end” consumer, with the assumption that the “high end” consumer eats seafood collected almost exclusively from the DMM stratum. This scenario is highly improbable because it assumes a level of harvest from the area that is unlikely to be sustainable, yet was chosen in order to assess the worst-case scenario for seafood consumption along the Wai‘anae coast. Even under such a consumption habit, however, it is highly likely that the benefits of consuming seafood (as opposed to a high fat content diet, for example) far outweigh the risk associated with seafood from the DMM stratum. For the average Wai‘anae community consumer, whose seafood consumption habits are greater than most Hawai‘i residents and far greater than considered typical of U.S. citizen consumption, there is no significant risk associated with consuming seafood from the DMM or other strata of Ordnance Reef (HI-06). It should be kept in mind the U.S. Food and Drug Administration (USFDA) has routinely recommended moderate seafood consumption in order to limit ingestion of mercury that is associated with certain high-end predatory fish found throughout the world’s oceans. A similar recommendation may be warranted here.

The ERA, using the 2009 UH OR Study data, indicates no risk from energetic compounds and barium detected in sediments. Potential risks to ecological receptors from exposure to lead and zinc in sediment were low and are probably negligible. Potential risk from copper in sediment was moderate and may warrant further investigation.

The potential for risk to piscivorous seabirds feeding at the DMM stratum are insignificant, although insufficient toxicity data are available to assess this pathway for four of the six energetic compounds that were detected in fish fillets (2- and 4-NT, HMX, and tetryl). The concentrations of compounds of potential ecological concern (COPECs) in fish samples from the

2009 UH OR Study did not exceed critical tissue level (CTLs) for fish when such values were available; however, tissue-based screening levels were only available for three of the ten COPECs detected in the fish samples (4-NT, RDX, and lead). No tissue-based screening levels were found for the COPECs detected in the other biota specific to those taxa.

HMX and five other energetics were observed in the fall of 2009 at detectable levels in fish muscle tissue but they were not detected in the spring 2009 samples. The source or exposure pathway for these energetics is not known, but it does not appear to be related to water or sediment concentrations or from the food chain. A significant area of uncertainty in the ERA is whether those increases in energetic in tissue pose a risk to the fish of the reef community. Observations of the reef community made during the 2006 investigation did not indicate signs of significant adverse effects and much of the DMM of Ordnance Reef (HI-06) was in the process of being encrusted by corals.

1.3.1.2 Study Area Description

This Follow-Up Investigation focused on the area previously studied by the USACE in 2002, and by NOAA and UH in 2006 (NOAA, 2007), and UH in 2009 (UH, 2014). Because the 2009 UH OR Study focused on assessing potential threats to human health, the depth range of the study area was defined as extending from 0 to 120 feet (36 m), as this is the depth range that most area users would frequent. Based on previous investigations, this study area includes munitions objects and areas where previous investigations found elevated concentrations of metals and energetics. As in 2009, the study area for the Follow-Up Investigation was divided into four strata: areas containing disposed military munitions (DMM), areas under the influence of nonpoint sources (NPS), areas under the possible influence of the wastewater treatment plant outfall (WWT), and control sites (CON). Discrete study sites were chosen from these strata. The sample sites in the DMM strata were adjacent to where DMM were recovered during the ROUMRS technology demonstration.

1.3.2 Physical Characteristics of the Site

The following section describes the physical characteristics of Ordnance Reef (HI-06) area and the adjacent lands of the Waiʻanae moku (district) on the island of Oʻahu.

1.3.2.1 Climate

Northeasterly trade winds prevail over Oʻahu approximately 80% of the time, with average wind speeds ranging from 10 to 15 mi per hour (16 to 24 km per hour). The trade winds blow most strongly and consistently from April through November. Southerly or "Kona" winds most frequently occur during the months of December through March. The northeasterly trade winds carry a large quantity of moisture from the Pacific Ocean to the island. Orographic lifting as the trade winds encounter the Koʻolau mountain range causes the air temperature to decrease and moisture to precipitate. The windward side of the island generally experiences more rainfall than the leeward side. Nevertheless, during Kona wind conditions, the relative humidity tends to rise, and the southern side of the island may experience periods of intense rainfall. Due to the impact of the rain shadow on storms driven by the trade winds, Waiʻanae is one of the driest areas on the island. The average annual rainfall in Waiʻanae is 22 in (55 centimeters [cm]), less than half of the average for Oʻahu as a whole (NOAA, 2006).

Temperatures at the surface of the study area are generally mild and fluctuate very little throughout the year. The mean annual temperature is approximately 77 degrees Fahrenheit (°F)

(25 degrees Celsius [°C]); temperature extremes range from 54 to 95°F (12 to 35°C). The mean daily temperature during the winter is 74°F (23°C), while the mean daily temperature in the hottest summer month (August) is 80°F (27°C) (Western Regional Climate Center, 2004).

1.3.2.2 Geology and Geomorphology

Like all regions of the Hawaiian Islands, the geology and geomorphology of Wai'anae are based on its individual volcanic origins and history. The island of O'ahu was formed by two volcanoes, the Wai'anae and Ko'olau, beginning approximately four million years ago (Stearns and Vaksvik, 1935; Macdonald et al., 1983). Soils in the Wai'anae moku (district) are a result of its volcanic history, as well as recent erosion processes. Volcanic eruption deposited lava flows and pyroclastics that built the main mass of the Wai'anae volcano, which has since gradually eroded to its current physical characteristics.

The Wai'anae mountain range is approximately 22 mi (35 km) long, with narrow ridges and steep slopes as the predominant features. Most of these features were formed through erosion before the Ko'olau mountain range rose high enough to intercept the prevailing trade winds and rainfall. The maximum rainfall at Mount Ka'ala, the highest point in the Wai'anae range and on O'ahu at 4,025 ft (1,227 m), is approximately 100 in (254 cm) per year.

The Wai'anae mountain range has been significantly eroded by the rain, sea waves, and landslides, resulting in amphitheater valleys including Lualualei and Mākua to the west. The striking features of the range are the great flat-floored valleys that slope up to the steep pali (cliffs) that join the back of the valleys.

Volcanic rocks of the Hawaiian Islands are basaltic in composition and have a trace element composition that differs widely from those encountered in continental settings (e.g., granite or limestone). Consequently, the occurrence of high concentrations of certain elements, most notably, chromium, cobalt, copper, nickel and, to a lesser extent, zinc, in marine sediments predominantly composed of calcium carbonate is not necessarily a result of environmental contamination but may simply reflect the presence of detrital volcanic matter carried into the ocean by stream or overland runoff (De Carlo et al., 2004, 2005).

1.3.2.3 Soils

Current surface soils in Wai'anae exist as a result of millions of years of erosional processes, including rain, stream action, waves, and landslides. Surface soils in the Wai'anae moku can generally be grouped into three predominant associations (U.S. Department of Agriculture, 1971):

- Lualualei Series, Fill Land, and 'Ewa Series Association
- Tropohumults-Dystrandepts Association
- Rock Land and Stony Steep Land Association

Other soil types and associations exist within Wai'anae, including the Kemo'o, Mahana, Mokulē'ia, and Pūlehu series. In addition, rock outcrops are present at various locations throughout the moku (NOAA, 2006).

1.3.2.4 Coastal Waters

All Hawaiʻi State marine waters are classified as Class A or Class AA (DOH, 2004). Class A waters have strict pollution discharge regulations to protect them for recreational and aesthetic enjoyment. Class AA waters have regulations against discharge to maintain the waters in a natural pristine state. The Waiʻanae coast is designated Class A waters from Barbers Point at the southern end to Mākua Beach near the northern end. The waters from Mākua Beach to Kaʻena Point are designated Class AA.

Water quality studies along the Waiʻanae coast describe a "pristine, unperturbed coastal region." Temperature and salinity values indicate that the region is well flushed and minimally affected by surface runoff of terrestrial sediments (Bienfang and Brock, 1980; Koch et al., 2004, Natural Resources Defense Council [NRDC] 2004). Although these studies described excellent water quality, two concerns regarding pollution have been cited. First, the water quality appears more compromised in the southernmost part of the coast. This appears to be related to runoff associated with development at Barbers Point and even pollution from Pearl and Honolulu Harbors during strong storm events (Bienfang and Brock, 1980). These more turbid waters have been seen moving northward along the coast during falling tide conditions. Second, there is some indication that groundwater percolation may be occurring along the shoreline. Groundwater in Waiʻanae has approximately 1,000-fold more dissolved nitrate than does the adjacent marine waters due to leaching from fertilization of agricultural lands. This problem has led to significant algal blooms in other coastal waters around Hawaiʻi, although no intense or persistent algal blooms have been documented in Waiʻanae. Another potential source of water enriched in nutrients is the Waiʻanae WTTP.

Coastal Water Quality

Land-based sources of materials, such as sediment, nutrients, and other contaminants, are one of several factors threatening water quality and coral reef ecosystems in Hawaiʻi. These pollutants are transported in surface water runoff and by groundwater seepage into coastal waters. While the complex interrelationship between land-based sources of pollution, water quality, and the health and integrity of coral reef ecosystems is not well understood, enough is known to require management policies that minimize polluted surface water runoff.

Nutrients

Nutrients are taken up by marine plants, phytoplankton, and marine algae for primary production. Nutrients commonly measured in seawater include silica and inorganic and organic forms of nitrogen (nitrate and nitrite, and dissolved organic nitrogen) and phosphorus (phosphate, dissolved organic phosphorus). Nutrient concentrations in seawater off the Waiʻanae coast are likely to vary with the time of year and location as observed in other coastal waters of Hawaiʻi (Ringuet and Mackenzie, 2005; De Carlo et al., 2007).

Land-based sources of nutrients from streams and surface water runoff cause localized increases in nutrient concentrations in coastal waters. The uptake of nutrients by marine plants and decomposition of marine life in the sea also contribute to variation in nutrient concentrations found in the water column. In general, open ocean surface waters near the Hawaiian Islands are oligotrophic (i.e., nutrient poor); this is particularly true off dry leeward sides of the islands such as Waiʻanae, where nutrient concentrations are extremely low. Primary production is generally considered to be limited by the availability of nitrogen and micronutrients such as iron (Ringuet and Mackenzie, 2005).

Waiʻanae Wastewater Treatment Plant

The C&C of Honolulu's conservation district use permit for installation of the WWTP outfall pipe at Waiʻanae, Oʻahu, Hawaiʻi, was approved in November 1983. The Waiʻanae WWTP outfall pipeline was installed in 1986 and extends 1.1 mi (1.8 km) offshore into 108 ft (33 m) of water. In 1996, the WWTP converted from a primary to a secondary WWTP, which discharges 3.4 million gallons (12.9 million liters) per day of mainly domestic wastewater through the outfall offshore. The diffuser is 530 ft (161.8 m) long and discharges approximately 1.5 ft (0.5 m) above the seafloor through vertical risers. The long-term monitoring program at the diffuser reported an immediate drop in levels of suspended particles and nutrients from its wastewater from 1995 through 2000, in accordance with the terms of its National Pollutant Discharge Elimination System (NPDES) permits (C&C of Honolulu, 2001).

Stream Flow

The majority of Waiʻanae's perennial streams flow consistently only in the upper elevations. The absence of perennial streams in the lower elevations is a reflection of the Waiʻanae region's arid climate and alluvial soils. Because of the general sandy qualities of these soils, surface water percolates down into them, creating "underflow" that either flows through the subsurface to the ocean, or enters the water table.

Streams in Hawaiʻi react quickly to storms, often reaching their maximum flow rates in less than one hour (e.g., Tomlinson and De Carlo, 2003). These high stream flows can transport large amounts of sediment, nutrients, trash, and other debris to the ocean and have a severe impact on coastal areas. Corals and intertidal fish nurseries are prone to injury from sedimentation, particularly in the presence of chemical contaminants.

Many of the streams of the Waiʻanae moku have been channelized through the urban areas. This causes water to reach the ocean much more quickly, potentially increasing levels of trash, nutrients and other pollutants entering the coastal water. In spite of this, only one stream, Kaupuni Stream, was on the 2004 list of impaired waters in Hawaiʻi (Koch et al., 2004). Of the 70 streams in the report, Kaupuni Stream is considered a medium priority listing with nutrients, turbidity and trash as the primary pollutants.

Currents and Tides

Hawaiʻi's semi-diurnal tidal cycle is characterized by two high waters and two low waters of each tidal day. Along the Waiʻanae coast, this tidal regime results in changing current patterns. During normal trade wind conditions on a rising or flood tide, current flow is from the northwest toward the southeast, parallel to the coastline, with a velocity of about 1 knot (0.5 meters per second (m/s)) (Bienfang and Brock 1980). This current reverses during falling or ebb tide conditions, flowing from the southeast to northwest at somewhat higher velocities, about 1.5 knots (0.8 m/s).

The mass of the Hawaiian Islands interacts with large-scale trade-wind conditions and ocean currents. This interaction causes winds and currents to slow and create calmer areas on the leeward sides of each island, known as Hawaiʻi's wake. Water movement along the Waiʻanae coast is influenced by these regional oceanographic phenomena, which create eddies, or swirls of water, where marine larvae and fish tend to concentrate. The existence of a warm-water countercurrent flowing from Asia toward the Hawaiian Islands has been attributed to Hawaiʻi's wake, resulting from the interaction between the islands and regional current and trade-wind conditions.

NOAA and UH deployed acoustic Doppler current profilers (ADCPs) for a year in the vicinity of Ordnance Reef (HI-06) to better characterize ocean circulation in the area. The data collected by the ADCPs indicates that the primary circulation along the west coast of O'ahu is along-shore because of the dominance of the semi-diurnal and diurnal tides (NOAA, 2012). Particles in this system are moved north and south along the coast, with weak on- and off-shore motion as the tides change from ebb to flood. During periods of mesoscale activity, current flow is primarily along-shore (clockwise-flowing eddies impinging on the shore will push particles along-shore towards the south). This summary matches the general understanding of currents and tides previously accepted to hold true in the vicinity of Ordnance Reef (HI-06).

Water Column Profile

The water column profile for the area off Kahe Point was studied extensively in the 1980s as part of the proposed, but never built 40-megawatt Ocean Thermal-Energy Conversion plant. Although Kahe Point is just outside the southern extent of the Wai'anae moku, information and data collected at Kahe Point can be considered relevant to the Wai'anae coast.

The mixed layer of the ocean off the Wai'anae coast extends from the surface to depths of about 98 to 197 ft (30 to 60 m). In the mixed layer, temperature is nearly uniform with depth. Below the mixed layer is the thermocline, the layer in which seawater temperature decreases rapidly with depth. In the thermocline, seawater temperature decreases from about 75°F (24°C) at a depth of 197 ft (60 m) to 59°F (15°C) at over 656 ft (200 m). Below this depth, temperature decreases gradually. At 2,953 ft (900 m) depth, seawater temperature off Kahe Point is about 39 F (4°C).

Surface water salinity off Kahe Point is about 34.8 parts per thousand (ppt), typical of the Pacific central water mass. This low-salinity warm surface layer grades into the underlying Pacific intermediate water mass, which is characterized by a maximum salinity of 35.1 ppt at 591 ft (180 m) and minimum of 34.2 ppt at 1,509 ft (460 m). At 2,953 ft (900 m) depth, seawater salinity off Kahe Point is about 34.4 ppt.

1.3.2.5 Marine Ecosystems

Wai'anae's coastal and marine ecosystems are characterized by rocky intertidal zones, coral reefs, and offshore pelagic and deep-sea marine environments. Intertidal zones provide rocky habitat to marine invertebrates and plants that are specifically adapted to constantly changing levels of exposure to waves and seawater. Coral reefs are found on the more protected leeward exposure of the Wai'anae coast but are subject to infrequent but severe Kona storms. Offshore pelagic and deep sea ecosystems off the Wai'anae coast are vast and support large marine animals like dolphins, whales, sea turtles, and the occasional endangered Hawaiian monk seal. Threats to coastal and marine ecosystems along the Wai'anae coast include land-based and sea-based human activities, natural disturbances from storms, and large-scale global climate change phenomena such as sea level rise and increased sea surface temperature.

Most reefs on the inhabited islands of Hawai'i are known as fringing reefs, growing near the shoreline. Fringing reefs are the first type of reef to form around young volcanic islands, such as Hawai'i, Maui, O'ahu, and Kaua'i. These reefs form in areas of low rainfall runoff, primarily along the leeward shores such as the Wai'anae coast of O'ahu. Typical reef zonation consists of:

- Reef flat zone (0 to 7 ft [0 to 2 m]),

- Reef bench zone (7 to 33 ft [2 to 10 m]),
- Reef slope zone (33 to 98 ft [10 to 30 m]), and
- Rubble zone (98 to 131 ft [30 to 40 m]) (AECOS, Inc., 2002).

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Section 2
Investigation Methods and Procedures

UH designed the sampling program for the Follow-Up Investigation to meet the stated objective described in Section 1.1, i.e., evaluate whether the recovery of DMM from Ordnance Reef (HI-06) during the Army’s ROUMRS technology demonstration had any impact on the concentrations of MC present in the environment. In order to meet this objective, the sampling program matched, to the extent possible, the sampling and analytical methods used previously. This program is described in more detail below.

2.1 Stratified Sampling Approach

During the Follow-Up Investigation, sediment and biota samples were collected from four different strata (Figure 2-1):

- WWT stratum: adjacent to the municipal sewage outfall of the WWTP;
- NPS stratum: nearshore coastal nonpoint source (NPS) discharge area near Mā‘ili‘ili Stream Channel;
- DMM stratum: natural reef area where ROUMRS recovered munitions; and
- CON stratum: natural reef area, without DMM, near Maunalahilahi.

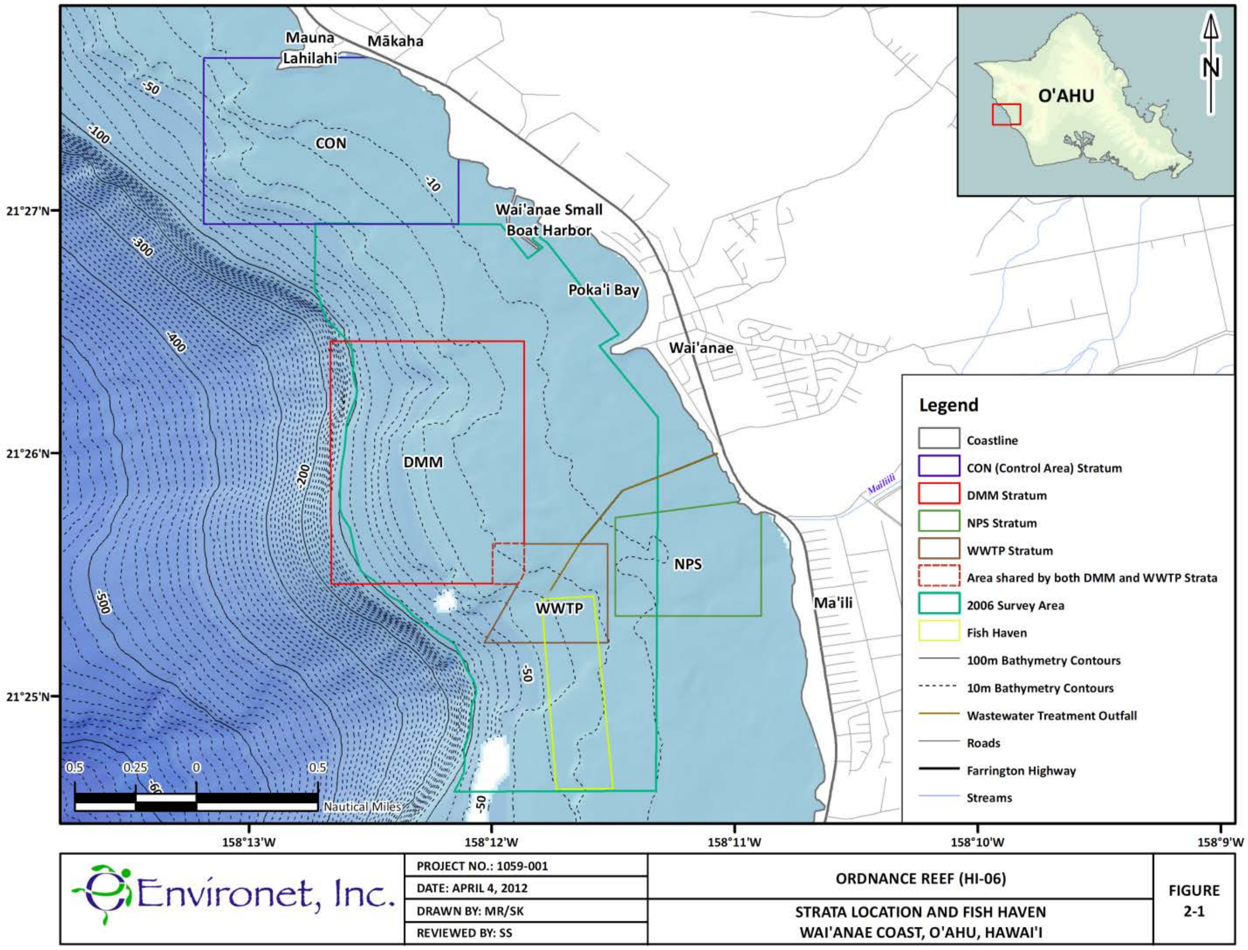
Within the WWT, NPS and CON strata, sample sites were randomly selected. A sufficient number of samples was collected to meet the data quality objectives (DQOs) set out in the Quality Assurance Project Plan (QAPP). The sample site selection process is described in more detail in Section 2.1.1 below. The location of each sample was documented using a GPS receiver with meter to sub-meter accuracy and illustrated in the field notes/drawings and geographic information system (GIS) product.

<u>Sample Site Selection</u>

Given the primary objective of the Follow-Up Investigation, considerable emphasis was placed on collecting DMM samples from locations where DMM were recovered during the ROUMRS technology demonstration. The sampling locations for the other strata were selected randomly but within the constraints of their respective definitions, i.e., CON samples were collected from an area removed from terrestrial and anthropogenic influence, WWT samples were collected in the vicinity of the WWTP outfall, and NPS samples were collected near the mouths of streams the empty into the coastal waters.

Strata were chosen in such a way as to compare munitions areas affected by the ROUMRS demonstration and other strata devoid of both DMM and ROUMRS operations.

Figure 2-1: Location and boundaries of the four sampling strata (CON, DMM, NPS, and WWT) and the State of Hawai‘i-designated fish haven (pale green boundary line)



UH used fishermen from the community, who are very familiar with the area, to conduct the biota sampling effort. If the targeted biota was found in close proximity to the targeted site, the fisherman collected sediment (see Section 2.2 for additional details), and returned to the surface to transfer the sediment and/or biota samples to the study’s field team. At this point, the Follow-Up Investigation field team took a GPS reading, queried the fishermen to describe the location at which the fishermen collected samples, and recorded relevant details on field sampling or note sheets (Appendix B – Field Collection Sheets).

The field team documented the location of each sample site within approximately a 30-ft (10-m) accuracy using a diver placed float and handheld GPS. GPS readings are actually rough estimates of the actual sampling location. This is true because of inherent GPS errors and the fact that, given currents, divers (the fishermen) were not able to maintain a position directly over a sample site as they surfaced. Nevertheless, the approximate recording of sample site location allowed the sampling results to be correlated with the results from previous studies and will facilitate future sampling, if necessary. Table 2-1 lists the samples collected during the August 2011, July 2012, and June 2013 sampling events and provides information such as collection site, date, time, depth, and coordinates.

Table 2-1: Post-ROUMRS (FUI1, FUI2, and FUI3) sample list with sample IDs, sampling times, water depth, locations, and analytes.

TestAmerica Lab ID	UH Lab ID*	Site Name[1]	Field ID	Distance	Collection Date	Collection Time	Depth[2] (m)	Latitude (N)	Longitude (W)	Sample Analyzed?	Analytes	Primary (P)/ Duplicate (D)/MS/MSD	Sample Description	Sample Length (cm)	Sample Width (cm)	Sample Weight[3] (g)	Comments
SEDIMENT 2011																	
ORD201S (composite of three samples)	**DMM-31r1**	DMM31	DMM31	Series of samples amongst multiple rounds of small rounds, no distance function	8/6/2011	1015	21.4	21° 25.720′	158° 12.088′	Yes	Energetics; Metals	P	Medium to coarse-grained sand with minor amounts of anoxic mud	--	--	/	Small arms site, ARA Item 81 location, many 20-mm remain on location, sandy bottom.
ORD202S (composite of three samples)	**DMM-31r2**		DMM32							Yes	Energetics; Metals	Duplicate of ORD201S		--	--	/	Series of samples amongst multiple rounds of small rounds, no distance function
			DMM33											--	--	/	--
ORD203S (composite of three samples)	**DMM-34**	DMM34	DMM34	Series of samples amongst multiple rounds of small rounds, no distance function	8/6/2011	1045	17.0	21° 25.718′	158° 12.087′	Yes	Energetics; Metals	P	Some fine, but mostly medium to coarse grained sand. DMM34 and 36 have mixed anoxic mud (minor amounts) DMM 35 has NO anoxic mud.	--	--	/	Small arms site, ARA Item 97 location, 50 caliber DMM remain on location.
			DMM35											--	--	/	Series of samples amongst multiple rounds, no distance function

Table 2-1: Post-ROUMRS (FUI1, FUI2, and FUI3) sample list with sample IDs, sampling times, water depth, locations, and analytes.

TestAmerica Lab ID	UH Lab ID*	Site Name[1]	Field ID	Distance	Collection Date	Collection Time	Depth[2] (m)	Latitude (N)	Longitude (W)	Sample Analyzed?	Analytes	Primary (P)/ Duplicate (D)/MS/MSD	Sample Description	Sample Length (cm)	Sample Width (cm)	Sample Weight[3] (g)	Comments
			DMM36											--	--	/	--
ORD204S	**DMM-37A**	DMM37	DMM37	0 ft	8/6/2011	1130	*21.3* (70 ft)	21° 25.698´	158° 12.089´	Yes	Energetics; Metals	P	Medium to coarse-grained sand, no anoxic mud	--	--	/	5" by 20" projectile site, ARA Item 93 location.
ORD205S	**DMM-37B**		DMM38	3 ft						Yes	Energetics; Metals	P		--	--	/	Series 3ft away from DMM 37
ORD206S	**DMM-37C**		DMM39	6 ft						Yes	Energetics; Metals	P		--	--	/	Series 6ft away from DMM 37
ORD207S	**DMM-40A**	DMM40	DMM40	0 ft	8/6/2011	1150	*21.3* (70 ft)	21° 25.614´	158° 12.018´	Yes	Energetics; Metals	P	DMM40 medium to coarse grained sand with some anoxic mud	--	--	/	5" by 18" projectile site, ARA Item 126 location, Sandy bottom.
ORD208S	**DMM-40B**		DMM41	3 ft						Yes	Energetics; Metals	P	DMM41 medium to coarse grained sand with some anoxic mud	--	--	/	Series 3ft away from DMM40
ORD209S	**DMM-40C**		DMM42	6 ft						Yes	Energetics; Metals	P	DMM 42 fine to medium grained sand with lots of shells	--	--	/	Series 6ft away from DMM40
ORD210S (composite of three samples)	**DMM-43**	DMM43	DMM43	Series of samples randomly selected, no distance function	8/6/2011	1215	*21.3* (70 ft)	21° 25.823´	158° 12.170´	Yes	Energetics; Metals	P	DMM43 fine-medium grained sand with no anoxic sediment	--	--	/	Small arms site, ARA Item 154 location, Sandy bottom.

Table 2-1: Post-ROUMRS (FUI1, FUI2, and FUI3) sample list with sample IDs, sampling times, water depth, locations, and analytes.

TestAmerica Lab ID	UH Lab ID*	Site Name[1]	Field ID	Distance	Collection Date	Collection Time	Depth[2] (m)	Latitude (N)	Longitude (W)	Sample Analyzed?	Analytes	Primary (P)/ Duplicate (D)/MS/MSD	Sample Description	Sample Length (cm)	Sample Width (cm)	Sample Weight[3] (g)	Comments
			DMM44										DMM44 has lots of anoxic sediment with medium grained sand	--	--	/	Series of samples randomly selected, no distance function
			DMM45										DMM45 are fine-medium grained sand with no anoxic sediment	--	--	/	--
ORD211S	**DMM-46A**	DMM46	DMM46	0 ft	8/6/2011	1245	*41.1* (135 ft)	21° 25.846′	158° 12.369′	Yes	Energetics; Metals	P	Lots of anoxic mud mixed with a little fine to medium grained sand	--	--	/	12" by 16" projectile, ARA Item 160 location, sandy bottom.
ORD212S	**DMM-46B**		DMM47	3 ft						Yes	Energetics; Metals	P	/	--	--	/	Series, 3ft away from DMM46
ORD213S	**DMM-46C**		DMM48	6 ft						Yes	Energetics; Metals	P	/	--	--	/	Series, 6ft away from DMM46
ORD214S	**DMM-49A**	DMM49	DMM49	0 ft	8/6/2011	1310	*23.2* (76 ft)	21° 25.711′	158° 12.065′	Yes	Energetics; Metals	P	Medium to coarse grained sand with munition fragments	--	--	/	5" by 7" projectile, ARA Item 156 location. Possibly a bomb fuze?
ORD215S	**DMM-49B**		DMM50	3 ft						Yes	Energetics; Metals	P	/	--	--	/	Series, 3ft away from DMM49
ORD216S	**DMM-49C**		DMM51	6 ft						Yes	Energetics; Metals	P	/	--	--	/	Series, 6ft away from DMM49

Table 2-1: Post-ROUMRS (FUI1, FUI2, and FUI3) sample list with sample IDs, sampling times, water depth, locations, and analytes.

TestAmerica Lab ID	UH Lab ID*	Site Name[1]	Field ID	Distance	Collection Date	Collection Time	Depth[2] (m)	Latitude (N)	Longitude (W)	Sample Analyzed?	Analytes	Primary (P)/ Duplicate (D)/MS/MSD	Sample Description	Sample Length (cm)	Sample Width (cm)	Sample Weight[3] (g)	Comments
ORD217S	**WWT-31r1**	WWT31	WWT31	--	8/6/2011	1325	*29.7* (92ft)	21° 25.421´	158° 11.821´	Yes	Energetics; Metals	P	Lots of anoxic mud with fine grained sediment	--	--	/	--
ORD218S	**WWT-31r2**									Yes	Energetics; Metals	Duplicate of ORD217S	Lots of anoxic mud with fine grained sediment	--	--	/	--
ORD219S	**WWT-32**	WWT32	WWT32	Track shoreward from WWT-31, approx 100m, used buoy dip to mark location… same for next two samples, each of which is another approx 100 m shoreward from the previous.	8/6/2011	1335	26.9	21° 25.447´	158° 11.779´	Yes	Energetics; Metals	P	Coarse grained sand with abundant anoxic mud	--	--	/	Track shoreward from WWT-31, approx 100m, used buoy dip to mark location… same for next two samples, each of which is another approx 100 m shoreward from the previous.
ORD220S	**WWT-33**	WWT33	WWT33	Track shoreward, approx 100 m from WWT-32	8/6/2011	1341	22.9	21° 25.486´	158° 11.745´	Yes	Energetics; Metals	P	lots of anoxic mud with fine grained sand	--	--	/	Track shoreward, approx 100 m from WWT-32,
ORD221S	**WWT-34**	WWT34	WWT34	Track shoreward, approx 100 m from WWT-33	8/6/2011	1346	19.5	21° 25.510´	158° 11.711´	Yes	Energetics; Metals	P	lots of anoxic mud with fine grained sand	--	--	/	Track shoreward, approx 100 m from WWT-33,

Table 2-1: Post-ROUMRS (FUI1, FUI2, and FUI3) sample list with sample IDs, sampling times, water depth, locations, and analytes.

TestAmerica Lab ID	UH Lab ID*	Site Name[1]	Field ID	Distance	Collection Date	Collection Time	Depth[2] (m)	Latitude (N)	Longitude (W)	Sample Analyzed?	Analytes	Primary (P)/ Duplicate (D)/MS/MSD	Sample Description	Sample Length (cm)	Sample Width (cm)	Sample Weight[3] (g)	Comments
ORD222S	**CON-42**	CON42	CON42	--	8/6/2011	1420	27.5	21° 27.187′	158° 12.970′	Yes	Energetics; Metals	P	/	--	--	/	near old CON-1 site from OR
ORD223S	**CON-43r1**	CON43	CON43	--	8/6/2011	1435	14.0	*21° 27.543′* (21.45905)[4]	*158° 13.076′* (158.21793)[4]	Yes	Energetics; Metals	P	/	--	--	/	near old Con 3 site
ORD224S	**CON-43r2**									Yes	Energetics; Metals	Duplicate of ORD223S	/	--	--	/	field duplicate
ORD225S	**CON-44**	CON44	CON44	--	8/6/2011	1440	8.0	*21° 27.587′* (21.45978)[4]	*158° 13.055′* (158.21758)[4]	Yes	Energetics; Metals	P	/	--	--	/	--
ORD226S	**CON-45**	CON45	CON45	--	8/6/2011	1445	8.2	*21° 27.422′* (21.45703)[4]	*158° 12.892′* (158.21487)[4]	Yes	Energetics; Metals	P	/	--	--	/	--
ORD227S	**NPS-40**	NPS40	NPS40	--	8/7/2011	1016	7.9	*21° 25.465′* (21.42442)[4]	*158° 11.050′* (158.18417)[4]	Yes	Energetics; Metals	P	/	--	--	/	Revisit of approximate Site NPS 34 location (see above)
ORD228S	**NPS-41**	NPS41	NPS41	--	8/7/2011	1030	5.7	*21° 25.511′* (21.42518)[4]	*158° 11.126′* (158.18544)[4]	Yes	Energetics; Metals	P	/	--	--	/	--
ORD229S	**NPS-42**	NPS42	NPS42	--	8/7/2011	1035	6.1	*21° 25.581′* (21.42635)[4]	*158° 11.141′* (158.18568)[4]	Yes	Energetics; Metals	P	/	--	--	/	--
ORD230S	**NPS-43r1**	NPS43	NPS43	--	8/7/2011	1044	5.6	*21° 25.703′* (21.42839)[4]	*158° 11.005′* (158.18341)[4]	Yes	Energetics; Metals	P	/	--	--	/	--
ORD231S	**NPS-43r2**		NPS44	--	8/7/2011	1044	5.6	*21° 25.703′* (21.42839)[4]	*158° 11.005′* (158.18341)[4]	Yes	Energetics; Metals	Duplicate of ORD230S	/	--	--	/	Field duplicate of NPS 43 but given a different field ID

Table 2-1: Post-ROUMRS (FUI1, FUI2, and FUI3) sample list with sample IDs, sampling times, water depth, locations, and analytes.

TestAmerica Lab ID	UH Lab ID*	Site Name[1]	Field ID	Distance	Collection Date	Collection Time	Depth[2] (m)	Latitude (N)	Longitude (W)	Sample Analyzed?	Analytes	Primary (P)/ Duplicate (D)/MS/MSD	Sample Description	Sample Length (cm)	Sample Width (cm)	Sample Weight[3] (g)	Comments
ORD232S	**NPS-45**	NPS45	NPS45	--	8/7/2011	1049	5.0	*21° 25.734′* (21.4289)[4]	*158° 10.982′* (158.18304)[4]	Yes	Energetics; Metals	P	/	--	--	/	--
SEDIMENT 2012																	
ORD319S; ORD319S-2	**DMM-52Ar1**	DMM52	DMM52	0 ft	7/16/2012	0930	21.4	21° 25.720′	158° 12.088′	Yes	Energetics; Metals	P	medium to coarse grain sand, minimal mud, minimal volcanic clasts	--	--	/	0 ft; collected by C. Jellings diver; ARA 81 site
ORD322S; ORD322S-2	**DMM-52Ar2**									Yes	Energetics; Metals	Duplicate of ORD319S		--	--	/	0 ft; collected by C. Jellings diver; ARA 81 site
ORD320S; ORD320S-2	**DMM-52B**		DMM53	3 ft						Yes	Energetics; Metals	P		--	--	/	3 ft; collected by C. Jellings diver; ARA 81 site
ORD321S	**DMM-52C**		DMM54	6 ft						Yes	Energetics; Metals	P		--	--	/	6 ft; collected by C. Jellings diver; ARA 81 site
ORD323S	**DMM-55A**	DMM55	DMM55	0 ft	7/16/2012	1100	17.0	21° 25.718′	158° 12.087′	Yes	Energetics; Metals	P	medium to coarse grain sand, minor volcanic clasts, 50 cal and other small arm clasts (e.g., 22mm)	--	--	/	0 ft; collected by C. Jellings diver; ARA 97 site
ORD324S	**DMM-55B**		DMM56	3 ft						Yes	Energetics; Metals	P		--	--	/	3 ft; collected by C. Jellings diver; ARA 97 site
ORD325S	**DMM-55C**		DMM57	6 ft						Yes	Energetics; Metals	P		--	--	/	6 ft; collected by C. Jellings diver; ARA 97 site

Table 2-1: Post-ROUMRS (FUI1, FUI2, and FUI3) sample list with sample IDs, sampling times, water depth, locations, and analytes.

TestAmerica Lab ID	UH Lab ID*	Site Name[1]	Field ID	Distance	Collection Date	Collection Time	Depth[2] (m)	Latitude (N)	Longitude (W)	Sample Analyzed?	Analytes	Primary (P)/ Duplicate (D)/MS/MSD	Sample Description	Sample Length (cm)	Sample Width (cm)	Sample Weight[3] (g)	Comments
ORD326S	**DMM-58A**	DMM58	DMM58	0 ft	7/16/2012	1140	22.3	21° 25.698′	158° 12.089′	Yes	Energetics; Metals	P	medium grain sand, no apparent volcanic clasts	--	--	/	0 ft; collected by C. Jellings diver; ARA 93 site
ORD327S	**DMM-58B**		DMM59	3 ft						Yes	Energetics; Metals	P		--	--	/	3 ft; collected by C. Jellings diver; ARA 93 site
ORD328S	**DMM-58Cr1**		DMM60	6 ft						Yes	Energetics; Metals	P		--	--	/	6 ft; collected by C. Jellings diver; ARA 93 site
ORD329S	**DMM-58Cr2**									Yes	Energetics; Metals	Duplicate of ORD328S		--	--	/	6 ft; collected by C. Jellings diver; ARA 93 site
ORD330S	**DMM-61A**	DMM61	DMM61	0 ft	7/16/2012	1230	22.4	21° 25.614′	158° 12.018′	Yes	Energetics; Metals	P	(1) 50 cal, propellant grain	--	--	/	0 ft; collected by C. Jellings diver; ARA 126 site
ORD331S	**DMM-61B**		DMM62	3 ft						Yes	Energetics; Metals	P	fine to coarse grain with large coral debris	--	--	/	3 ft; collected by C. Jellings diver; ARA 126 site
ORD332S	**DMM-61C**		DMM63	6 ft						Yes	Energetics; Metals	P	coarse to fine sand, anoxic mud, some volcanic clasts	--	--	/	6 ft; collected by C. Jellings diver; ARA 126 site
ORD333S	**DMM-64A**	DMM64	DMM64	0 ft	7/16/2012	1300	24.1	21° 25.823′	158° 12.170′	Yes	Energetics; Metals	P	fine to medium grain sand	--	--	/	0 ft; collected by C. Jellings diver; ARA 154 site

Table 2-1: Post-ROUMRS (FUI1, FUI2, and FUI3) sample list with sample IDs, sampling times, water depth, locations, and analytes.

TestAmerica Lab ID	UH Lab ID*	Site Name[1]	Field ID	Distance	Collection Date	Collection Time	Depth[2] (m)	Latitude (N)	Longitude (W)	Sample Analyzed?	Analytes	Primary (P)/ Duplicate (D)/MS/MSD	Sample Description	Sample Length (cm)	Sample Width (cm)	Sample Weight[3] (g)	Comments
ORD334S MS/MSD	**DMM-64B**		DMM65	3 ft						Yes	Energetics; Metals	P, MS/MSD	fine to coarse grain sand with coral/shell fragments	--	--	/	3 ft; collected by C. Jellings diver; ARA 154 site
ORD335S	**DMM-64C**		DMM66	6 ft						Yes	Energetics; Metals	P	fine to coarse grain sand with no fragments	--	--	/	6 ft; collected by C. Jellings diver; ARA 154 site
ORD336S	**DMM-67A**	DMM67	DMM67	0 ft	7/16/2012	1335	22.1	21° 25.711′	158° 12.065′	Yes	Energetics; Metals	P	fine to coarse grain sand, little anoxic mud	--	--	/	0 ft; collected by C. Jellings diver; ARA 156 site
ORD337S	**DMM-67B**	DMM67	DMM68	3 ft	7/16/2012	1335	22.1	21° 25.711′	158° 12.065′	Yes	Energetics; Metals	P	fine to coarse sand, minor anoxic mud	--	--	/	3 ft; collected by C. Jellings diver; ARA 156 site
ORD338S	**DMM-67C**	DMM67	DMM69	6 ft	7/16/2012	1335	22.1	21° 25.711′	158° 12.065′	Yes	Energetics; Metals	P	fine to coarse sand with lots of coral and rubble	--	--	/	6 ft; collected by C. Jellings diver; ARA 156 site
ORD339S	**DMM-70A**	DMM70	DMM70	0 ft	7/17/2012	0930	43.0	21° 25.846′	158° 12.369′	Yes	Energetics; Metals	P	fine to coarse grain sand with some anoxic mud and coral/shell fragments	--	--	/	0 ft; collected by C. Jellings diver; ARA 160 site
ORD301S; ORD301S-2	**DMM-70B**	DMM70	DMM71	3 ft	7/17/2012	0930	43.0	21° 25.846′	158° 12.369′	Yes	Energetics; Metals	P	fine to coarse grain sand with some anoxic mud and coral/shell fragments	--	--	/	3 ft; collected by C. Jellings diver; ARA 160 site
ORD340S	**DMM-70C**	DMM70	DMM72	6 ft	7/17/2012	0930	43.0	21° 25.846′	158° 12.369′	Yes	Energetics; Metals	P	fine to coarse grain sand with some anoxic mud and coral/shell fragments	--	--	/	6 ft; collected by C. Jellings diver; ARA 160 site

Table 2-1: Post-ROUMRS (FUI1, FUI2, and FUI3) sample list with sample IDs, sampling times, water depth, locations, and analytes.

TestAmerica Lab ID	UH Lab ID*	Site Name[1]	Field ID	Distance	Collection Date	Collection Time	Depth[2] (m)	Latitude (N)	Longitude (W)	Sample Analyzed?	Analytes	Primary (P)/ Duplicate (D)/MS/MSD	Sample Description	Sample Length (cm)	Sample Width (cm)	Sample Weight[3] (g)	Comments
ORD303S; ORD303S-2	**CON-46**	CON46	CON46	--	7/17/2012	1230	14.4	21° 27.535′	158° 13.081′	Yes	Energetics; Metals	P, MS/MSD	uniformly medium grain sand with lots of volcanic clasts	--	--	/	collected by C. Jellings diver
ORD304S; ORD304S-2	**CON-47**	CON47	CON47	--	7/17/2012	1305	8.5	21° 27.437′	158° 12.955′	Yes	Energetics; Metals	P	fine to medium grain sand, few fragments (shell/coral), minor volcanic clasts	--	--	/	collected by C. Jellings diver
ORD305S; ORD305S-2	**CON-48**	CON48	CON48	--	7/18/2012	0925	26.2	21° 27.203′	158° 12.986′	Yes	Energetics; Metals	P	fine to medium grain sand with abundant crustose and algae	--	--	/	collected by C. Jellings diver
ORD306S; ORD306S-2	**CON-49r1**	CON49	CON49	--	7/18/2012	1005	14.0	21° 27.530′	158° 13.076′	Yes	Energetics; Metals	P	uniform fine grain sand with lots of volcanic clasts	--	--	/	collected by C. Jellings diver
ORD307S; ORD307S-2	**CON-49r2**		CON50	--	7/18/2012	1005	14.0	21° 27.530′	158° 13.076′	Yes	Energetics; Metals	Duplicate of ORD306S		--	--	/	duplicate of CON49; collected by C. Jellings diver
ORD308S; ORD308S-2	**CON-51**	CON51	CON51	--	7/18/2012	1040	5.5	21° 27.450′	158° 12.799′	Yes	Energetics; Metals	P	fine to medium grain sand, some coral fragments, minor clasts	--	--	/	collected by C. Jellings diver
ORD309S; ORD309S-2	**NPS-46**	NPS46	NPS46	--	7/18/2012	1150	3.4	21° 25.700′	158° 10.959′	Yes	Energetics; Metals	P	fine to medium grain sand, minor clasts	--	--	/	collected by PONAR

Table 2-1: Post-ROUMRS (FUI1, FUI2, and FUI3) sample list with sample IDs, sampling times, water depth, locations, and analytes.

TestAmerica Lab ID	UH Lab ID*	Site Name[1]	Field ID	Distance	Collection Date	Collection Time	Depth[2] (m)	Latitude (N)	Longitude (W)	Sample Analyzed?	Analytes	Primary (P)/ Duplicate (D)/MS/MSD	Sample Description	Sample Length (cm)	Sample Width (cm)	Sample Weight[3] (g)	Comments
ORD310S; ORD310S-2	**NPS-47**	NPS47	NPS47	--	7/18/2012	1157	4.8	21° 25.712′	158° 10.983′	Yes	Energetics; Metals	P	mostly fine grain sand with some anoxic mud	--	--	/	collected by PONAR
ORD311S; ORD311S-2	**NPS-48**	NPS48	NPS48	--	7/18/2012	1209	7.6	21° 25.709′	158° 11.082′	Yes	Energetics; Metals	P	uniformly fine grain sand with some clasts and no anoxic mud	--	--	/	collected by PONAR
ORD312S; ORD312S-2	**NPS-49r1**	NPS49	NPS49	--	7/18/2012	1214	7.7	21° 25.694′	158° 11.095′	Yes	Energetics; Metals	P	fine to medium grain sand, some coral/shell fragments, some volcanic clasts	--	--	/	collected by PONAR
ORD313S; ORD313S-2	**NPS-49r2**		NPS50	--	7/18/2012	1214	7.7	21° 25.694′	158° 11.095′	Yes	Energetics; Metals	Duplicate of ORD312S		--	--	/	duplicate of NPS49; collected by PONAR
ORD314S; ORD314S-2	**NPS-51**	NPS51	NPS51	--	7/18/2012	1234	6.3	21° 25.625′	158° 11.082′	Yes	Energetics; Metals	P	uniformly fine grain sand, minor volcanic clasts, anoxia	--	--	/	collected by PONAR
ORD315S; ORD315S-2	**WWT-35**	WWT35	WWT35	At WWTP discharge outlet	7/17/2012	1040	31.6	21° 25.414′	158° 11.807′	Yes	Energetics; Metals	P	fine grain sand with rubble, relatively anoxic	--	--	/	collected by C. Jellings diver
ORD302S; ORD302S-2	**WWT-36**	WWT36	WWT36	Track shoreward, approx 100-200 m from WWT-35	7/17/2012	1050	26.9	21° 25.436′	158° 11.783′	Yes	Energetics; Metals	P	fine to medium grain sand with lots of fragments, somewhat anoxic	--	--	/	collected by C. Jellings diver; coordinates from C. Jellings

Table 2-1: Post-ROUMRS (FUI1, FUI2, and FUI3) sample list with sample IDs, sampling times, water depth, locations, and analytes.

TestAmerica Lab ID	UH Lab ID*	Site Name[1]	Field ID	Distance	Collection Date	Collection Time	Depth[2] (m)	Latitude (N)	Longitude (W)	Sample Analyzed?	Analytes	Primary (P)/ Duplicate (D)/MS/MSD	Sample Description	Sample Length (cm)	Sample Width (cm)	Sample Weight[3] (g)	Comments
ORD316S; ORD316S-2	**WWT-37r1**	WWT37	WWT37	Track shoreward, approx 100-200 m from WWT-36	7/17/2012	1055	25.7	21° 25.452′	158° 11.770′	Yes	Energetics; Metals	P	fine to medium grain sand with some fragments (shell), not anoxic	--	--	/	collected by C. Jellings diver; coordinates from C. Jellings
ORD317S; ORD317S-2	**WWT-37r2**											Duplicate of ORD316S		--	--	/	
ORD318S; ORD318S-2	**WWT-38**	WWT38	WWT38	Track shoreward, approx 100-200 m from WWT-37	7/17/2012	1100	21.9	21° 25.485′	158° 11.753′	Yes	Energetics; Metals	P	fine to coarse grain sand with significant fragments, mildly anoxic	--	--	/	collected by C. Jellings diver; coordinates from C. Jellings
--	**PB-07**	Pokai Bay	PB07	--	7/18/2012	1105	4.2	21° 26.657′	158° 11.526′	Yes	Energetics; Metals	P	uniformly fine grain sand, some volcanic clasts	--	--	/	Collected by UH diver
--	**PB-08**	Pokai Bay	PB08	--	7/18/2012	1110	3.3	21° 26.685′	158° 11.593′	Yes	Energetics; Metals	P	uniformly fine grain sand, minor volcanic clasts, anoxia	--	--	/	Collected by UH diver
--	**PB-08**	Pokai Bay	PB09	--	7/18/2012	1115	2.9	21° 26.742′	158° 11.636′	Yes	Energetics; Metals	P	fine to medium coarse sediment with few shell fragments	--	--	/	Collected by UH diver
--	**PB-09**	Pokai Bay	PB10	--	7/18/2012	1117	3.2	21° 26.799′	158° 11.674′	Yes	Energetics; Metals	P	uniformly fine grain sand, minor clasts	--	--	/	Collected by UH diver
SEDIMENT 2013																	
ORD411S	**DMM-73Ar1**	DMM73	DMM73	0 ft	6/3/2013	0912	21.4	21° 25.720′	158° 12.088′	Yes	Energetics; Metals	P		--	--	102.89	ARA 81; 0 ft; Collected by

Table 2-1: Post-ROUMRS (FUI1, FUI2, and FUI3) sample list with sample IDs, sampling times, water depth, locations, and analytes.

TestAmerica Lab ID	UH Lab ID*	Site Name[1]	Field ID	Distance	Collection Date	Collection Time	Depth[2] (m)	Latitude (N)	Longitude (W)	Sample Analyzed?	Analytes	Primary (P)/ Duplicate (D)/MS/MSD	Sample Description	Sample Length (cm)	Sample Width (cm)	Sample Weight[3] (g)	Comments
																	C. Jellings Divers
ORD412S	**DMM-73Ar2**									Yes	Energetics; Metals	Duplicate of ORD411S		--	--	121.00	ARA 81; 0 ft; Collected by C. Jellings Divers
ORD401S	**DMM-73B**		DMM74	3 ft						Yes	Energetics; Metals	P		--	--	150.85	ARA 81; 3 ft; Collected by C. Jellings Divers
ORD402S	**DMM-73C**		DMM75	6 ft						Yes	Energetics; Metals	P		--	--	46.59	ARA 81; 6 ft; Collected by C. Jellings Divers
ORD403S	**DMM-76Ar1**	DMM76	DMM76	0 ft	6/3/2013	1035	17.0	21° 25.718′	158° 12.087′	Yes	Energetics; Metals	P		--	--	63.52	ARA 97; 0 ft; Collected by C. Jellings Divers
ORD404S	**DMM-76Ar2**									Yes	Energetics; Metals	Duplicate of ORD403S				91.21	ARA 97; 0 ft; Collected by C. Jellings Divers
ORD413S	**DMM-76B**		DMM77	3 ft						Yes	Energetics; Metals	MS/MSD		--	--	148.13	ARA 97; 3 ft; Collected by C. Jellings Divers
ORD405S	**DMM-76C**		DMM78	6 ft						Yes	Energetics; Metals	P		--	--	124.04	ARA 97; 6 ft; Collected by C. Jellings Divers
ORD406S	**DMM-79A**	DMM79	DMM79	0 ft	6/3/2013	1116	22.3	21° 25.698′	158° 12.089′	Yes	Energetics; Metals	P		--	--	22.8	ARA 93; 0 ft; Collected by C. Jellings Divers
--			~~DMM80~~	--						--	--	--		--	--	/	No sample collected; Divers said no sediment
ORD414S	**DMM-79C**		DMM81	6 ft						Yes	Energetics; Metals	P		--	--	150.01	ARA 93; 6 ft; Collected by C. Jellings

Table 2-1: Post-ROUMRS (FUI1, FUI2, and FUI3) sample list with sample IDs, sampling times, water depth, locations, and analytes.

TestAmerica Lab ID	UH Lab ID*	Site Name[1]	Field ID	Distance	Collection Date	Collection Time	Depth[2] (m)	Latitude (N)	Longitude (W)	Sample Analyzed?	Analytes	Primary (P)/ Duplicate (D)/MS/MSD	Sample Description	Sample Length (cm)	Sample Width (cm)	Sample Weight[3] (g)	Comments
																	Divers
ORD407S	**DMM-82A**	DMM82	DMM82	0 ft	6/3/2013	1203	22.4	21° 25.614′	158° 12.018′	Yes	Energetics; Metals	P		--	--	55.74	ARA 126; 0 ft; Collected by C. Jellings Divers
ORD408S	**DMM-82B**	DMM82	DMM83	3 ft	6/3/2013	1203	22.4	21° 25.614′	158° 12.018′	Yes	Energetics; Metals	P		--	--	59.82	ARA 126; 3 ft; Collected by C. Jellings Divers
ORD409S	**DMM-82C**	DMM82	DMM684	6 ft	6/3/2013	1203	22.4	21° 25.614′	158° 12.018′	Yes	Energetics; Metals	P		--	--	77.17	ARA 126; 6 ft; Collected by C. Jellings Divers
ORD410S	**DMM-85A**	DMM85	DMM85	0 ft	6/3/2013	1325	24.1	21° 25.823′	158° 12.170′	Yes	Energetics; Metals	P		--	--	151.71	ARA 154; 0 ft; Collected by C. Jellings Divers
ORD415S	**DMM-85B**	DMM85	DMM86	3 ft	6/3/2013	1325	24.1	21° 25.823′	158° 12.170′	Yes	Energetics; Metals	P		--	--	149.78	ARA 154; 3 ft; Collected by C. Jellings Divers
ORD416S	**DMM-85C**	DMM85	DMM87	6 ft	6/3/2013	1325	24.1	21° 25.823′	158° 12.170′	Yes	Energetics; Metals	P		--	--	148.05	ARA 154; 6 ft; Collected by C. Jellings Divers
ORD425S	**DMM-88A**	DMM88	DMM88	0 ft	6/7/2013	0915	43.0	21° 25.846′	158° 12.369′	Yes	Energetics; Metals	P		--	--	63.03	ARA 160; 0 ft; Collected by C. Jellings Divers
ORD426S	**DMM-88B**	DMM88	DMM89	3 ft	6/7/2013	0915	43.0	21° 25.846′	158° 12.369′	Yes	Energetics; Metals	P		--	--	62.89	ARA 160; 3 ft; Collected by C. Jellings Divers
ORD427S	**DMM-88C**	DMM88	DMM90	6 ft	6/7/2013	0915	43.0	21° 25.846′	158° 12.369′	Yes	Energetics; Metals	P		--	--	86.53	ARA 160; 6 ft; Collected by C. Jellings Divers
ORD417S	**DMM-91A**	DMM91	DMM91	0 ft	6/7/2013	0955	22.1	21° 25.711′	158° 12.065′	Yes	Energetics; Metals	P		--	--	126.14	ARA 156; 0 ft; Collected by C. Jellings Divers

Table 2-1: Post-ROUMRS (FUI1, FUI2, and FUI3) sample list with sample IDs, sampling times, water depth, locations, and analytes.

TestAmerica Lab ID	UH Lab ID*	Site Name[1]	Field ID	Distance	Collection Date	Collection Time	Depth[2] (m)	Latitude (N)	Longitude (W)	Sample Analyzed?	Analytes	Primary (P)/ Duplicate (D)/MS/MSD	Sample Description	Sample Length (cm)	Sample Width (cm)	Sample Weight[3] (g)	Comments
ORD418S	**DMM-91B**		DMM92	3 ft						Yes	Energetics; Metals	P		--	--	113.73	ARA 156; 3 ft; Collected by C. Jellings Divers
ORD428S	**DMM-91C**		DMM93	6 ft						Yes	Energetics; Metals	P		--	--	26.85	ARA 156; 6 ft; Collected by C. Jellings Divers
ORD419S	**CON-52**	CON	CON52	--	6/7/2013	1220	13.2	21° 27.526′	158° 13.064′	Yes	Energetics; Metals	P		--	--	119.9	--
ORD420S	**CON-53r1**	CON	CON53	--	6/7/2013	1235	9.0	21° 27.404′	158° 12.968′	Yes	Energetics; Metals	P		--	--	63.33	--
ORD421S	**CON-53r2**	CON	CON54	--	6/7/2013	1245	9.0	21° 27.404′	158° 12.968′	Yes	Energetics; Metals	Field duplicate of CON53		--	--	36.95	*blind time
ORD422S	**CON-55**	CON	CON55	--	6/7/2013	1305	25.8	21° 27.214′	158° 12.948′	Yes	Energetics; Metals	P		--	--	139.56	--
ORD423S	**CON-56**	CON	CON56	--	6/7/2013	1345	14.2	21° 27.540′	158° 13.076′	Yes	Energetics; Metals	P		--	--	144.50	--
ORD424S	**CON-57**	CON	CON57	--	6/7/2013	1415	5.5	21° 27.652′	158° 13.021′	Yes	Energetics; Metals	MS/MSD		--	--	154.49	--
BIOTA 2012																	
OCTOPUS *(HE'E)*																	
--		DMM52	DMM52-O001	--	7/16/12	1000	21.4	21° 25.720′	158° 12.088′	No	--	--	**--**	**--**	**--**	**/**[5]	gutted and de-beaked; no deformities
--		DMM52	DMM52-O002	--	7/16/12	1030	21.4	21° 25.720′	158° 12.088′	No	--	--	**--**	**--**	**--**	**/**[5]	gutted and de-beaked
ORD316O	**DMM-52A**	DMM52	DMM52-O003	--	7/16/12	1050	21.4	21° 25.720′	158° 12.088′	Yes	Energetics; Metals	P	**--**	**--**	**--**	**/**[5]	gutted and de-beaked; no deformities
ORD311O	**DMM-55A**	DMM55	DMM55-O004	--	7/16/12	1130	17.0	21° 25.718′	158° 12.087′	Yes	Energetics; Metals; Arsenic	P	**--**	**--**	**--**	**/**[5]	gutted and de-beaked; no deformities
ORD314O	**DMM-58A**	DMM58	DMM58-O005	--	7/16/12	1215	22.3	21° 25.698′	158° 12.089′	Yes	Energetics; Metals	P	**--**	**--**	**--**	**/**[5]	gutted and de-beaked;

Table 2-1: Post-ROUMRS (FUI1, FUI2, and FUI3) sample list with sample IDs, sampling times, water depth, locations, and analytes.

TestAmerica Lab ID	UH Lab ID*	Site Name[1]	Field ID	Distance	Collection Date	Collection Time	Depth[2] (m)	Latitude (N)	Longitude (W)	Sample Analyzed?	Analytes	Primary (P)/ Duplicate (D)/MS/MSD	Sample Description	Sample Length (cm)	Sample Width (cm)	Sample Weight[3] (g)	Comments
																	no deformities
ORD313O	**DMM-61A**	DMM61	DMM61-O006	--	7/16/12	1245	22.4	21° 25.614′	158° 12.018′	Yes	Energetics; Metals	P	--	--	--	/ [5]	gutted and de-beaked; no deformities
ORD315O	**DMM-64Ar1 DMM-64Ar2**	DMM64	DMM64-O007	--	7/16/12	1317	24.1	21° 25.823′	158° 12.170′	Yes	Energetics; Metals	Duplicate is ORD315O DUP	--	--	--	/ [5]	gutted and de-beaked; very large sample; no deformities
ORD310O	**DMM-67A**	DMM67	DMM67-O008	--	7/16/12	1412	22.1	21° 25.711′	158° 12.065′	Yes	Energetics; Metals; Arsenic	P	--	--	--	/ [5]	gutted and de-beaked
ORD309O	**WWT-OCA**	WWT	WWT-O009	--	7/17/12	1145	33.0	21° 25.431′	158° 11.936′	Yes	Energetics; Metals; Arsenic	P	--	--	--	/ [5]	gutted and de-beaked; 7 & 1/2 legs, very large sample; no deformities
ORD307O	**NPS-OCA**	NPS	NPS-O010	--	7/17/12	1205	12.6	21° 25.523′	158° 11.573′	Yes	Energetics; Metals; Arsenic	P	--	--	--	/ [5]	gutted and de-beaked; no deformities
--		NPS	NPS-O011	--	7/17/12	1205	12.6	21° 25.523′	158° 11.573′	No	--	--	--	--	--	/ [5]	gutted and de-beaked; no deformities
ORD308O	**NPS-OCB**	NPS	NPS-O012	--	7/17/12	1215	21.1	21° 25.472′	158° 11.573′	Yes	Energetics; Metals	P	--	--	--	/ [5]	gutted and de-beaked; no deformities
ORD302O	**CON-46r1 CON-46r2**	CON46	CON46-O013	--	7/17/12	1250	14.4	21° 27.535′	158° 13.081′	Yes	Energetics; Metals	Duplicate is ORD302O DUP	--	--	--	/ [5]	gutted and de-beaked; no deformities
ORD305O	**CON-47**	CON47	CON47-O014	--	7/17/12	1325	8.5	21° 27.437′	158° 12.955′	Yes	Energetics; Metals	MS/MSD	--	--	--	/ [5]	gutted and de-beaked; no deformities
ORD303O	**CON-48**	CON48	CON48-	--	7/18/12	0955	26.2	21° 27.203′	158° 12.986′	Yes	Energetics;	P	--	--	--	/ [5]	gutted and

Table 2-1: Post-ROUMRS (FUI1, FUI2, and FUI3) sample list with sample IDs, sampling times, water depth, locations, and analytes.

TestAmerica Lab ID	UH Lab ID*	Site Name[1]	Field ID	Distance	Collection Date	Collection Time	Depth[2] (m)	Latitude (N)	Longitude (W)	Sample Analyzed?	Analytes	Primary (P)/ Duplicate (D)/MS/MSD	Sample Description	Sample Length (cm)	Sample Width (cm)	Sample Weight[3] (g)	Comments
			O015								Metals; Arsenic						de-beaked; no deformities
ORD301O	**CON-49**	CON49	CON49-O016	--	7/18/12	1030	14.0	21° 27.530′	158° 13.076′	Yes	Energetics; Metals	P	--	--	--	/ [5]	gutted and de-beaked; no deformities
ORD304O	**CON-51**	CON51	CON51-O017	--	7/18/12	1050	5.5	21° 27.450′	158° 12.799′	Yes	Energetics; Metals; Arsenic	P	--	--	--	/ [5]	gutted and de-beaked; no deformities
CRAB																	
ORD301C	**WWT-CCA**	WWT	WWT-C001	--	7/31/2012	0809	*36.6* (120 ft)	21° 25.283′	158° 11.786′	Yes	Energetics; Metals	P	--	12.0	10.0	52.96	Pulled up on 2nd WWTP drop
ORD302C	**WWT-CCB**	WWT	WWT-C002	--	7/31/2012	0859	*36.6* (120 ft)	21° 25.250′	158° 11.768′	Yes	Energetics; Metals; Arsenic	P	--	13.0	10.5	64.11	Pulled up on 3rd WWTP drop
ORD303C	**WWT-CCC**	WWT	WWT-C003	--	7/31/2012	0903	*36.6* (120 ft)	21° 25.269′	158° 11.738′	Yes	Energetics; Metals	P	--	10.0	8.0	37.51	Pulled up on 3rd WWTP drop
ORD304C	**WWT-CCD**	WWT	WWT-C004	--	7/31/2012	1420	*39.6* (130 ft)	21° 25.088′	158° 11.834′	Yes	Energetics; Metals	P	--	12.0	10.5	53.95	Pulled up on 4th WWTP drop
ORD305C	**DMM-CCA**	DMM	DMM-C005	--	7/31/2012	1010	*33.5* (110 ft)	21° 26.186′	158° 12.177′	Yes	Energetics; Metals; Arsenic	P	--	10.5	9.0	37.01	Pulled up on 1st DMM drop
ORD306C	**DMM-CCB**	DMM	DMM-C006	--	7/31/2012	1019	*30.5* (100 ft)	21° 26.229′	158° 12.080′	Yes	Energetics; Metals	MS/MSD	--	12.5	11.5	65.12	Pulled up on 1st DMM drop
--		DMM	DMM-C007	--	7/31/2012	1020	*30.5* (100 ft)	21° 26.229′	158° 12.080′	No	--	--	--	11.0	9.0	27.75	Pulled up on 1st DMM drop. *Partially eaten by stingray
ORD307C	**DMM-CCCr1 DMM-CCCr2**	DMM	DMM-C008	--	7/31/2012	1135	*36.6* (120 ft)	21° 26.144′	158° 12.358′	Yes	Energetics; Metals	Duplicate is ORD307C DUP	--	12.0	10.5	49.97	Following replaced 2nd DMM drop

Table 2-1: Post-ROUMRS (FUI1, FUI2, and FUI3) sample list with sample IDs, sampling times, water depth, locations, and analytes.

TestAmerica Lab ID	UH Lab ID*	Site Name[1]	Field ID	Distance	Collection Date	Collection Time	Depth[2] (m)	Latitude (N)	Longitude (W)	Sample Analyzed?	Analytes	Primary (P)/ Duplicate (D)/MS/MSD	Sample Description	Sample Length (cm)	Sample Width (cm)	Sample Weight[3] (g)	Comments
ORD308C	**DMM-CCD**	DMM	DMM-C009	--	7/31/2012	1217	*27.4* (90 ft)	21° 26.232′	158° 12.224′	Yes	Energetics; Metals; Arsenic	P	--	10.0	9.0	29.96	3rd DMM drop
ORD309C	**DMM-CCE**	DMM	DMM-C010	--	7/31/2012	1222	*33.5* (110 ft)	21° 26.192′	158° 12.282′	Yes	Energetics; Metals	P	--	10.0	8.5	36.56	3rd DMM drop
ORD310C	**DMM-CCF**	DMM	DMM-C011	--	7/31/2012	1524	*27.4* (90 ft)	21° 26.250′	158° 12.234′	Yes	Energetics; Metals	P	--	9.5	8.5	30.01	4th DMM drop
--		CON	CON-C012	--	8/2/2012	0842	*27.4* (90 ft)	21° 28.363′	158° 13.738′	No	--	--	--	11.0	10.0	39.46	2nd drop, slightly outside CON
ORD311C	**CON-CCAr1 CON-CCAr2**	CON	CON-C013	--	8/2/2012	0842	*27.4* (90 ft)	21° 28.363′	158° 13.738′	Yes	Energetics; Metals	Duplicate is ORD311C DUP	--	12.5	11.0	59.23	2nd drop, slightly outside CON
--		CON	CON-C014	--	8/2/2012	0852	*36.6* (120 ft)	21° 28.408′	158° 13.884′	No	--	--	--	10.0	8.0	23.80	2nd drop, slightly outside CON
ORD312C	**CON-CCCB**	CON	CON-C015	--	8/2/2012	0852	*36.6* (120 ft)	21° 28.408′	158° 13.884′	Yes	Energetics; Metals; Arsenic	P	--	10.0	8.0	34.72	2nd drop, slightly outside CON
ORD313C	**CON-CCC**	CON	CON-C016	--	8/2/2012	0935	*30.5* (100 ft)	21° 28.305′	158° 13.793′	Yes	Energetics; Metals	P	--	12.0	10.0	42.33	3rd drop, slightly outside CON
ORD314C	**CON-CCD**	CON	CON-C017	--	8/2/2012	0941	*30.5* (100 ft)	21° 28.375′	158° 13.879′	Yes	Energetics; Metals	P	--	9.5	8.5	33.67	3rd drop, slightly outside CON
ORD315C	**CON-CCE**	CON	CON-C018	--	8/2/2012	0947	*36.6* (120 ft)	21° 28.404′	158° 13.918′	Yes	Energetics; Metals; Arsenic	P	--	11.0	10.0	50.09	3rd drop, slightly outside CON
SEAWEED *(LIMU)*																	
ORD306L	**DMM-52Ar1 DMM-52Ar2**	DMM52	DMM52-L001	--	7/16/2012	1050	21.4	21° 25.720′	158° 12.088′	Yes	Energetics; Metals; Arsenic	Duplicate is ORD306L DUP	--	--	--	95.83	--
ORD307L	**DMM-55A**	DMM55	DMM55-L002	--	7/16/2012	1130	17.0	21° 25.718′	158° 12.087′	Yes	Energetics; Metals; Arsenic	P	--	--	--	23.18	--
ORD308L	**DMM-61A**	DMM61	DMM61-L003	--	7/16/2012	1245	22.4	21° 25.614′	158° 12.018′	Yes	Energetics; Metals;	P	--	--	--	28.99	--

Table 2-1: Post-ROUMRS (FUI1, FUI2, and FUI3) sample list with sample IDs, sampling times, water depth, locations, and analytes.

TestAmerica Lab ID	UH Lab ID*	Site Name[1]	Field ID	Distance	Collection Date	Collection Time	Depth[2] (m)	Latitude (N)	Longitude (W)	Sample Analyzed?	Analytes	Primary (P)/ Duplicate (D)/MS/MSD	Sample Description	Sample Length (cm)	Sample Width (cm)	Sample Weight[3] (g)	Comments
											Arsenic						
ORD309L	**DMM-64A**	DMM64	DMM64-L004	--	7/16/2012	1317	24.1	21° 25.823′	158° 12.170′	Yes	Energetics; Metals; Arsenic	P	--	--	--	10.97	--
ORD310L	**DMM-67A**	DMM67	DMM67-L005	--	7/16/2012	1412	22.1	21° 25.711′	158° 12.065′	Yes	Energetics; Metals; Arsenic	P	--	--	--	6.62	--
ORD311L	**DMM-70A**	DMM70	DMM70-L006	--	7/17/2012	1020	43.0	21° 25.846′	158° 12.369′	Yes	Energetics; Metals; Arsenic	P	--	--	--	12.17	--
ORD301L	**CON-46r1 CON-46r2**	CON46	CON46-L007	--	7/17/2012	1250	14.4	21° 27.535′	158° 13.081′	Yes	Energetics; Metals; Arsenic	Duplicate is ORD301L DUP	--	--	--	21.64	--
ORD303L	**CON-47**	CON47	CON47-L008	--	7/17/2012	1325	8.5	21° 27.437′	158° 12.955′	Yes	Energetics; Metals; Arsenic	P	--	--	--	15.88	--
ORD302L	**CON-48**	CON48	CON48-L009	--	7/18/2012	0955	26.2	21° 27.203′	158° 12.986′	Yes	Energetics; Metals; Arsenic	P	--	--	--	23.61	--
ORD304L	**CON-49**	CON49	CON49-L010	--	7/18/2012	1030	14.0	21° 27.530′	158° 13.076′	Yes	Energetics; Metals; Arsenic	P	--	--	--	18.6	--
ORD305L	**CON-51**	CON51	CON51-L011	--	7/18/2012	1050	5.5	21° 27.450′	158° 12.799′	Yes	Energetics; Metals; Arsenic	MS/MSD	--	--	--	37.05	--
FISH *(WEKE)*																	
--			CON-F001							No	--	--	Red, Female	22.5	--	/	--
--			CON-F002							No	--	--	Red, Female	21.5	--	/	--
ORD303F	**CON-FCAr1 CON-FCAr2**	CON	CON-F003	--	7/18/2012	1315	--	21° 27.537′	158° 12.808′	Yes	Energetics; Metals	Duplicate is ORD303F DUP	Red, Female	25.7	--	/	--
--			CON-F004							No	--	--	Red, Female	21.5	--	/	--
ORD305F	**CON-FCB**		CON-F005							Yes	Energetics; Metals;	P	Red, Female	23.0	--	/	--

Table 2-1: Post-ROUMRS (FUI1, FUI2, and FUI3) sample list with sample IDs, sampling times, water depth, locations, and analytes.

TestAmerica Lab ID	UH Lab ID*	Site Name[1]	Field ID	Distance	Collection Date	Collection Time	Depth[2] (m)	Latitude (N)	Longitude (W)	Sample Analyzed?	Analytes	Primary (P)/ Duplicate (D)/MS/MSD	Sample Description	Sample Length (cm)	Sample Width (cm)	Sample Weight[3] (g)	Comments
											Arsenic						
--			CON-F006							No	--	--	Red, Male	22.6	--	/	--
ORD307F	**CON-FCC**		CON-F007							Yes	Energetics; Metals	P	White, Female	25.1	--	41.02	--
ORD308F	**CON-FCD**		CON-F008							Yes	Energetics; Metals	MS/MSD	White, Female	25.2	--	56.1	--
--			CON-F009							No	--	--	White, Female	23.5	--	66.72	--
--		CON	CON-F010	--	7/18/2012	1315	--	21° 27.518′	158° 12.441′	No	--	--	White, Female	22.4	--	36.91	--
--			CON-F011							No	--	--	White, Female	24.3	--	45.95	--
ORD312F	**CON-FCE**		CON-F012							Yes	Energetics; Metals; Arsenic	P	White, Male	24.7	--	65.28	--
--			CON-EXTRA							No	--	--	White, Female	23.4	--	36.38	--
ORD313F	**WWT-FCA**	WWT	WWT-F002	--	7/19/2012	2017	*18.3* (60 ft)	21° 25.575′	158° 11.820′	Yes	Energetics; Metals	P	Red, Male	22.2	--	50.74	--
ORD314F	**WWT-FCB**	WWT	WWT-F005	--	7/19/2012	2017	*18.3* (60 ft)	21° 25.541′	158° 11.798′	Yes	Energetics; Metals	P	Red, Female	22.1	--	55.58	--
ORD315F	**WWT-FCC**	WWT	WWT-F006	--	7/19/2012	2017	*18.3* (60 ft)	21° 25.533′	158° 11.798′	Yes	Energetics; Metals; Arsenic	P	Red, Male	22.7	--	58.47	--
--		WWT	WWT-F001	--	7/19/2012	2017	*18.3* (60 ft)	21° 25.575′	158° 11.820′	No	--	--	Red, Male	22.1	--	46.6	--
--		WWT	WWT-F003	--	7/19/2012	2017	*18.3* (60 ft)	21° 25.554′	158° 11.805′	No	--	--	Red, Male	19.0	--	18.81	--
--		WWT	WWT-F004	--	7/19/2012	2017	*18.3* (60 ft)	21° 25.549′	158° 11.804′	No	--	--	Red, Female	21.1	--	29.33	--
--		WWT	WWT-F008	--	7/19/2012	2017	*18.3* (60 ft)	21° 25.533′	158° 11.797′	No	--	--	Red, Female	18.7	--	20.45	--
ORD316F	**WWT-FCD**		WWT-F007							Yes	Energetics; Metals	P	White, Male	22.1	--	24.33	--
ORD317F	**WWT-FCE**	WWT	WWT-F009	--	7/19/2012	2017	*18.3* (60 ft)	21° 25.532′	158° 11.797′	Yes	Energetics; Metals; Arsenic	P	White, Female	23.7	--	46.89	--
ORD318F	**DMM-FCA**	DMM	DMM-F010	--	7/19/2012	2100	*15.2* (50 ft)	21° 25.673′	158° 11.861′	Yes	Energetics; Metals	P	Red, Female	20.0	--	29.91	--

Table 2-1: Post-ROUMRS (FUI1, FUI2, and FUI3) sample list with sample IDs, sampling times, water depth, locations, and analytes.

TestAmerica Lab ID	UH Lab ID*	Site Name[1]	Field ID	Distance	Collection Date	Collection Time	Depth[2] (m)	Latitude (N)	Longitude (W)	Sample Analyzed?	Analytes	Primary (P)/ Duplicate (D)/MS/MSD	Sample Description	Sample Length (cm)	Sample Width (cm)	Sample Weight[3] (g)	Comments
ORD319F	**DMM-FCB**	DMM	DMM-F011	--	7/19/2012	2100	*15.2* (50 ft)	21° 25.685′	158° 11.872′	Yes	Energetics; Metals	P	White, Male	23.4	--	33.88	--
ORD320F	**DMM-FCC**		DMM-F012							Yes	Energetics; Metals	P	Red, Female	19.8	--	27.94	--
--			DMM-F013							No	--	--	Red, Female	20.0	--	25.35	--
--		DMM	DMM-F014	--	7/19/2012	2100	*15.2* (50 ft)	21° 25.704′	158° 11.878′	No	--	--	White, Female	21.3	--	24.7	--
ORD323F	**DMM-FCD**	DMM	DMM-F015	--	7/19/2012	2100	*15.2* (50 ft)	21° 25.704′	158° 11.881′	Yes	Energetics; Metals; Arsenic	P	Red, Female	20.3	--	27.71	--
--			DMM-F016							No	--	--	White, Male	19.0	--	27.87	--
ORD325F	**DMM-FCE**	DMM	DMM-F017	--	7/19/2012	2100	*15.2* (50 ft)	21° 25.715′	158° 11.885′	Yes	Energetics; Metals	P	White, Female	21.2	--	29.48	--
ORD326F	**DMM-FCF**	DMM	DMM-F018	--	7/19/2012	2100	*15.2* (50 ft)	21° 25.728′	158° 11.890′	Yes	Energetics; Metals; Arsenic	P	White, Male	22.5	--	34.45	--
ORD327F	**DMM-FCGr1 DMM-FCGr2**	DMM	DMM-F019	--	7/19/2012	2100	*15.2* (50 ft)	21° 25.734′	158° 11.901′	Yes	Energetics; Metals	Duplicate is ORD327F DUP	Red, Female	20.1	--	26.07	--
--		DMM	DMM-F020	--	7/19/2012	2100	*15.2* (50 ft)	21° 25.745′	158° 11.980′	No	--	--	Red, Male	21.1	--	45.28	--
ORD329F	**DMM-FCH**		DMM-F021							Yes	Energetics; Metals	P	White, Male	21.7	--	35.71	--
--			DMM-F022							No	--	--	Red, Female	19.5	--	23.52	--
--			DMM-F023							No	--	--	White, Male	19.4	--	22.62	--
BIOTA 2013																	
OCTOPUS *(HE‘E)*																	
ORD401O	**DMM-73A**	DMM73	DMM73-O001	--	6/3/13	1025	21.4	21° 25.720′	158° 12.088′	Yes	Energetics; Metals	P	large	--	--	**/**[5]	**--**
ORD402O	**DMM-76Ar1 DMM-76Ar2**	DMM76	DMM76-O002	--	6/3/13	1105	17.0	21° 25.718′	158° 12.087′	Yes	Energetics; Metals; Arsenic	Duplicate is ORD402O DUP	very large	--	--	**/**[5]	**--**

Table 2-1: Post-ROUMRS (FUI1, FUI2, and FUI3) sample list with sample IDs, sampling times, water depth, locations, and analytes.

TestAmerica Lab ID	UH Lab ID*	Site Name[1]	Field ID	Distance	Collection Date	Collection Time	Depth[2] (m)	Latitude (N)	Longitude (W)	Sample Analyzed?	Analytes	Primary (P)/ Duplicate (D)/MS/MSD	Sample Description	Sample Length (cm)	Sample Width (cm)	Sample Weight[3] (g)	Comments
ORD403O	**DMM-79A**	DMM79	DMM79-O003	--	6/3/13	1155	22.3	21° 25.698′	158° 12.089′	Yes	Energetics; Metals	P	Small	--	--	/[5]	--
ORD404O	**DMM-82A**	DMM82	DMM82-O004	--	6/3/13	1240	22.4	21° 25.614′	158° 12.018′	Yes	Energetics; Metals	P	7 tentacles	--	--	/[5]	--
ORD405O	**DMM-85A**	DMM85	DMM85-O005	--	6/3/13	1350	24.1	21° 25.823′	158° 12.170′	Yes	Energetics; Metals; Arsenic	P	Small	--	--	/[5]	--
ORD411O	**DMM-88A**	DMM88	DMM88-O006	Caught 25 ft from marker	6/7/13	0942	43.0	21° 25.846′	158° 12.369′	Yes	Energetics; Metals	MS/MSD	large	--	--	/[5]	Caught 25 ft from marker
ORD412O	**DMM-91A**	DMM91	DMM91-O007	--	6/7/13	1025	22.1	21° 25.711′	158° 12.065′	Yes	Energetics; Metals	P	average	--	--	/[5]	--
ORD406O	**CON-52**	CON52	CON52-O008	--	6/7/13	1217	13.2	21° 27.526′	158° 13.064′	Yes	Energetics; Metals	P	tiny	--	--	180.91	--
ORD407O	**CON-53r1 CON-53r2**	CON53	CON53-O009	--	6/7/13	1253	9.0	21° 27.404′	158° 12.968′	Yes	Energetics; Metals	Duplicate is ORD407O DUP	average	--	--	/[5]	--
ORD408O	**CON-56**	CON56	CON56-O010	--	6/7/13	1400	14.2	21° 27.540′	158° 13.076′	Yes	Energetics; Metals; Arsenic	P	tiny	--	--	151.88	--
ORD409O	**CON-55**	CON55	CON55-O011	Caught near CON55	6/11/13	1045	*24.4* (80 ft)	21° 27.175′	158° 12.875′	Yes	Energetics; Metals; Arsenic	P	large	--	--	/[5]	Caught near CON55; coordinates from C. Jellings
ORD410O	**CON-57**	CON57	CON57-O012	--	6/11/13	1210	*6.1* (20 ft)	21° 27.661′	158° 12.999′	Yes	Energetics; Metals	P	average	--	--	/[5]	Caught near CON57; coordinates from C. Jellings
FISH *(WEKE)*																	
ORD401F	**CON-FDA**	CON	CON-F001	--	6/11/2013	1325	*6.1* (20 ft)	21° 27.180′	158° 12.429′	Yes	Energetics; Metals; Arsenic	P	Red	18.5	--	44.65	--
--			CON-F002							No	--	--	--	--	--	--	--
ORD403F	**CON-FDB**		CON-F003							Yes	Energetics; Metals	MS/MSD	Red	19.5	--	51.83	--

Table 2-1: Post-ROUMRS (FUI1, FUI2, and FUI3) sample list with sample IDs, sampling times, water depth, locations, and analytes.

TestAmerica Lab ID	UH Lab ID*	Site Name[1]	Field ID	Distance	Collection Date	Collection Time	Depth[2] (m)	Latitude (N)	Longitude (W)	Sample Analyzed?	Analytes	Primary (P)/ Duplicate (D)/MS/MSD	Sample Description	Sample Length (cm)	Sample Width (cm)	Sample Weight[3] (g)	Comments
--			CON-F004							No	--	--	--	--	--	--	--
ORD405F	**CON-FDCr1 CON-FDCr2**		CON-F005							Yes	Energetics; Metals	Duplicate is ORD405F DUP	Red	19	--	43.13	--
--			CON-F006							No	--	--	--	--	--	--	--
--			CON-F007							No	--	--	--	--	--	--	--
--			CON-F008							No	--	--	--	--	--	--	--
--			CON-F021							No	--	--	--	--	--	--	--
--			CON-F022							No	--	--	--	--	--	--	--
--			CON-F023							No	--	--	--	--	--	--	--
--			CON-F024							No	--	--	--	--	--	--	--
--			CON-F025							No	--	--	--	--	--	--	--
--			CON-F026							No	--	--	--	--	--	--	--
--			CON-F027							No	--	--	--	--	--	--	--
--			CON-F009							No	--	--	--	--	--	--	--
--			CON-F010							No	--	--	--	--	--	--	--
--			CON-F011							No	--	--	--	--	--	--	--
ORD412F	**CON-FDD**	CON	CON-F012	--	6/11/2013	1300	*6.1* (20 ft)	21° 27.549′	158° 12.794′	Yes	Energetics; Metals	P	White	19	--	53.16	--
--			CON-F013							No	--	--	--	--	--	--	--
--			CON-F014							No	--	--	--	--	--	--	--
ORD415F	**CON-FDEr1 CON-**		CON-F015							Yes	Energetics; Metals	Duplicate is ORD415F DUP	White	21.5	--	58.69	--

Table 2-1: Post-ROUMRS (FUI1, FUI2, and FUI3) sample list with sample IDs, sampling times, water depth, locations, and analytes.

TestAmerica Lab ID	UH Lab ID*	Site Name[1]	Field ID	Distance	Collection Date	Collection Time	Depth[2] (m)	Latitude (N)	Longitude (W)	Sample Analyzed?	Analytes	Primary (P)/ Duplicate (D)/MS/MSD	Sample Description	Sample Length (cm)	Sample Width (cm)	Sample Weight[3] (g)	Comments
	FDEr2																
--			CON-F016							No	--	--	--	--	--	--	--
ORD417F	**CON-FDF**		CON-F017							Yes	Energetics; Metals; Arsenic	P	White	24	--	93.62	--
--			CON-F018							No	--	--	--	--	--	--	--
--			CON-F019							No	--	--	--	--	--	--	--
--			CON-F020							No	--	--	--	--	--	--	--
ORD418F	**DMM-FDA**	DMM	DMM-F028	--	6/19/2013	2045	*18.3* (60 ft)	21° 25.737′	158° 12.046′	Yes	Energetics; Metals	P	White	23	--	58.28	--
ORD424F	**DMM-FDG**	DMM	DMM-F029	--	6/19/2013	2047	*18.3* (60 ft)	21° 25.729′	158° 12.043′	Yes	Energetics; Metals	P	Red	25.5	--	84.38	--
--			DMM-F030							No	--	--	White	--	--	--	--
ORD419F	**DMM-FDB**	DMM	DMM-F031	--	6/19/2013	2050	*18.3* (60 ft)	21° 25.701′	158° 12.030′	Yes	Energetics; Metals	P	Red	23	--	71.32	--
ORD420F	**DMM-FDC**	DMM	DMM-F032	--	6/19/2013	2051	*18.3* (60 ft)	21° 25.697′	158° 12.027′	Yes	Energetics; Metals; Arsenic	P	Red	26	--	79.31	--
ORD421F	**DMM-FDD**	DMM	DMM-F033	--	6/19/2013	2053	*18.3* (60 ft)	21° 25.673′	158° 12.017′	Yes	Energetics; Metals	P	Red	23	--	69.56	--
ORD422F	**DMM-FDE**	DMM	DMM-F034	--	6/19/2013	2054	*18.3* (60 ft)	21° 25.665′	158° 12.019′	Yes	Energetics; Metals	MS/MSD	Red	26	--	95.84	--
ORD423F	**DMM-FDF**	DMM	DMM-F035	--	6/19/2013	20:55	*18.3* (60 ft)	21° 25.636 N	158° 12.006 W	Yes	Energetics; Metals	P	Red	21.5	--	67.26	--
ORD425F	**DMM-FDH**	DMM	DMM-F036	--	6/19/2013	2057	*18.3* (60 ft)	21° 25.611′	158° 11.998′	Yes	Energetics; Metals; Arsenic	P	White	27	--	94.97	--
ORD426F	**DMM-FDI**	DMM	DMM-F037	--	6/19/2013	2059	*18.3* (60 ft)	21° 25.605′	158° 12.000′	Yes	Energetics; Metals	P	White	23	--	52.16	--
ORD427F	**DMM-FDJ**	DMM	DMM-F038	--	6/19/2013	2100	*18.3* (60 ft)	21° 25.547′	158° 11.977′	Yes	Energetics; Metals; Arsenic	P	White	22	--	54.65	--
ORD428F	**DMM-FDK**	DMM	DMM-F039	--	6/19/2013	2101	*18.3* (60 ft)	21° 25.547′	158° 11.981′	Yes	Energetics; Metals	P	White	23.5	--	70.68	--

Table 2-1: Post-ROUMRS (FUI1, FUI2, and FUI3) sample list with sample IDs, sampling times, water depth, locations, and analytes.

TestAmerica Lab ID	UH Lab ID*	Site Name[1]	Field ID	Distance	Collection Date	Collection Time	Depth[2] (m)	Latitude (N)	Longitude (W)	Sample Analyzed?	Analytes	Primary (P)/ Duplicate (D)/MS/MSD	Sample Description	Sample Length (cm)	Sample Width (cm)	Sample Weight[3] (g)	Comments
ORD429F	**DMM-FDLr1 DMM-FDLr2**	DMM	DMM-F040	--	6/19/2013	2103	*18.3* (60 ft)	21° 25.544′	158° 11.971′	Yes	Energetics; Metals	Duplicate is ORD429F DUP	Red	19.5	--	40.06	--
ORD430F	**DMM-FDM**	DMM	DMM-F041	--	6/19/2013	2105	*18.3* (60 ft)	21° 25.540′	158° 11.967′	Yes	Energetics; Metals	P	Red	21	--	56.27	--
--			DMM-F042							No	--	--	Red	--	--	--	--
--			DMM-F043							No	--	--	Red	--	--	--	--
ORD431F	**DMM-FDN**	DMM	DMM-F044	--	6/19/2013	2109	*18.3* (60 ft)	21° 25.535′	158° 11.965′	Yes	Energetics; Metals	P	White	23.5	--	63.71	--
--			DMM-F045							No	--	--	White	--	--	--	--
--			DMM-F046							No	--	--	White	--	--	--	--
--			DMM-F047							No	--	--	White	--	--	--	--
ORD432F	**DMM-FDO**	DMM	DMM-F048	--	6/19/2013	2110	*18.3* (60 ft)	21° 25.522′	158° 11.962′	Yes	Energetics; Metals	P	Red	22	--	73.6	--
ORD433F	**DMM-FDPr1 DMM-FDPr2**	DMM	DMM-F049	--	6/19/2013	2113	*18.3* (60 ft)	21° 25.513′	158° 11.955′	Yes	Energetics; Metals	Duplicate is ORD433F DUP	White	24	--	88.5	--
--			DMM-F050							No	--	--	White	--	--	--	--
ORD434F	**DMM-FDQ**	DMM	DMM-F051	--	6/19/2013	2114	*18.3* (60 ft)	21° 25.502′	158° 11.951′	Yes	Energetics; Metals	P	White	24.5	--	72.26	--
--			DMM-F052							No		--	White	--	--	--	--
ORD435F	**DMM-FDR**	DMM	DMM-F053	--	6/19/2013	2116	*18.3* (60 ft)	21° 25.497′	158° 11.953′	Yes	Energetics; Metals	P	Red	22	--	70.73	--
--			DMM-F054							No	--	--	Red	--	--	--	--
--			DMM-F055							No	--	--	Red	--	--	--	--
ORD436F	**DMM-FDS**	DMM	DMM-F056	--	6/19/2013	2120	*18.3* (60 ft)	21° 25.450′	158° 11.937′	Yes	Energetics; Metals; Arsenic	P	Red	20.5	--	57.16	--
--			DMM-F057							No	--	--	Red	--	--	--	--

Table 2-1: Post-ROUMRS (FUI1, FUI2, and FUI3) sample list with sample IDs, sampling times, water depth, locations, and analytes.

TestAmerica Lab ID	UH Lab ID*	Site Name[1]	Field ID	Distance	Collection Date	Collection Time	Depth[2] (m)	Latitude (N)	Longitude (W)	Sample Analyzed?	Analytes	Primary (P)/ Duplicate (D)/MS/MSD	Sample Description	Sample Length (cm)	Sample Width (cm)	Sample Weight[3] (g)	Comments
--			DMM-F058							No	--	--	Red	--	--	--	--
--			DMM-F059							No	--	--	Red	--	--	--	--
--			DMM-F060							No	--	--	Red	--	--	--	--
--			DMM-F061							No	--	--	Red	--	--	--	--
ORD437F	**DMM-FDT**		DMM-F062							Yes	Energetics; Metals	P	White	23	--	62.08	--
--			DMM-F063							No	--	--	White	--	--	--	--
--			DMM-F064							No	--	--	White	--	--	--	--
--			DMM-F065							No	--	--	White	--	--	--	--
--			DMM-F066							No	--	--	White	--	--	--	--
--			DMM-F067							No	--	--	White	--	--	--	--
--			DMM-F068							No	--	--	White	--	--	--	--
--			DMM-F069							No	--	--	White	--	--	--	--
--			DMM-F070							No	--	--	White	--	--	--	--
--			DMM-F071							No	--	--	White	--	--	--	--
--			DMM-F072							No	--	--	White	--	--	--	--
--			DMM-F073							No	--	--	White	--	--	--	--
--			DMM-F074							No	--	--	White	--	--	--	--
SEAWEED *(LIMU)*																	
ORD401L	**DMM-73A**	DMM73	DMM73-L001	--	6/3/2013	1025	21.4	21° 25.720′	158° 12.088′	Yes	Energetics; Metals; Arsenic	P	--	--	--	12.54	--
ORD402L	**DMM-76A**	DMM76	DMM76-L002	--	6/3/2013	1105	17.0	21° 25.718′	158° 12.087′	Yes	Energetics; Metals;	P	--	--	--	8.9	--

Table 2-1: Post-ROUMRS (FUI1, FUI2, and FUI3) sample list with sample IDs, sampling times, water depth, locations, and analytes.

TestAmerica Lab ID	UH Lab ID*	Site Name[1]	Field ID	Distance	Collection Date	Collection Time	Depth[2] (m)	Latitude (N)	Longitude (W)	Sample Analyzed?	Analytes	Primary (P)/ Duplicate (D)/MS/MSD	Sample Description	Sample Length (cm)	Sample Width (cm)	Sample Weight[3] (g)	Comments
											Arsenic						
ORD403L	**DMM-79A**	DMM79	DMM79-L003	--	6/3/2013	1155	22.3	21° 25.698′	158° 12.089′	Yes	Energetics; Metals; Arsenic	P		--	--	14.54	--
ORD404L	**DMM-82Ar1 DMM-82Ar2**	DMM82	DMM82-L004	--	6/3/2013	1306	22.4	21° 25.614′	158° 12.018′	Yes	Energetics; Metals; Arsenic	Duplicate is ORD404L DUP	--	--	--	23.01	--
ORD405L	**DMM-85**	DMM85	DMM85-L005	--	6/3/2013	1350	24.1	21° 25.823′	158° 12.170′	Yes	Energetics; Metals; Arsenic	P	--	--	--	23.00	--
ORD412L	**DMM-88A**	DMM88	DMM88-L006	--	6/7/2013	0942	43.0	21° 25.846′	158° 12.369′	Yes	Energetics; Metals; No Arsenic Speciation[6]	P	--	--	--	4.5	--
ORD413L	**DMM-91A**	DMM91	DMM91-L007	--	6/7/2013	1025	22.1	21° 25.711′	158° 12.065′	Yes	Energetics; Metals; Arsenic			--	--	13.67	--
ORD406L	**CON-52**	CON52	CON52-L008	--	6/7/2013	1140	14.4	21° 27.533′	158° 13.090′	Yes	Energetics; Metals; Arsenic	P	--	--	--	23.22	--
ORD407L	**CON-53**	CON53	CON53-L009	--	6/7/2013	1253	9.0	21° 27.404′	158° 12.968′	Yes	Energetics; Metals; Arsenic	P	--	--	--	10.54	--
--		CON55	CON55-L010	--	6/7/2013	1335	25.8	21° 27.214′	158° 12.948′	No	--	--	Very small sample; Diver went back to site on 6/11/13 to collect more sample	--	--	--	--
ORD409L	**CON-56**	CON56	CON56-L011	--	6/7/2013	1410	14.2	21° 27.540′	158° 13.076′	Yes	Energetics; Metals; Arsenic	MS/MSD		--	--	43.61	--
ORD410L	**CON-57r1 CON-57r2**	CON57	CON57-L012	--	6/7/2013	1437	5.5	21° 27.652′	158° 13.021′	Yes	Energetics; Metals; Arsenic	Duplicate is ORD410L DUP		--	--	39.29	--

Table 2-1: Post-ROUMRS (FUI1, FUI2, and FUI3) sample list with sample IDs, sampling times, water depth, locations, and analytes.

TestAmerica Lab ID	UH Lab ID*	Site Name[1]	Field ID	Distance	Collection Date	Collection Time	Depth[2] (m)	Latitude (N)	Longitude (W)	Sample Analyzed?	Analytes	Primary (P)/ Duplicate (D)/MS/MSD	Sample Description	Sample Length (cm)	Sample Width (cm)	Sample Weight[3] (g)	Comments
ORD411L	**CON-55**	CON55	CON55-L013	--	6/11/2013	1045	*24.4* (80 ft)	21° 27.175′	158° 12.875′	Yes	Energetics; Metals; No Arsenic Speciation[6]	P	Nearby CON55. Repeat collection for more sample	--	--	4.90	**--**

* Note: The "r1" and "r2" in the UHM IDs indicate replicate samples. Biota with UHM IDs containing numbers correspond to (or nearly to) a specific sediment sampling location; otherwise the first 3 letters indicate the stratum, the 4th letter indicates the organism type, the 5th letter is the biota sampling event (C = FUI2 [2012] and D = FUI3 [2013]), and the 6th letter is sequential.

1 Site names were designated by the sample field ID of the first sediment sample collected at a location.

2 Some depth measurements were recorded in the field in feet but were converted to meters for this table; the converted depths are italicized.

3 Fish weights are estimated weights of the fish filets which were prepared and weighed in the UH laboratory. Limu weights are estimated weights of rinsed limu which were prepared and weighed in the UH laboratory. Crab weights are estimated weights of the crab meat which were extracted and weighed in the UH laboratory.

4 Coordinates were recorded in the field as decimal degrees but were converted into degrees and decimal minutes for this table; the converted coordinates are italicized.

5 Octopus sample weights exceeded the capacity of the available UH laboratory scale.

6 Samples were not sent to Brooks Rand for arsenic speciation due to insufficient sample size.

cm – centimeter, ft – feet, g – gram, m – meter, -- not applicable

As stated above, within the three remaining strata (CON, NPS, and WWT), sample sites were randomly selected although based on presence of biota and/or sediment. Similar to the approach used at the DMM stratum, the Follow-Up Investigation field team would lead the fishermen to the targeted location, and then the fishermen would dive and look for a target invertebrate (octopus or crab) in an area with sufficient sediment for sampling. Within the CON, NPS, and WWT strata, the fishermen surveyed the area prior to sample collection to ensure that no DMM were within approximately 100 ft (30.5 m) of the sample location. Once the fishermen selected an appropriate location, they would conduct the sampling and return to the surface to transfer the samples to the study's field team as described above.

The currents within Ordnance Reef (HI-06) were an important aspect of stratum selection. From July 2009 to August 2010, NOAA deployed four acoustic Doppler current profilers (ADCPs) off the Wai‘anae coast at roughly the corners of Ordnance Reef (HI-06) study area. Using these current data, NOAA modeled the currents within the area. Data collected by the ADCP generally confirm the observations of local experts that currents at Ordnance Reef (HI-06) run predominantly from northwest to southeast (NOAA, 2012).

2.2 Sampling Procedures

2.2.1 Analyte and COPC Selection

2.2.1.1 Energetics

The study team based its initial selection of COPCs for the Ordnance Reef (HI-06) Follow-Up Investigation on the results of previous surveys and studies. The COPCs are specific MC and associated MC-degradation products that are related to DMM reported at Ordnance Reef (HI-06) that were considered a potential source of COPCs. The Army identified the following energetic compounds as COPCs:

- picric acid
- nitroglycerin (also known as glyceryl trinitrate or GTN)
- 2-amino (Am)-4,6-DNT
- 4-Am-2,6-DNT
- 2,4-DNT
- 2,6-DNT
- RDX
- 2,4,6-TNT
- 2,4-dinitrophenol
- picramic acid

2.2.1.2 Elements

This study also evaluated the potential effect of munitions casings and other MC on the composition of sediment and biota consumed by local residents by analyzing for selected elements specifically associated with munitions. These elements can be released to the surrounding environment through the corrosion and decomposition of the munitions. In order to distinguish the elements associated with munitions from those present within the DMM stratum as a result of other anthropogenic activities (e.g., delivered to the ocean through NPS pollution or WWTP outfalls) or from geologic materials, the list of elements analyzed was expanded beyond the dominant COPC listed below. Given the amount of coastal pollution generally reported as present in O‘ahu’s nearshore areas, and the pollution that NOAA’s 2006 (NOAA, 2007) and the 2009 UH OR Study (UH, 2014) documented as being present at O‘ahu’s Wai‘anae Coast, it was considered likely that elements from sources other than DMM may be present in the sediments and biota at Ordnance Reef (HI-06).

The majority of a large munition’s body is made of steel but a rotating band of copper may also be present. Medium and small caliber munitions generally have brass casings. Therefore, the metals typically associated with large and medium munitions include, iron and to a lesser degree copper, and zinc, although small amounts of lead may also be present. Iron, which is one of the most abundant elements on Earth, has extremely low toxicity and is an essential element for life. As iron does not present a significant hazard to human health and the environment, it was not included as a COPC for this study. Nonetheless, iron, along with other elements (e.g., aluminum, chromium, etc.), can be indicative of terrestrial influences such as stormwater runoff. A variety of other elements, often in varying amounts, are present within munitions; however, such elements are typically present in much lower quantities than iron (MIDAS PEP data).

The metal and metalloid COPC in sediment and biota for the Ordnance Reef (HI-06) Follow-Up Investigation are the following:

- arsenic (speciated into inorganic versus organic forms),
- copper, and
- lead.

Although arsenic, an essential element in the human diet for stimulating metabolism (Emsley, 1989; ATSDR, 2000), is a toxic element on USEPA’s priority pollutant list, arsenic is not found in conventional munitions except in trace amounts. Trace amounts of arsenic are also found in most earth substances and human products. The Army included arsenic as a COPC in this study because of the local community’s deep-seated concern regarding its potential to pose a health hazard. Other elements, including a number of heavy metals, were selected for analysis in sediment samples based on USACE’s historical records and previous environmental studies performed at the WWTP and other locations on O‘ahu (e.g., De Carlo et al., 2004; De Carlo et al., 2005). With this in mind, zinc is also discussed extensively along with the metal COPC, owing to its potential to help elucidate elemental sources and associations.

Sediment samples were, therefore, analyzed for a suite of major, minor, and trace elements selected based on their potential to help identify individual contributions from munitions, terrestrial runoff (NPS) pollution, WWTP effluents, and natural terrestrial petrogenic (volcanic) materials and marine carbonates to the overall composition of sediment at Ordnance Reef (HI-06). The elements analyzed included aluminum, antimony, arsenic, barium, cadmium, calcium, chromium, cobalt, copper, iron, lead, magnesium, manganese, nickel, selenium, strontium, thallium, titanium, uranium, vanadium, and zinc

2.2.2 Mobilization

Mobilization included preparing for each of the Follow-Up Investigation team's field activities, determination of, gathering and checking of necessary materials and equipment, and organizing and assembling trained field personnel. The field team assembled and checked field equipment, batteries, and materials prior to transferring them to the Ordnance Reef (HI-06) study area. All field personnel received site-specific health and safety training and familiarization with Ordnance Reef (HI-06) prior to commencing work. Demobilization occurred with the same attention to detail and continuous coordination that was applied to the mobilization process.

2.2.3 Sediment Sampling

A total of 88 sediment samples (not including field replicate samples) was collected and sent to the laboratory for element and energetics analysis. The sample information and field activities are documented in Appendix B – Field Collection Sheets; Appendix C – Photo Log; and Table 2-1.

The collection of sediment samples using a Ponar grab sampler was only marginally successful on reefs, reef flats and other hard substrate where sediment tends to accumulate only in depressions or as a thin veneer. When the Ponar was unsuccessful at obtaining a sediment sample, the fisherman contracted to collect biota were instructed to collect sediment samples by scooping sediment from the top 0.79 to 1.57 in (2 to 4 cm) of the substrate directly into pre-labeled gallon-sized plastic storage bags. To minimize the potential for cross contamination, the fishermen were careful to ensure that only the inside of the bag contacted the material being sampled.

When possible, given bottom conditions and the presence of an adequate amount of sediment for analyses, the divers collected samples directly adjacent to, nominally 3 ft (0.9 m) away from, and nominally 6 ft (1.8 m) away from a specific DMM site and labeled with the DMM site name and A, B, and C, respectively. In some cases, the distances from the DMM where sediment samples were collected were slightly different than described above. In such cases, the fishermen noted the distances, which the study team subsequently recorded in the field notes. The study team ensured that the fishermen could keep track of the sediments collected at each of the three sample locations by using pre-labeled sampling bags. The bags were pre-labeled A, B, and C, with A always designated as the sample collected closest to the DMM. Fishermen carried the bags to the surface and handed them to the field sampling team. Sampling locations were individually documented using a handheld GPS (refer to Section 2.2 for further detail).

On recovery of the Ponar or the plastic storage bag, the field team placed the individual sediment samples onto decontaminated plastic trays and noted the visual characteristics of the sediments. Each sediment sample was then transferred into laboratory-supplied sample containers and clean plastic storage bags using a decontaminated plastic spoon. Sample containers were labeled according to the procedures established in the Field Sampling Plan (FSP), then immediately cooled to 39°F (4°C) for preservation. The coolers containing the samples were removed from the boat upon completion of each day's work. The sample containers were then returned to the laboratory, stored, chilled, and subsequently shipped, under chain-of-custody (COC), to the appropriate laboratory for analysis (see Appendix D for a compilation of laboratory COC forms).

2.2.4 Biological Sampling

We collected the organisms (biota samples) to match those collected for the 2009 UH OR Study (UH, 2014) to allow a direct comparison of the results. The species targeted for this study included fish, invertebrates (crab and octopus), and seaweed (see Table 2-2). The goal for biota sampling in the DMM stratum included collection, at each sample site, of at least one of each type fish, one invertebrate, and one seaweed sample. The goal for non-DMM strata included collection, at each sample site, of one fish, one invertebrate, and one seaweed sample. A total of 108 biota samples was collected during the Follow-Up Investigation (not including replicate samples). Of the samples collected, 44 were fish, 26 were octopus, 15 were crab, and 23 were seaweed.

Table 2-2: Biota species studied at Ordnance Reef (HI-06).

Common Name(s)	Hawaiian Name	Scientific Name	Biota Type
White goatfish or yellowstripe goatfish	White weke	*Mulloidichthys flavolineatus*	Fish
Red goatfish or yellowfin goatfish	Red weke	*Mulloidichthys vanicolensis*	Fish
Octopus	Heʻe	*Octopus cyanea*	Invertebrate
Kona crab	Papaikualoa	*Ranina ranina*	Invertebrate
	Limu kohu	*Asparagopsis taxiformis*	Seaweed

Octopus were caught by the tactical spearing technique, Kona crab were caught in bottom traps, and seaweed was harvested by hand. Because fish are transient and foraging organisms, the spatial goal for fish collection was modified slightly. Fish were trapped in nets, which the fishermen left in place overnight, at prime collection spots within each stratum. The fish collected were considered representative of fish that would spend time in proximity of the stratum in which they were caught. As an example, fish caught in the DMM stratum were considered representative of fish that had spent time in proximity to DMM. Seaweed was not abundant and was difficult to locate at any given sample site. Because of this, seaweed was often harvested over a larger geographic area in the vicinity of a given sample site until a sufficient mass was collected to enable laboratory analysis.

A secondary goal of biota sampling was to attempt to collect fish and invertebrate samples of relatively similar size or mass (i.e., within 10% to 20%, if possible). This would allow the comparison of biota of approximately the same age or stage of development. For the majority of the samples this was achieved.

UH field personnel shadowed the fishermen in a separate surface vessel to both ensure accurate documentation of the locations where biota samples were collected and take custody of the biota samples. Sampling locations were recorded using a GPS, as described in Section 2.1.1. Samples, which were packaged in trace metal clean plastic bags, were stored on ice until return to the laboratory. Storage and handling of the biota samples followed procedures outlined in the FSP. A summary of the number of biota samples collected by stratum, season, and biota type is presented in Table 2-3.

Table 2-3: Number of sediment and biota samples collected by stratum and date.

	August 2011	July to August 2012	June 2013*
Sediment			
DMM	15	21	20
WWT	4	4	0
NPS	5	5	0
CON	4	5	5
Fish			
DMM	0	8	20
WWT	0	5	0
NPS	0	0	0
CON	0	5	6
Octopus			
DMM	0	6	7
WWT	0	1	0
NPS	0	2	0
CON	0	5	5
Crab			
DMM	0	6	0
WWT	0	4	0
NPS	0	0	0
CON	0	5	0
Limu			
DMM	0	6	7
WWT	0	0	0
NPS	0	0	0
CON	0	5	5

Note: The counts presented on this table include only primary samples analyzed by the laboratory (i.e., the counts do not include quality control samples [e.g., duplicates]).
*In June 2013, samples were only collected from the control (CON) and DMM strata.

Only edible portions of the biota collected were sent for analysis. This provided a good representation of the potential exposure the community would experience through consumption of the types of biota collected. To accomplish this, each specimen of fish was filleted, the meat was extracted from the body and appendages of each specimen of crab, and the ink sac and beak were removed from each specimen of octopus in a Class 100 laminar flow hood at UH. Limu specimens, which were also rinsed in a Class 100 laminar flow hood to remove sediment particles, were submitted intact to the laboratory. A ceramic knife used for filleting the fish and processing the octopus, and all the plasticware used for sample storage, handling, and processing were scrupulously cleaned by a series of acid washing steps that exceed USEPA recommendations, as previously described by Spencer et al. (1995) and De Carlo and Spencer (1997). These cleaning procedures were originally developed to minimize trace metal contamination prior to analysis but were equally applicable to prevention of contamination of any type during sample processing.

After sample preparation of fish and crab tissue, all biota samples were stored in a -22°F (-30°C) freezer and subsequently shipped to the contract laboratory for analysis on ice packs to maintain the sample temperature near 32°F (0°C) and prevent thawing. To preserve sample integrity and preparation consistency, the contract analytical laboratory was responsible for subsequent preparation and analysis of all biota tissue. All analyses for trace elements and energetics were conducted at TestAmerica West Sacramento. Tissue samples were analyzed for trace elements using USEPA Methods 6010B and 7471A and energetics using USEPA Method 8330 (modified for marine matrices). Arsenic speciation was performed by Brooks Rand Laboratories (BRL) on aliquots of tissue prepared by TestAmerica West Sacramento. Arsenic speciation was conducted on roughly 10% of the biota samples to estimate the percent inorganic arsenic versus the percent organic arsenic in each biota type. BRL conducted the arsenic speciation by analyzing for inorganic arsenic using a modified USEPA Method 1632 and total arsenic using a modified USEPA Method 1638.

2.2.5 Sample Numbering and Labeling

Sampling procedures required that all samples collected be labeled with a field identification (ID) number as soon after collection as practical. Samples submitted to the laboratory for analysis were also assigned a sample ID number to facilitate data tracking and storage (see Table 2-1). The format for sample ID numbers was:

xxxyyyz

where

xxx Project description (ORD)

yyy Chronological number, starting with 201 in 2011, starting with 301 in 2012, and starting with 401 in June 2013

z letter indicating matrix type (s = sediment, f = fish, o = octopus, and c = crab; l = limu [seaweed]).

(Note: sediment metal samples were provided with ID numbers in a different format than described above. In most cases, the ID number consisted of a combination of the site and field ID number [see Table 2-1]).

2.3 Equipment Decontamination Procedures

Sediment sampling equipment used at each strata included the Ponar grab sampler or the appropriate clean sampling container, if diver collected. The study team decontaminated the ponar between each use by a triple seawater rinse over the side of the vessel complemented by nylon brush scrubbing to remove any adhering material. Because sediment in the study area is composed largely of sand-sized particles with minor to trace amounts of clay/silt-sized particles, there was usually no adhesion of sediment to the Ponar grab surfaces after the first seawater rinse. Other sample handling materials used during the study included clean laboratory-supplied sampling containers, disposable plastic spoons, and nitrile gloves, which were only used once and then discarded. No decontamination was required for these materials.

2.4 Investigation-Derived Waste Management

Investigation-derived waste (IDW) is defined as any solid or liquid material used or generated during the study’s field investigation. Solid IDW generated during this study was limited to nitrile gloves, plastic spoons, and paper towels. There was no liquid IDW generated during this study. Based on knowledge of Ordnance Reef (HI-06), the waste generator determined that all IDW were non-hazardous solid waste allowing it to be disposed of offsite. Biota samples were processed in their entirety at the UH laboratory to remove non-edible portions of each specimen. Again, based on knowledge of the materials, the waste generator determined tissue parts removed from each animal were a non-hazardous solid waste and they were disposed of offsite.

2.5 Field Quality Assurance and Quality Control

2.5.1 Sample Collection and Management

The field team conducted its activities per the FSP. Evaluation and quality control (QC) assessment of field activities included oversight of procedures for field sampling activities, instrument calibration, and daily *tailgate* meetings, where discussions included a review of the day's activities, proper sampling, site safety, and a preview of upcoming activities.

2.5.2 Field QC Samples

Follow-Up Investigation field QC samples consisted of collection of field duplicate samples (hereafter referred to as replicates). Equipment rinsate blanks, trip blanks, and temperature blanks were not necessary for this study.

Field replicates were collected at the same time and locations as their respective primary samples to gain precision information on homogeneity, handling, shipping, storage and preparation, and analysis. Precision characterizes the amount of variability and bias inherent in a data set. It also describes the reproducibility of measurements of the same parameter for a sample under the same or similar conditions. Field replicates were collected at a rate of about 10% of the total samples.

For sediment samples, of the 99 samples analyzed by the laboratory for elements and energetics, 11 (11%) of these samples were field replicates. Sediment field replicates were assigned a unique ID number in sequence with the primary samples to ensure their independent analysis. Sediment field replicates, which were sent to the contract laboratory as blind samples, were analyzed for the same parameters as the primary samples (see Appendix E).

For biota samples, specimens were sent to the laboratory either intact (octopus [minus beaks and ink sacks] and limu) or as prepared tissue samples (fish fillets and crab meat), thus the laboratory was responsible for preparing splits of a subset of the samples. Of the 124 samples analyzed by the laboratory, 16 (13%) were replicate samples. Replicate samples were analyzed for the same analytes as the primary samples.

Standard COC protocols were followed during sample collection, management, and shipment to the analytical laboratories. COCs were maintained for each day's samples. The laboratories followed their internal COC process once the samples arrived. The COC forms for the samples collected during this study are found in Appendix D.

2.5.3 Field Instrument Calibration/Documentation

The only field instruments used during the study were sensors on the Sea-Bird Electronics SBE19*plus* V2® CTD (conductivity, temperature, and depth) system equipped with an SBE43® dissolved oxygen sensor and a WET Labs FLNTURTD® chlorophyll fluorescence and turbidity sensor, used for profiling the water column. These sensors, which are factory calibrated, do not require user calibration either in the laboratory or the field. Upon annual factory maintenance and calibration, the manufacturer provided new calibration coefficients. New calibration coefficients, which the manufacturer entered into SBE proprietary software, were used to calculate field data values (e.g., concentrations) for relevant parameters upon downloading of raw CTD files from the instrument. This approach is standard oceanographic practice. No field calibrations were carried out as the design characteristics of SBE systems do not permit operator/field calibrations.

2.6 Chemical Analysis

TestAmerica West Sacramento analyzed all samples, with the exception of major and minor elements (aluminum, calcium, iron, magnesium, manganese, strontium, and titanium) in sediment, which were analyzed by Dr. De Carlo's UH laboratory, and the arsenic speciation samples, which were conducted by BRL. All analyses were performed using USEPA or equivalent methods. High Performance Liquid Chromatography (HPLC) methods employed for this study included second column confirmation of positive detections.

All sediment samples intended for major and most minor element analysis (see above) were processed in Dr. De Carlo's UH laboratory. Sediment samples were dried in an induction oven at 104°F (40°C) to a constant weight and homogenized with a tungsten-carbide ball and mill. Splits (approximately 0.01 ounces (200 milligrams [mg]) of the sample powders were digested in closed Teflon® containers using concentrated minerals acids and subsequently analyzed by either optical emission spectrometry (OES) or mass spectrometry (MS) for their elemental composition using methods routinely used in Dr. De Carlo's laboratory (e.g., Wen et al., 1997; De Carlo et al., 2004; De Carlo et al., 2005; De Carlo et al., 2013). These digestion procedures and analyses are comparable to those described in USEPA solid waste (SW) 846 (e.g., Method 3050, 3051 or 3052) followed by inductively coupled plasma optical emission spectrophotometer (ICP-OES) Method 6010. Standard quality assurance (QA) and QC procedures were undertaken during the course of sample preparation and analysis. These include the preparation and analysis of reagent and procedural blanks, replicate sample analyses, duplicate digested solution analysis, analysis of spiked solutions, and analysis of certified reference materials. Sediment samples submitted to TestAmercia West Sacramento were analyzed for energetics using USEPA Method 8330 and for trace elements using USEPA Method 6020.

Tissue samples were analyzed for trace elements using USEPA Methods 6010B and 7471A and energetics using USEPA Method 8330. Arsenic speciation was performed by BRL on aliquots of tissue prepared by TestAmerica West Sacramento. BRL conducted the arsenic speciation by analyzing for inorganic arsenic using a modified USEPA Method 1632 and total arsenic using a modified USEPA Method 1638.

2.7 Statistical Analysis

Various statistical analyses were performed in order to better describe the data collected during the Follow-Up Investigation (Post-ROUMRS) and the 2009 UH OR (pre-ROUMRS) study and to compare the results of these two investigations in an effort to determine the effect, if any, of the ROUMRS technology demonstration.

2.7.1 Detection and Reporting Limits and Censored Data

Some but certainly not all laboratory data are censored, i.e., they fall in the range between 0 and the detection limit (DL). These data are referred to as nondetects (NDs) or left-censored data. An ND does not necessarily mean the analyte was not present but, if it was present, it was at a concentration below the DL. To complicate matters further, DLs often vary from sample to sample within a single lab run and between different lab runs. This results in multiple DLs, also known as multiply left-censored data.

In addition, at the request of clients, labs such as TestAmerica report estimated values (flagged with a "J"). These are values that lie between the DL and the reporting limit (RL). The RL, also referred to as the quantitation limit (QL), is the level at or above which the lab will state that the result is quantitative; below the RL, the result should be considered an estimate.

Fortunately, there are a number of statistical techniques, some of which have been around for more than a half a century, specifically designed to handle left-censored and interval-censored data that do not compromise the results of statistical analyses by using substitution. A number of authors, most notably Cohen (1957, 1961), Miesch (1967), Millard and Deverel (1988), Helsel and Cohn (1988), Farewell (1989), Akritas et al. (1994), and Helsel (2005, 2012), have addressed the issue of analyzing censored data and the problems that can arise if substitution (e.g., one half the detection limit or ½DL) is used.

2.7.2 Summary Statistics

In an effort to avoid using substitution (which can compromise the statistical analyses) to calculate summary statistics, a variety of statistical methods were used. If the data for a particular analyte did not contain NDs, summary statistics were calculated using Minitab 16®'s built-in descriptive statistics feature. For those analytes with <50% NDs, nonparametric Kaplan-Meier survival analysis was used. Kaplan-Meier survival statistics have been used for decades for medical and industrial applications where the data are most often right-censored. Generally, however, environmental data such as those received from a laboratory are left-censored (i.e., <DL). This requires that these data be temporarily *flipped* so they become right-censored for the Kaplan-Meier analysis. This procedure is discussed in detail in Helsel (2012) and will not be repeated here. Helsel (2012) also wrote the Minitab® macro *kmstats* to automatically flip left-censored data and calculate the summary statistics (mean, standard error, standard deviation, and various percentiles including the median or 50th percentile). For Kaplan-Meier, the result, estimated value, or DL is used and is accompanied by a code (indicator variable) to indicate whether the value is <DL (code = 1) or was detected (code = 0). For those analytes with ≥50% and <80% NDs, regression on order statistics (ROS) were used, again, with Minitab® and another macro (*cros*) also provided by Helsel (2012). Finally, for those analytes with ≥80% NDs, the maximum value and number and percentage of NDs was reported.

The summary statistics (mean, standard error, standard deviation, maximum, 75th percentile, median [50th percentile], 25th percentile, and minimum) were all tabulated along with the DL range for the 2009 UH OR Study pooled data and the Follow-Up Investigation pooled data, number of samples, number of NDs, percent NDs, and the method by which the statistics were calculated. We produced summary statistics tables for the sediments and biota to facilitate data descriptions and comparisons between pre- and post-ROUMRS sediment strata and organisms. For some analytes, certain summary statistics could not be calculated. This was particularly true with the energetics data, which typically had a high numbers of NDs.

2.7.3 Kendall’s Tau Nonparametric Correlation Analysis

Kendall’s tau (τ) is a nonparametric (distribution-free) correlation analysis that can be applied to multiply left-censored data (Helsel, 2012). For this test, the estimated (J-flagged) values were included. Kendall’s τ is analogous to the familiar parametric Pearson’s r and, like Pearson’s correlation test, the test for Kendall’s τ also provides a measure of the correlation significance.

For the determination of Kendall’s τ the input data were formatted in a manner identical to that used for the Kaplan-Meier analysis. Helsel’s (2012) *ckend* (for censored Kendall’s τ) Minitab® macro was used. This macro incorporates a correction to account for the fact that censored data have many more tied comparisons than uncensored data (Helsel, 2012). Currently there is no software for creating a correlation matrix for censored data. Therefore, the *ckend* results (τ, p, and n) for each analyte pair were manually entered into a correlation matrix created in Excel®. If Kendall’s τ was significant at $\alpha = 0.05$, the τ and p values were in bold type and if positively correlated, the bold values were coded green, if negatively correlated, they were coded red.

The more familiar Pearson’s *r,* works with linear monotonic data, where 0 indicates no correlation and +1 indicates a perfect positive correlation between two variables (i.e., as one variable increases, so does the other variable) and a -1 indicates a perfect negative correlation (i.e., as one variable increases, the other variable decreases). If the data are monotonic but not necessarily linear, Kendall’s τ can be used. Kendall’s τ is a nonparametric rank-based procedure, which also means it is not sensitive to the effects of a few outliers (Helsel and Hirsch, 2002). Typically, Kendall’s τ will be lower than Pearson’s r by about 0.20, which means that a Pearson’s r of 0.9 or above corresponds to a Kendall’s τ of about 0.7 or above (Helsel and Hirsch, 2002). Kendall’s τ, however, is not less sensitive than Pearson’s r but simply uses a different correlation scale. Therefore, to equate Kendall’s τ with Pearson’s r add 0.2 to a positive Kendall’s τ or subtract 0.2 from a negative Kendall’s τ.

In addition to providing Kendall’s τ and the probability or p value, the *ckend* macro also created a censored scatterplot of each analyte pair. These plots provided an additional analytical tool for examining the data. Scatterplots indicate whether or not a relationship is monotonic (steadily increasing or decreasing), whether or not the relationship is linear, and if there are outliers. Fortunately, Kendall’s τ is not affected by the latter two characteristics.

As valuable as correlation analyses are, it is important to remember that even a significant, strong correlation does not necessarily imply cause and effect. A strong correlation can simply mean that some biogeochemical process affects two analytes similarly. Therefore, a process that affects the concentration of one will also affect the concentration of the other analyte and thus show a strong correlation between the two analytes. On the other hand, a significant correlation does suggest that two analytes may be related in some way. These relationships are often most evident with ordination techniques such as nonmetric multidimensional scaling (NMDS) discussed below.

2.7.4 Nonmetric Multidimensional Scaling (NMDS)

NMDS is a nonparametric exploratory ordination technique that uses interval-censored data to search for and identify patterns in complex data. Being a nonparametric procedure, there are no data distribution requirements (e.g., normal, log-normal, etc.) for NMDS. Moreover, unlike other ordination procedures such as principal components analysis, factor analysis, or classical multidimensional scaling, NMDS does not require that the data be linear (Helsel, 2012). Finally, because NMDS uses interval-censored data, there is no need to use substitution (e.g., ½DL) for NDs and NMDS can work with the fact that data between the DL and the RL are not necessarily quantitative.

For NMDS, UH used the procedures described in Helsel (2012). The result, DL, and RL for each analyte were imported into an Excel® spreadsheet and the data rearranged and recoded so that each result for every analyte was represented by a low and high value. In the case of NDs (i.e., <DL), the low was 0 and the high was the DL. For J-flagged data, the low value was the DL and the high value was the RL. Finally, for data above the RL, the low and high values were simply the reported value repeated.

The sediment element and energetics data, reorganized and recoded as described above for each sampling event, were copied to Minitab 16® worksheets and saved. Using the Minitab® macro *uscore* provided by Helsel (2012), the u-scores and ranks for the interval-censored data were calculated for each analyte. According to Helsel (2012), the "… u-score forms the basis for the Mann-Whitney test, and is related to Kendall's tau and other nonparametric methods. Kaplan-Meier percentiles for censored observations [discussed previously] use this score [as well]."

After running the *uscore* macro in Minitab®, the u-scores and ranks were appended to the Minitab® worksheet. These u-scores and ranks for each analyte were also appended to the original Excel® worksheet containing the sediment data. The u-score ranks were saved to a separate Excel® spreadsheet saved as an XLS file for importing into the freely available statistical software R (Version 3.0.3). Prior to importing the data, the R packages *Rcmdr* (R graphical user interface or GUI), *MASS* (loaded as part of *Rcmdr*), and *vegan* were loaded. The sediment data from the XLS file were imported into R and the metaMDS routine in the R package *vegan* was run. This routine generates a number of variables including "species" (variables for our case, i.e., R mode analysis) and "points" (samples or sites for our case, i.e., Q mode analysis). The multidimensional scale distances were then copied to an Excel® spreadsheet for plotting. While plots were created in R, Excel® provides more plotting format options for NMDS, particularly with the freely available *X-Y Chart Labeler* add-in for Excel®.

2.7.5 Interval-Censored Score Test

Ultimately, the question that needed to be answered was – Is there a statistically significant difference in COPC concentration in the sediments and biota between the 2009 UH OR Study (pre-ROUMRS) and this investigation (post-ROUMRS)? To answer this question, UH again turned to Helsel (2012), who offers an interval-censored analog to the generalized Wilcoxon test. Using interval-censored data and the nonparametric score test outlined by Helsel (2012), the pooled 2009 UH OR data were compared with the post-ROUMRS Follow-Up Investigation data. This score test uses the R package *interval* contributed by Fay and Shaw (2010) to compare analytes collected during the 2009 UH OR Study and Follow-Up Investigation. If, after conducting the test between the two groups, the p value is ≤ 0.05 (α), then there is a statistically significant difference between the two groups.

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Section 3
Results of the Follow-Up Investigation

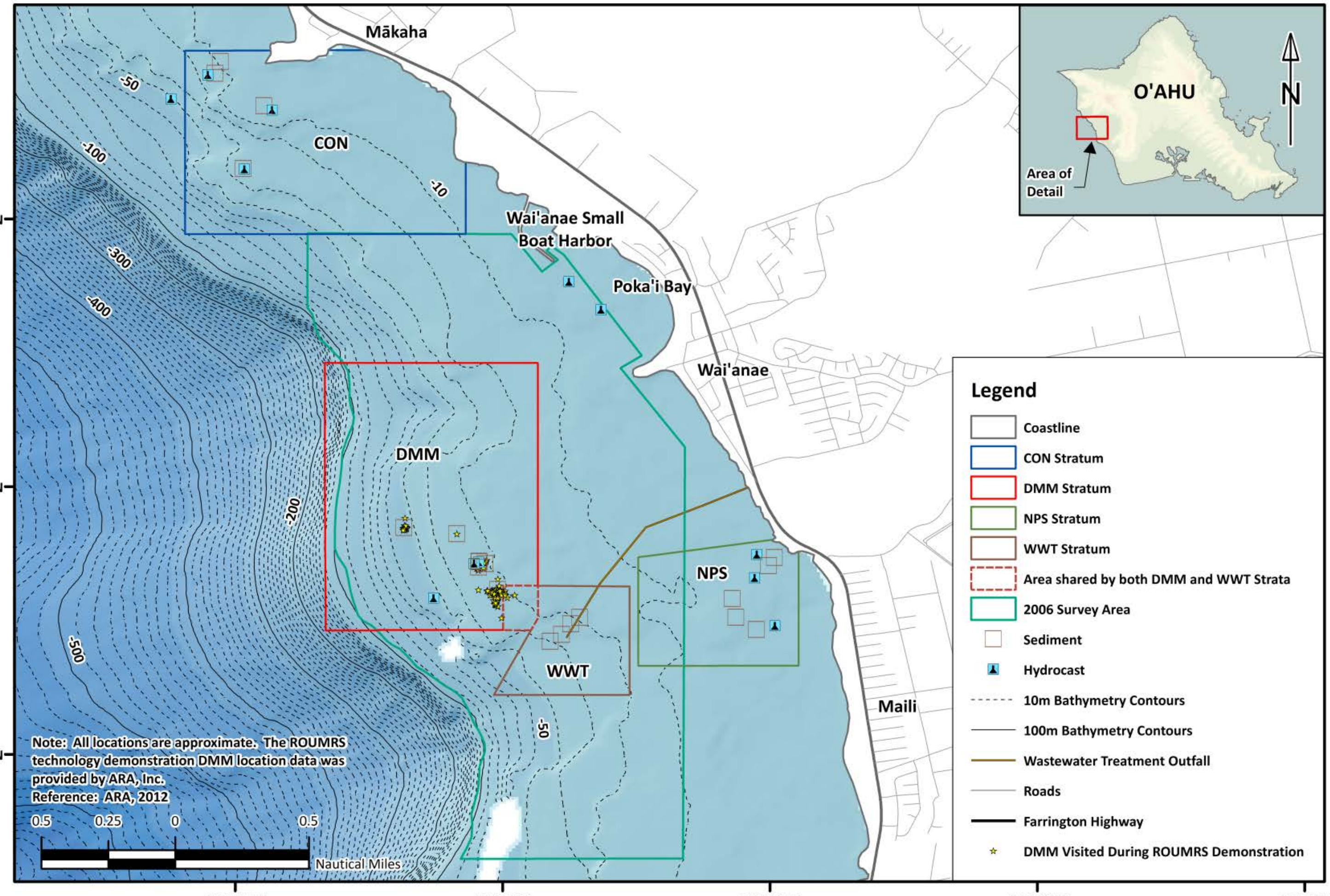
The Follow-Up Investigation focused on quantifying the effects of the summer 2011 ROUMRS technology demonstration on contaminants in the sediment and biota at Ordnance Reef (HI-06). There were three sampling events during the Follow-Up Investigation. The dates, types of sampling, and sample locations (as map figures) follow:

FUI1	August 2011	(sediment)	Figures 3-1 through 3-5;
FUI2	July-August 2012	(sediment & biota)	Figures 3-6 through 3-12; and
FUI3	June 2013	(sediment & biota)	Figures 3-13 through 3-15.

The following subsections present a discussion of the potential fate and transport of the COPCs, and the results from analysis of the sediment and biota samples collected at Ordnance Reef (HI-06). In addition to a discussion on the occurrence and concentrations observed, a discussion of possible sources for the various analytes is presented. The final subsection discusses the hydrocasts and the resulting water column profile plots.

Summary statistics for the pooled FUI1 through FUI3 sediment data (by strata) are presented in Table 3-1; summary statistics for the pooled FUI2 and FUI3 biota data (by organism type) are presented in Table 3-2. The summary statistics include the mean, standard error, standard deviation, maximum, 75th percentile, median (50th percentile), 25th percentile, and minimum. In addition, the number of samples (n), number and percent NDs (i.e., <DL), and the range of the DLs are also included along with the method used to calculate the statistics (discussed in detail in Section 2.0 of this report). These tables also include the summary statistics for the 2009 UH OR Study. A comparison of the results of the 2009 UH OR data (pre-ROUMRS) with the 2011 through 2013 Follow-Up Investigation (post-ROUMRS) data is included in Section 4.0 of this report.

Figure 3-1: Approximate sampling locations for all strata in 2011off the Wai'anae Coast, O'ahu, Hawai'i.



Environet, Inc.	PROJECT NO.: 1108-000 DATE: AUGUST 5, 2014 DRAWN BY: CB/SK REVIEWED BY: SS	ORDNANCE REEF (HI-06) APPROXIMATE 2011 SAMPLE LOCATIONS WAI'ANAE COAST, O'AHU, HAWAI'I	FIGURE 3-1

Figure 3-2: Approximate sampling locations for the CON stratum in 2011off the Wai'anae Coast, O'ahu, Hawai'i.

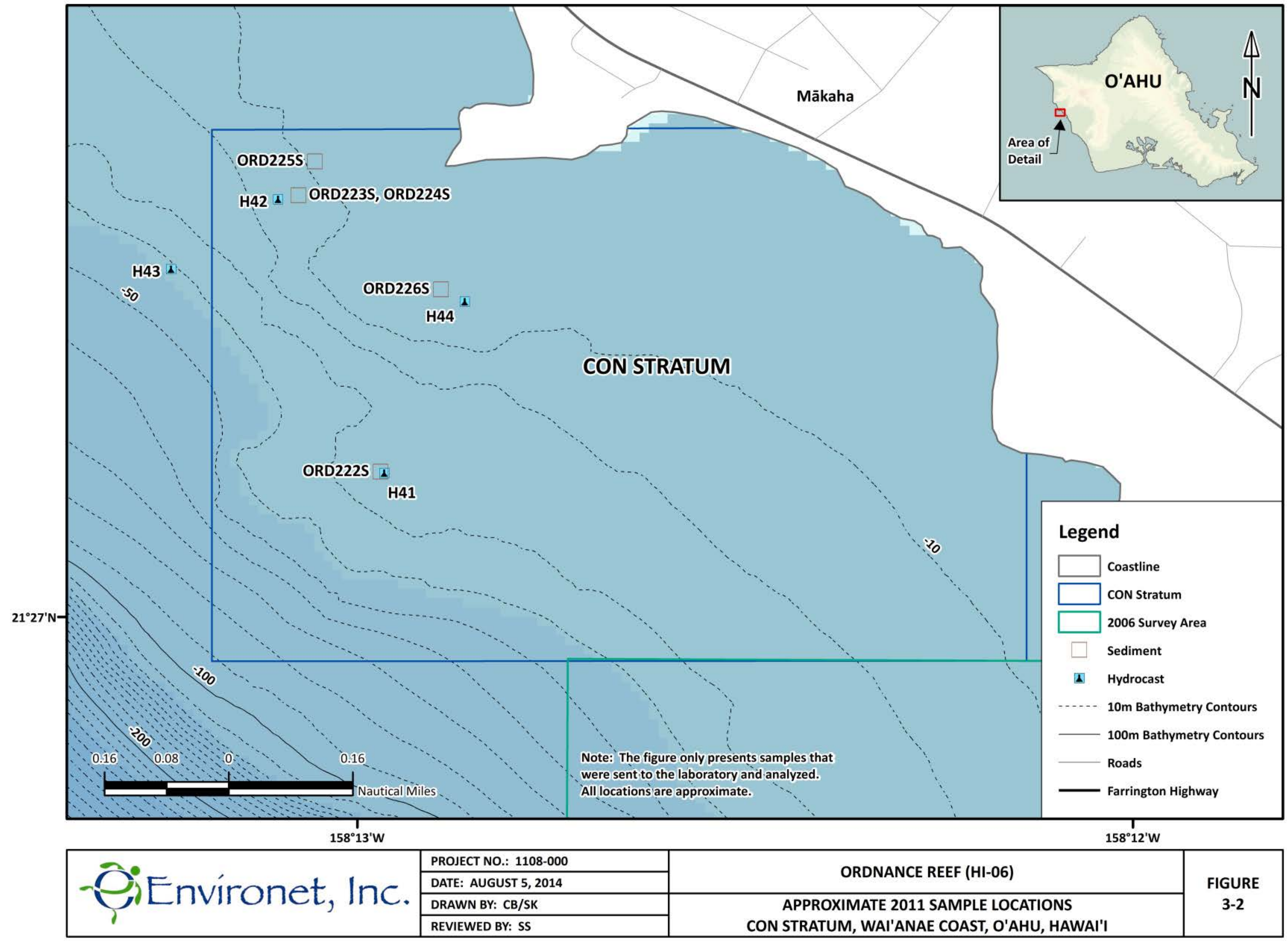
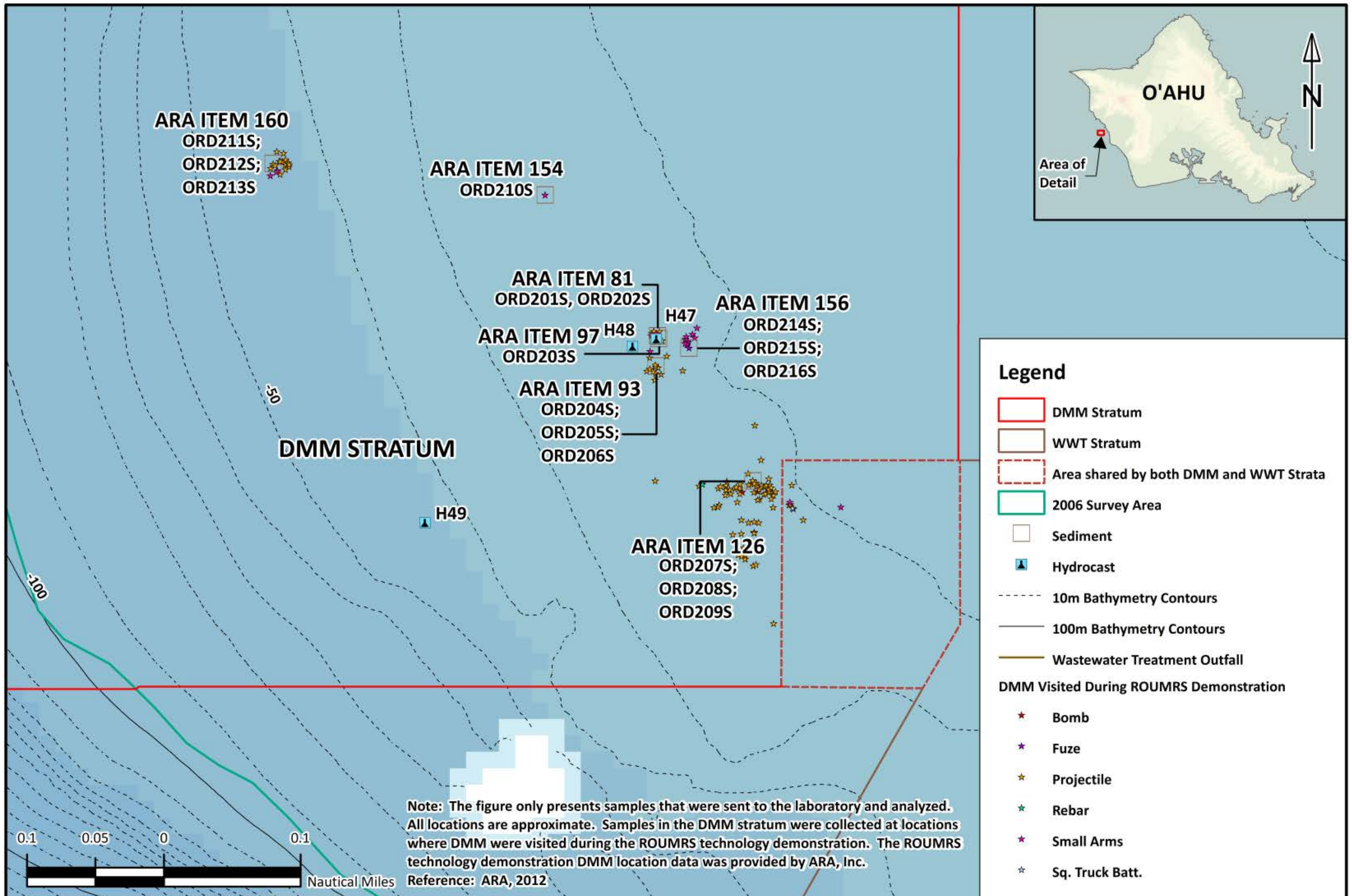


Figure 3-3: Approximate sampling locations for the DMM stratum in 2011off the Wai'anae Coast, O'ahu, Hawai'i.



Environet, Inc.	PROJECT NO.: 1108-000	ORDNANCE REEF (HI-06)	FIGURE 3-3
	DATE: AUGUST 5, 2014		
	DRAWN BY: CB/SK	APPROXIMATE 2011 SAMPLE LOCATIONS DMM STRATUM, WAI'ANAE COAST, O'AHU, HAWAI'I	
	REVIEWED BY: SS		

Figure 3-4: Approximate sampling locations for the WWT stratum in 2011off the Wai‘anae Coast, O‘ahu, Hawai‘i.

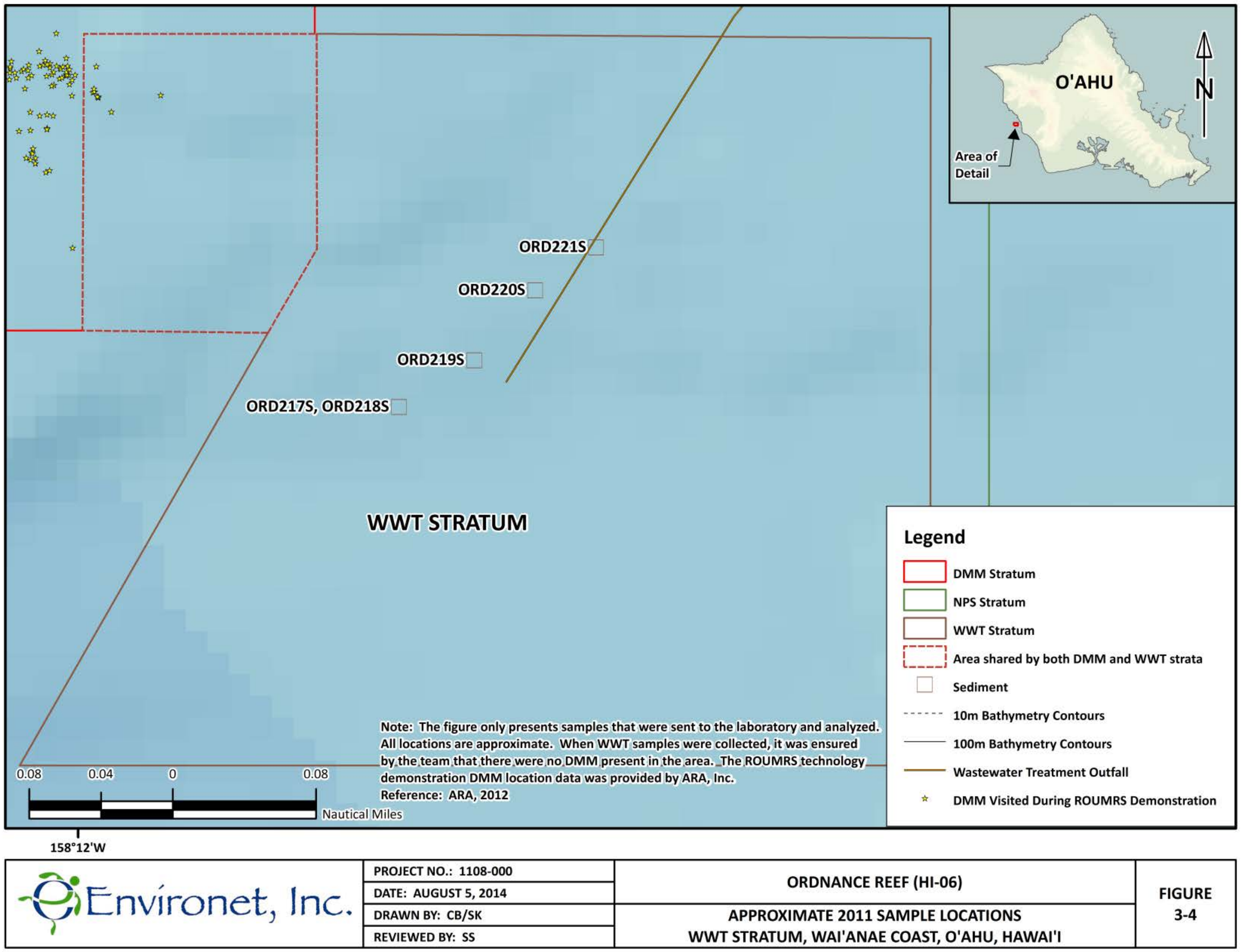
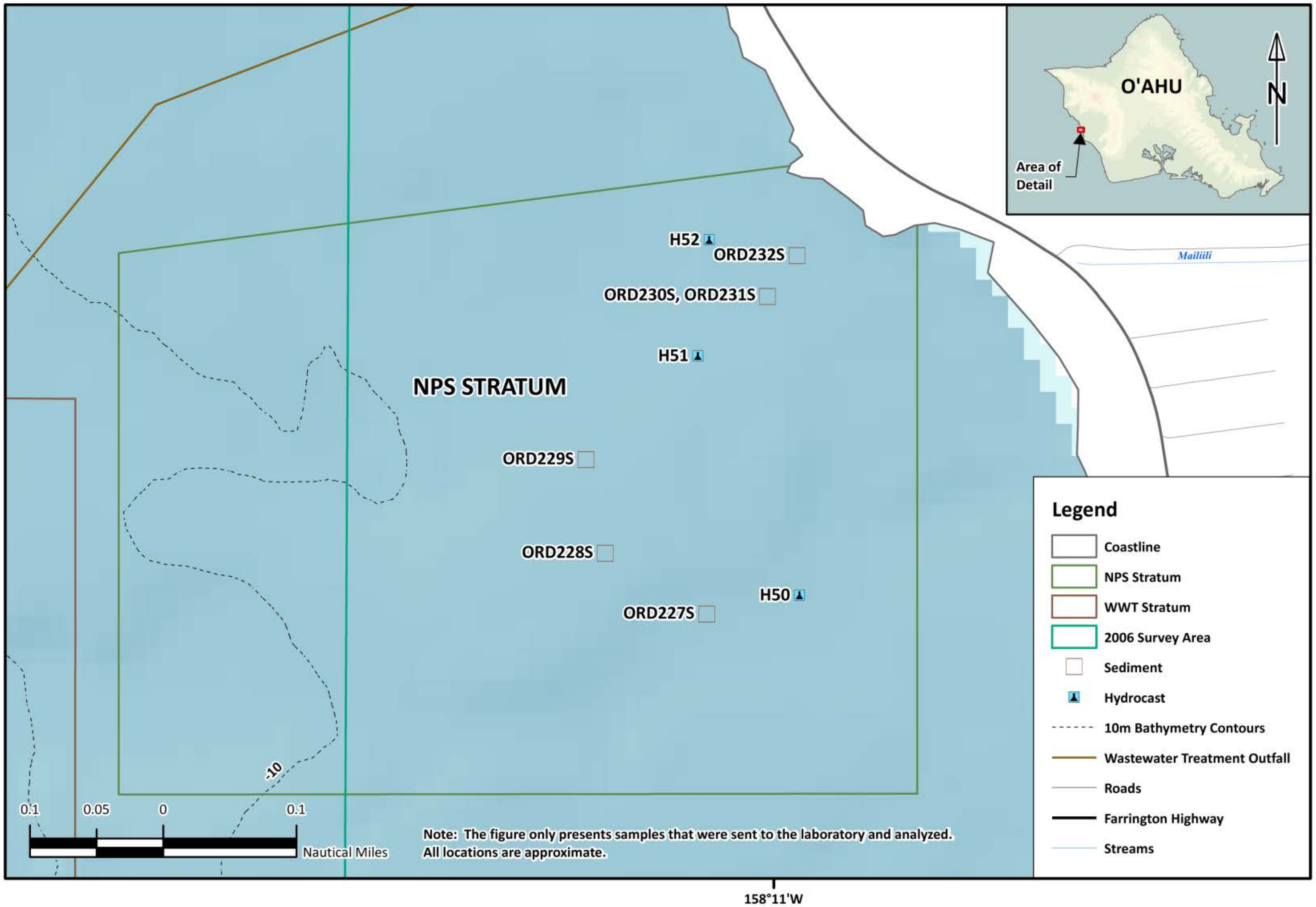
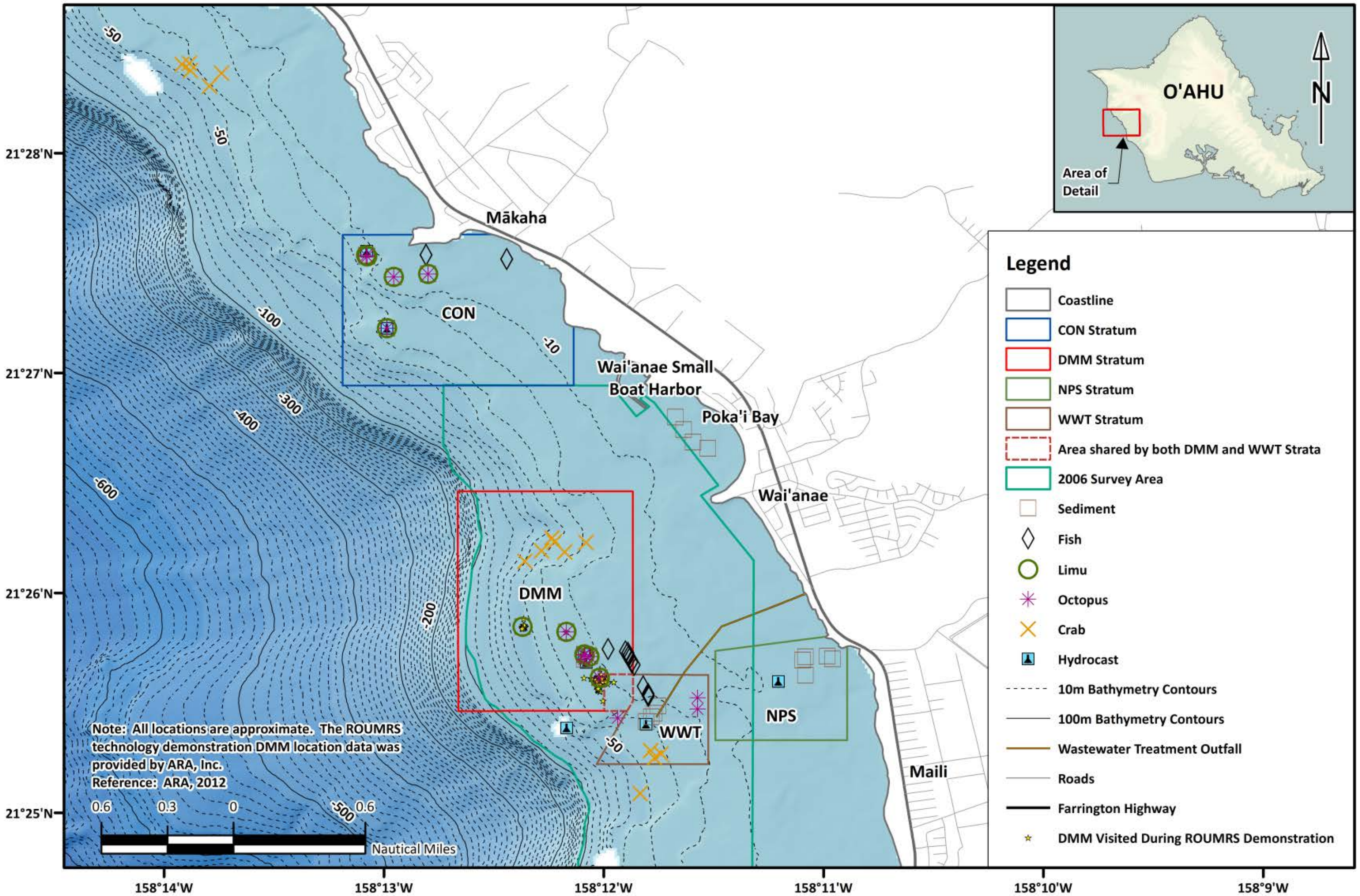


Figure 3-5: Approximate sampling locations for the NPS stratum in 2011off the Wai'anae Coast, O'ahu, Hawai'i.



Environet, Inc.	PROJECT NO.: 1108-000	ORDNANCE REEF (HI-06)	FIGURE 3-5
	DATE: AUGUST 5, 2014		
	DRAWN BY: CB/SK	APPROXIMATE 2011 SAMPLE LOCATIONS NPS STRATUM, WAI'ANAE COAST, O'AHU, HAWAI'I	
	REVIEWED BY: SS		

Figure 3-6: Approximate sampling locations for <u>all strata</u> in 2012off the Wai'anae Coast, O'ahu, Hawai'i.



Environet, Inc.	PROJECT NO.: 1108-000	ORDNANCE REEF (HI-06)	FIGURE 3-6
	DATE: AUGUST 5, 2014		
	DRAWN BY: CB/SK	APPROXIMATE 2012 SAMPLE LOCATIONS WAI'ANAE COAST, O'AHU, HAWAI'I	
	REVIEWED BY: SS		

Figure 3-7: Approximate sampling locations for the CON stratum in 2012 off the Wai'anae Coast, O'ahu, Hawai'i.

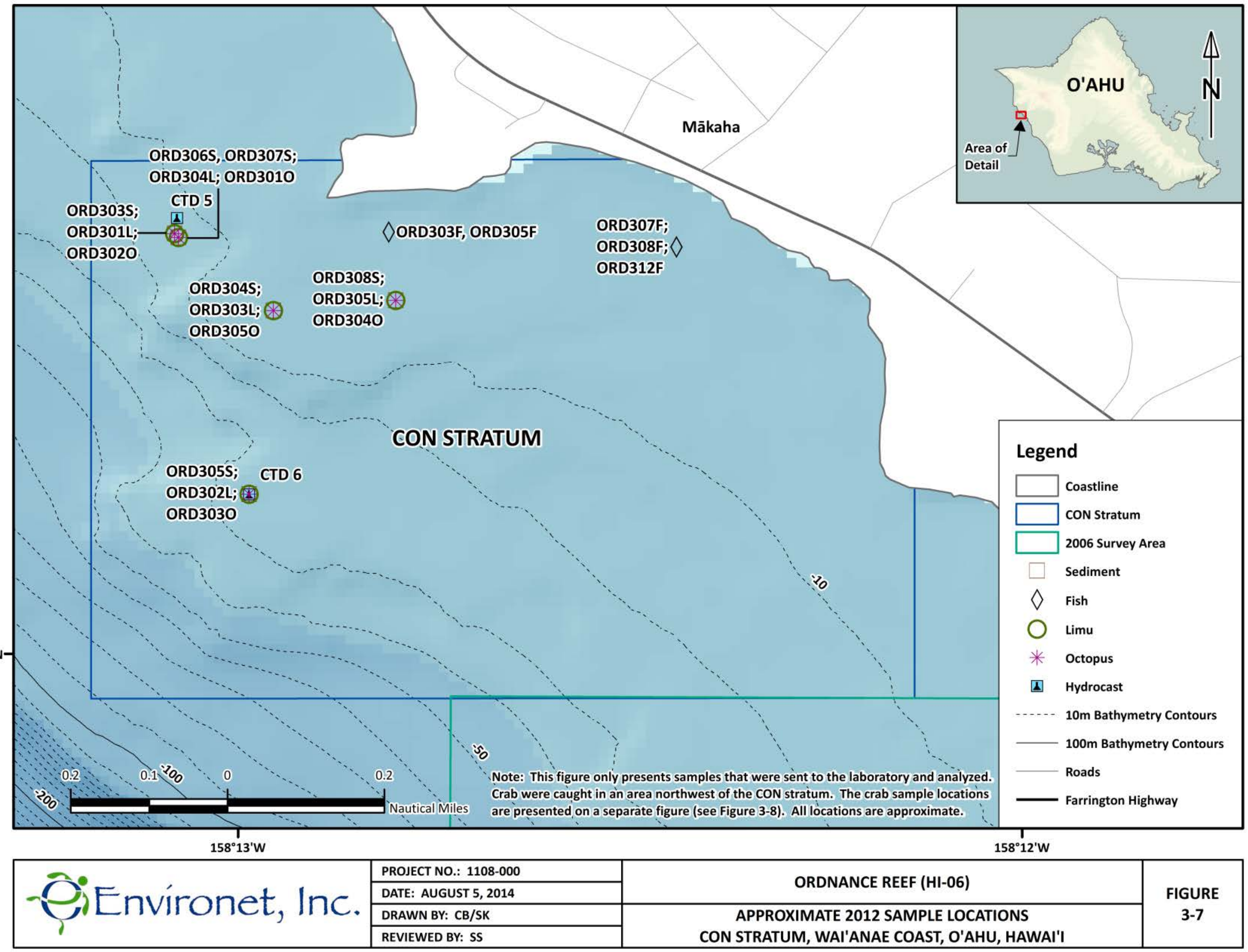


Figure 3-8: Approximate sampling locations for northwest of CON stratum in 2012 off the Wai'anae Coast, O'ahu, Hawai'i.

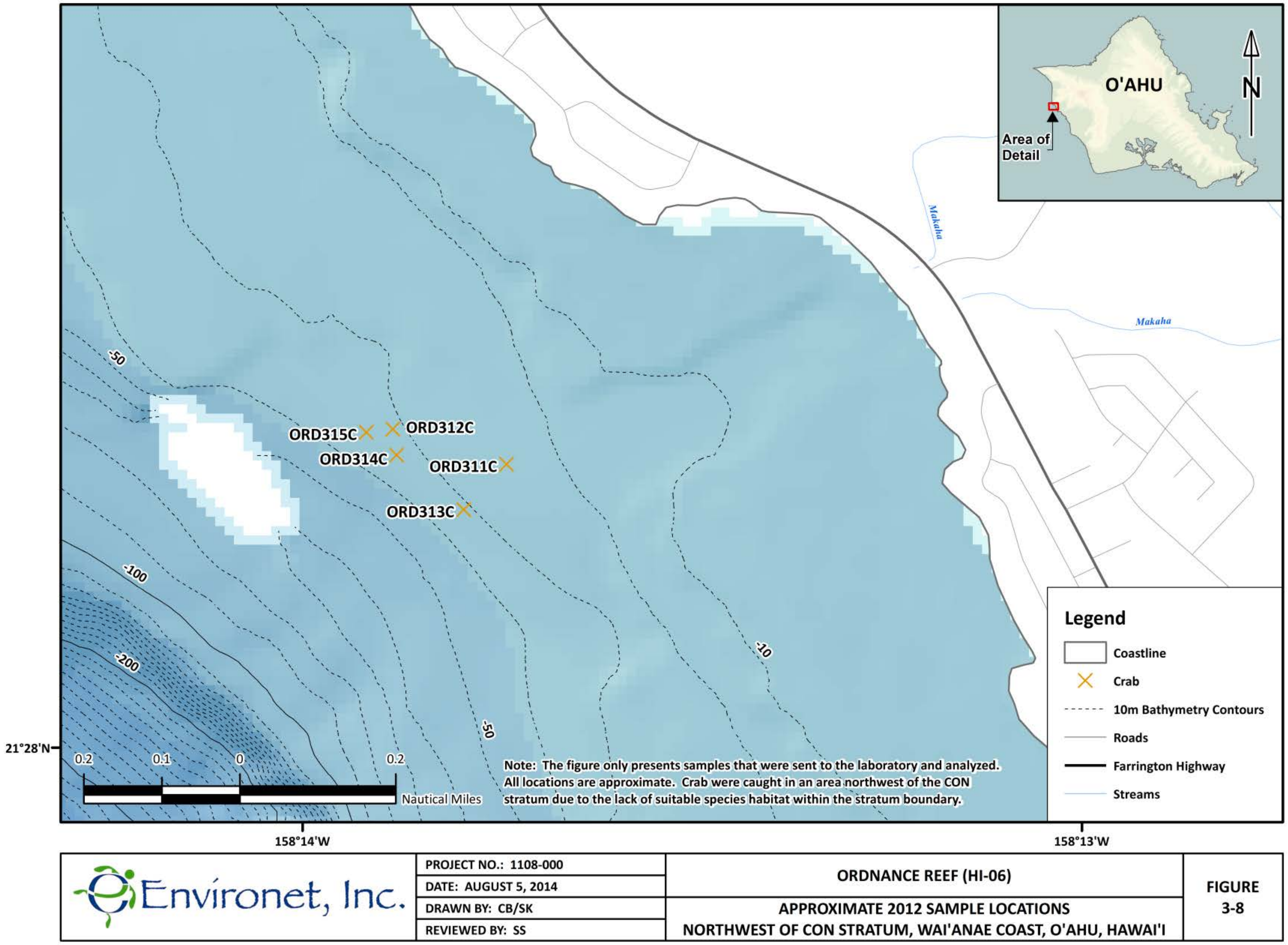
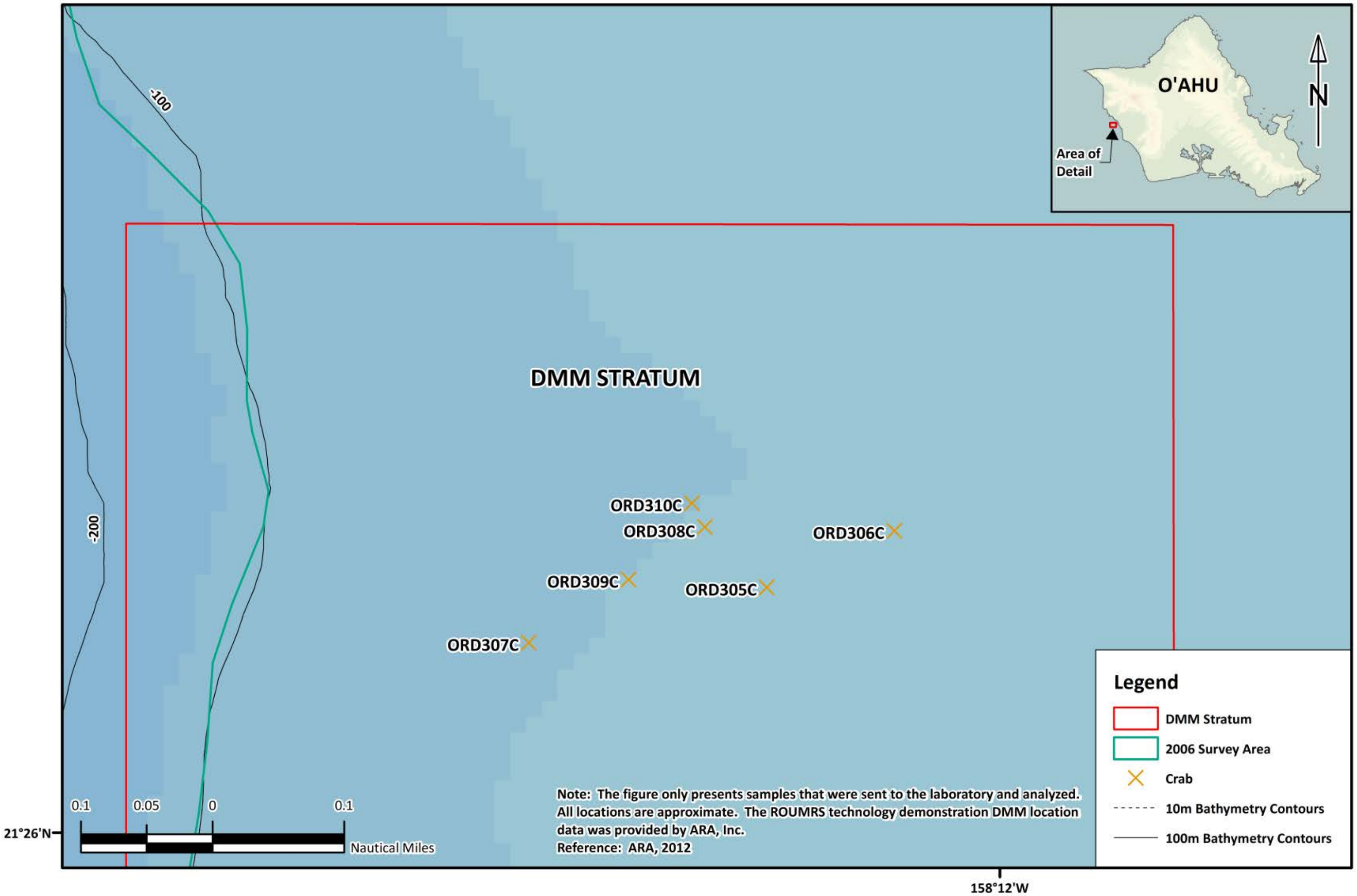
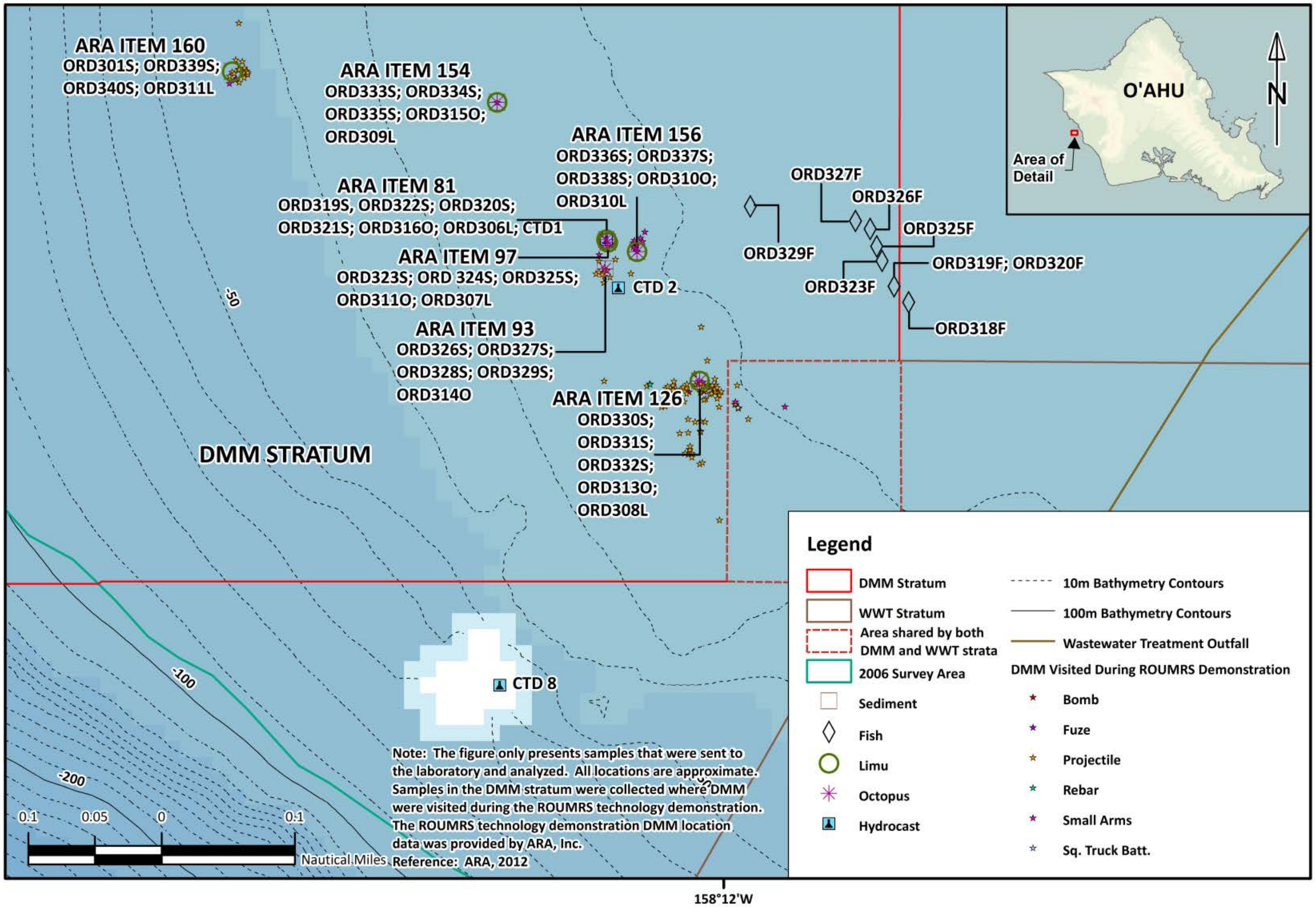


Figure 3-9: Approximate sampling locations for DMM stratum in 2012 off the Wai'anae Coast, O'ahu, Hawai'i.



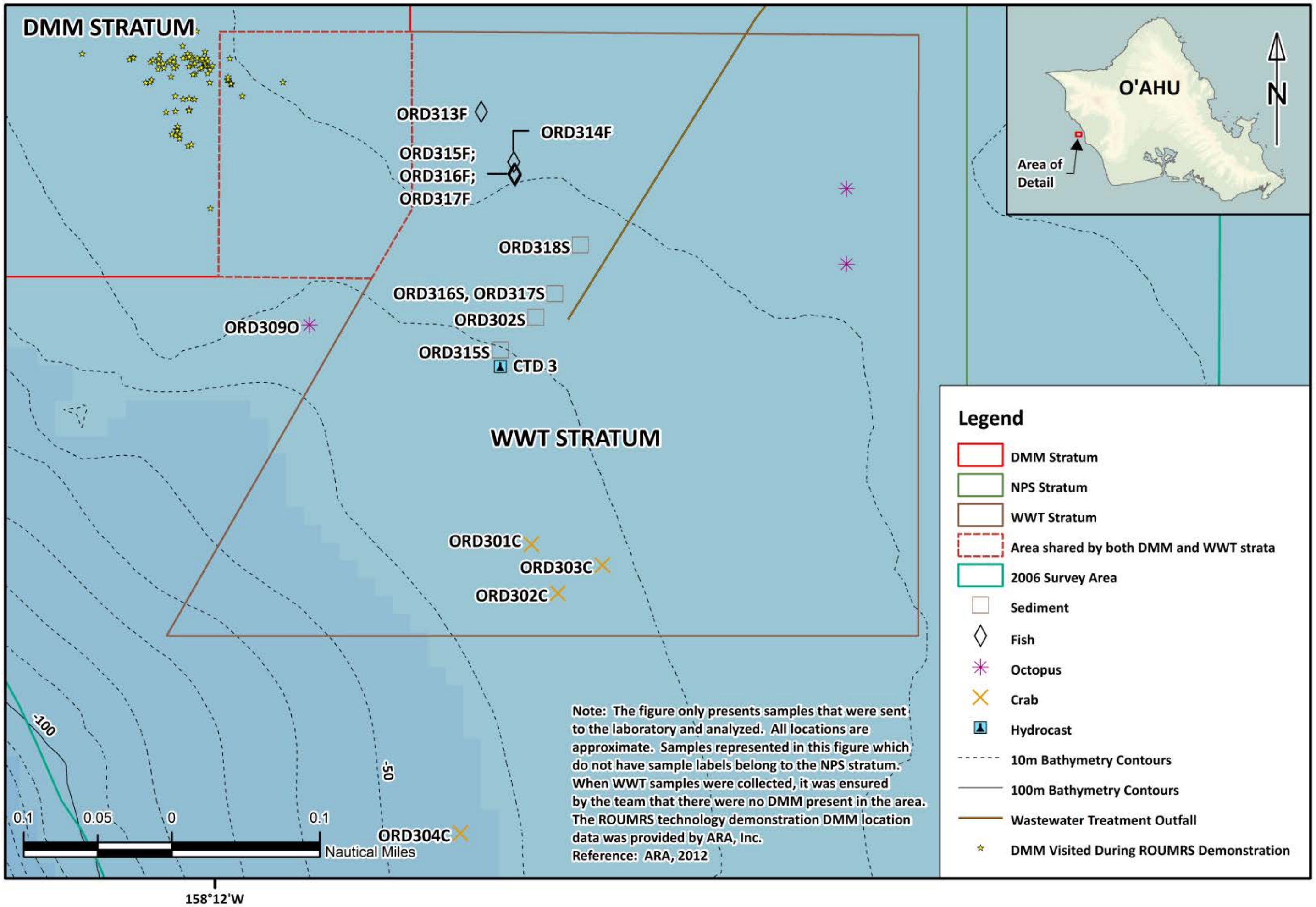
Environet, Inc.	PROJECT NO.: 1108-000	ORDNANCE REEF (HI-06)	FIGURE 3-9
	DATE: AUGUST 5, 2014		
	DRAWN BY: CB/SK	APPROXIMATE 2012 SAMPLE LOCATIONS DMM STRATUM (NORTH), WAI'ANAE COAST, O'AHU, HAWAI'I	
	REVIEWED BY: SS		

Figure 3-10: Approximate sampling locations for DMM stratum (south) in 2012off the Wai'anae Coast, O'ahu, Hawai'i.



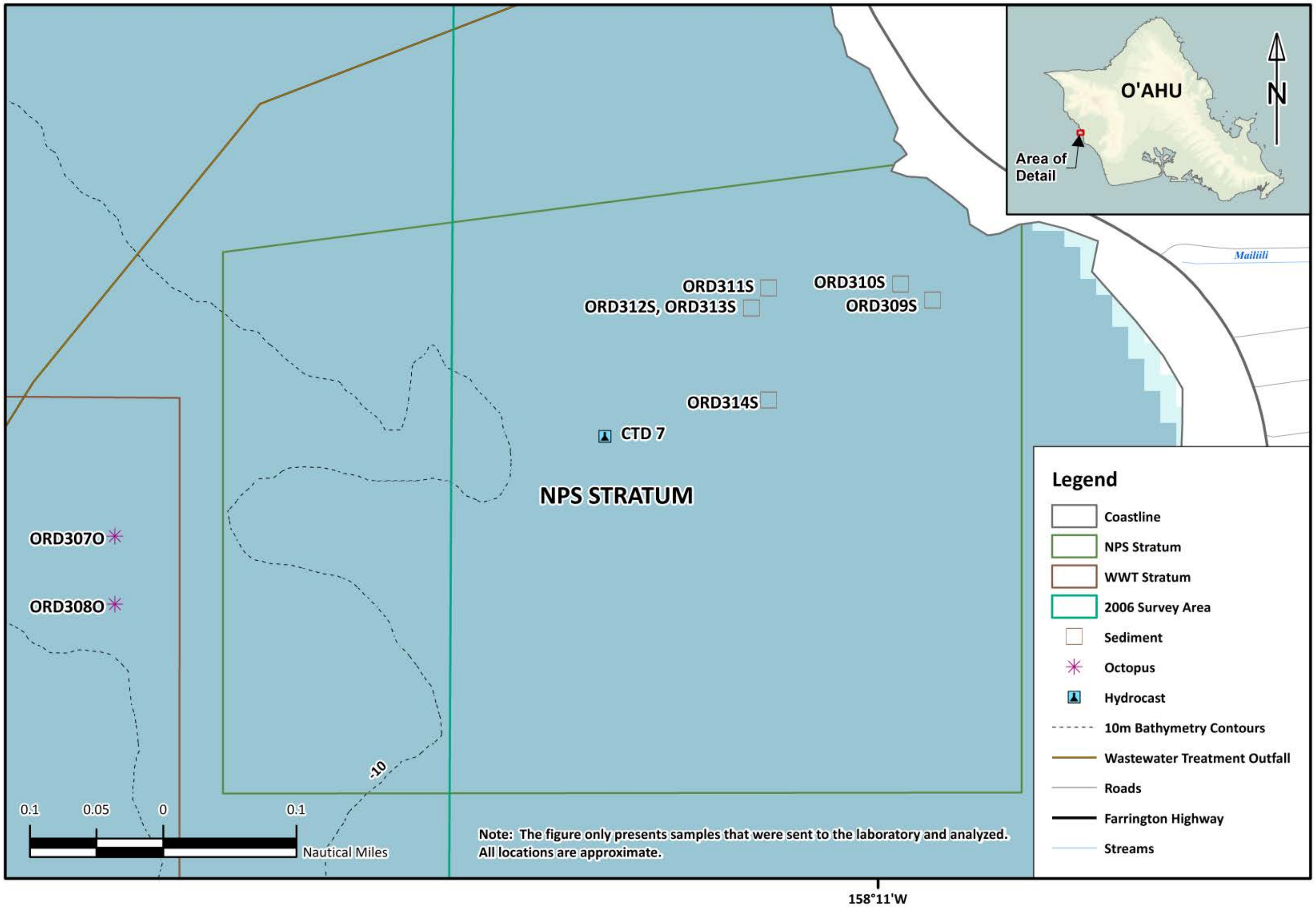
Environet, Inc.	PROJECT NO.: 1108-000 DATE: AUGUST 5, 2014 DRAWN BY: CB/SK REVIEWED BY: SS	ORDNANCE REEF (HI-06) APPROXIMATE 2012 SAMPLE LOCATIONS DMM STRATUM (SOUTH), WAI'ANAE COAST, O'AHU, HAWAI'I	FIGURE 3-10

Figure 3-11: Approximate sampling locations for WWT stratum in 2012 off the Wai‘anae Coast, O‘ahu, Hawai‘i.



Environet, Inc.	PROJECT NO.: 1108-000 DATE: August 5, 2014 DRAWN BY: CB/SK REVIEWED BY: SS	ORDNANCE REEF (HI-06) APPROXIMATE 2012 SAMPLE LOCATIONS WWT STRATUM, WAI'ANAE COAST, O'AHU, HAWAI'I	FIGURE 3-11

Figure 3-12: Approximate sampling locations for NPS stratum in 2012 off the Wai'anae Coast, O'ahu, Hawai'i.



Environet, Inc.	PROJECT NO.: 1108-000	ORDNANCE REEF (HI-06)	FIGURE 3-12
	DATE: AUGUST 5, 2014		
	DRAWN BY: CB/SK	APPROXIMATE 2012 SAMPLE LOCATIONS NPS STRATUM, WAI'ANAE COAST, O'AHU, HAWAI'I	
	REVIEWED BY: SS		

Figure 3-13: Approximate sampling locations for all strata in 2013 off the Wai'anae Coast, O'ahu, Hawai'i.

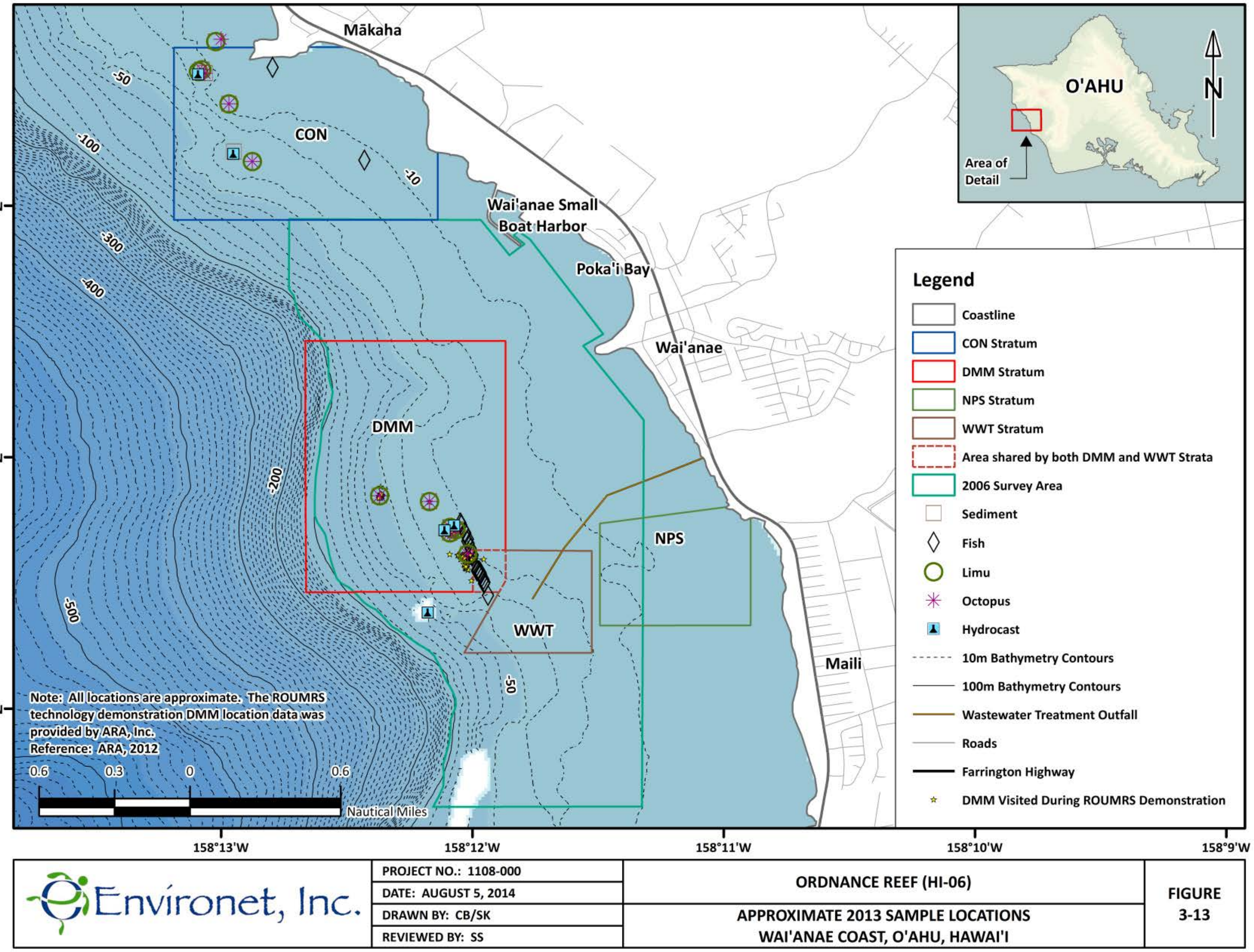
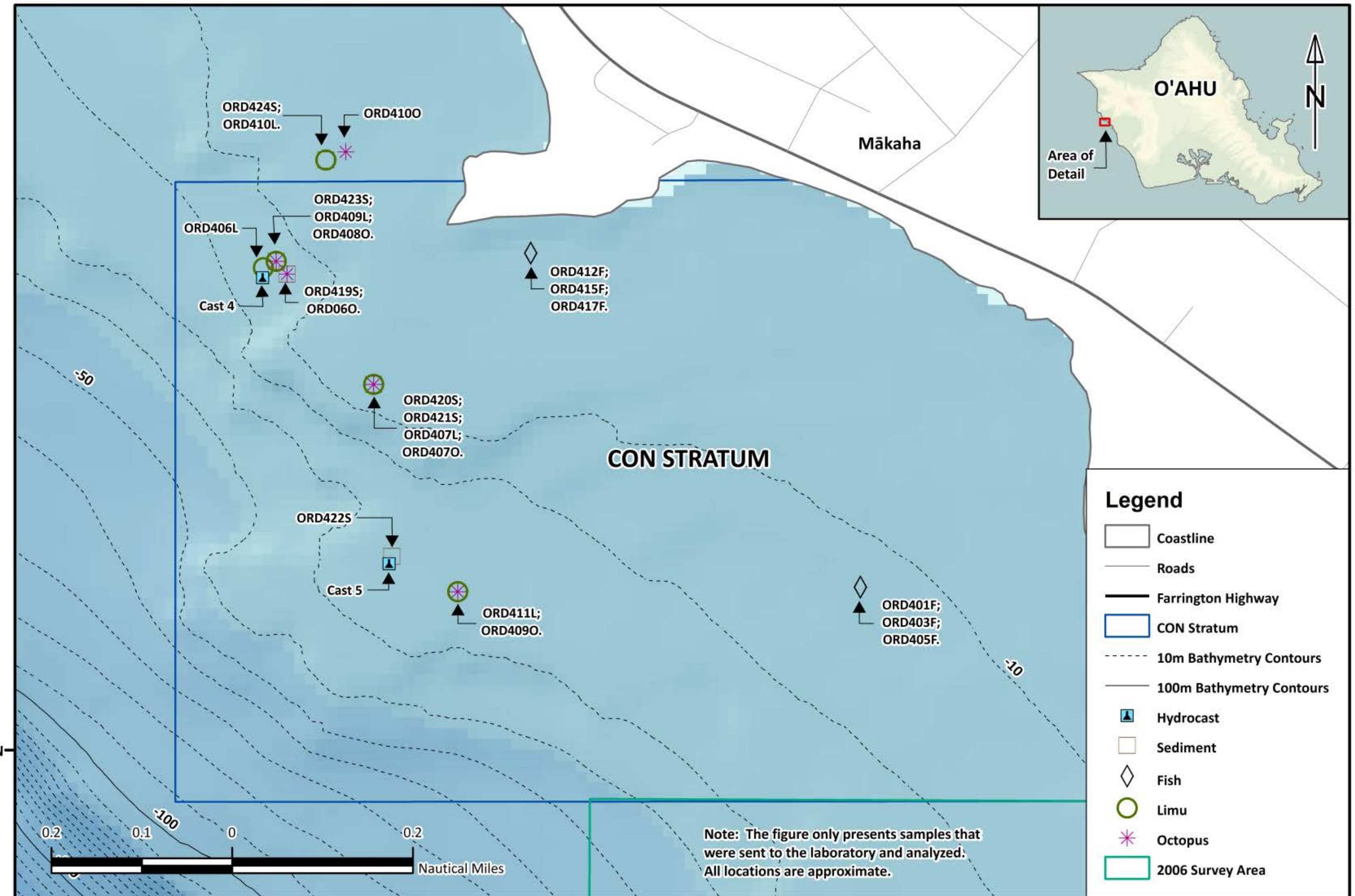


Figure 3-14: Approximate sampling locations for the CON stratum in 2013 off the Wai'anae Coast, O'ahu, Hawai'i.



Environet, Inc.	PROJECT NO.: 1108-000	ORDNANCE REEF (HI-06)	FIGURE 3-14
	DATE: AUGUST 5, 2014		
	DRAWN BY: CB/SK	APPROXIMATE 2013 SAMPLE LOCATIONS	
	REVIEWED BY: SS	CON STRATUM, WAI'ANAE COAST, O'AHU, HAWAI'I	

Figure 3-15: Approximate sampling locations for the DMM stratum in 2013 off the Wai‘anae Coast, O‘ahu, Hawai‘i.

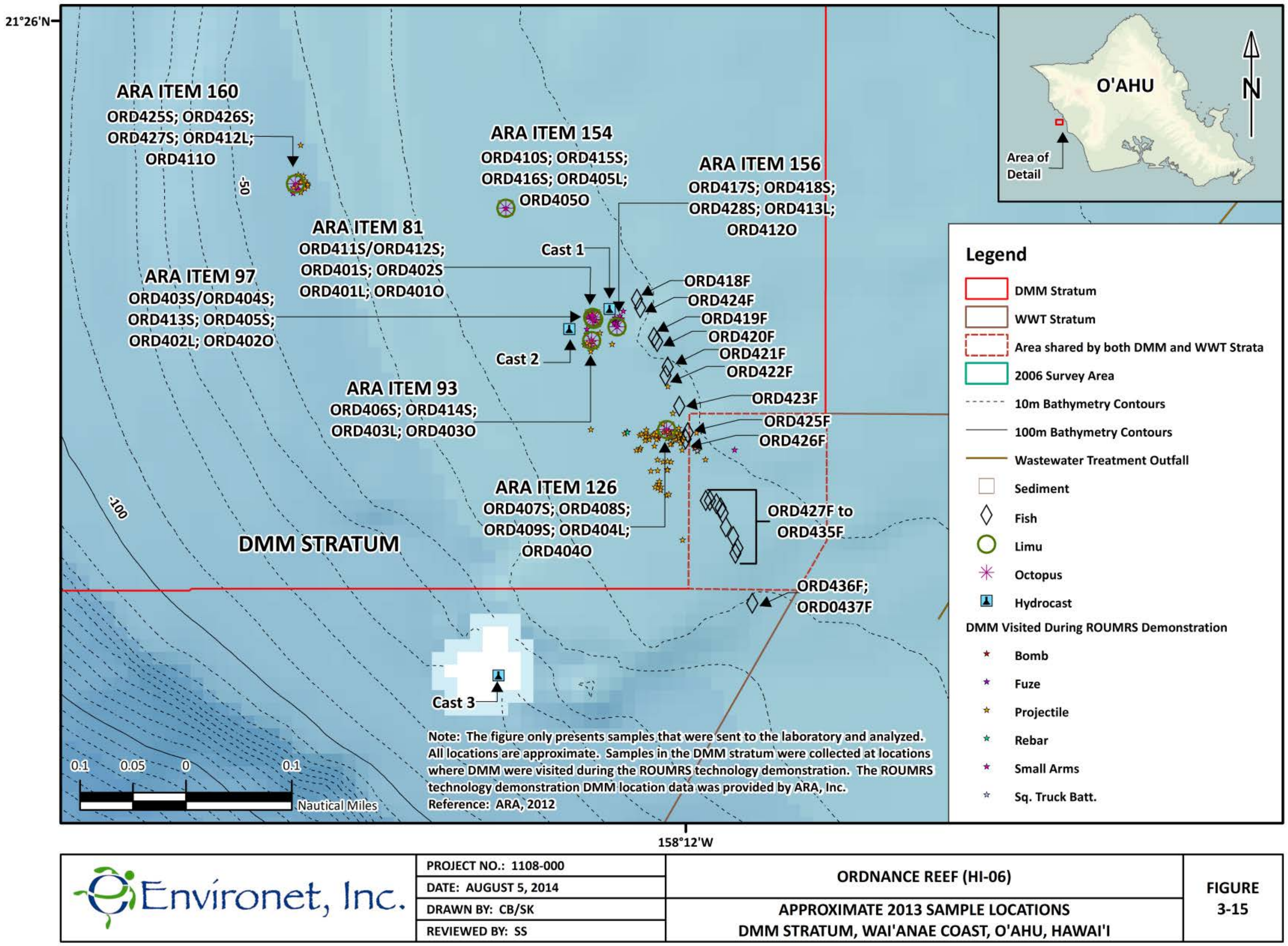


Table 3-1: Statistical summary of pre-ROUMRS (2009 UH OR Study) and post-ROUMRS (Follow-Up Investigation) sediment data (all units are in mg/kg-dw)

Analyte	Strata	Study	Mean	Std Error	Std Dev	Max	75th Pctl	Median	25th Pctl	Min	DL Range	n	# of NDs	%NDs	Method
Aluminum (Al)	DMM	OR	1009	47.0	244	1767	1140	970	876	616	---	27	0	0.0%	Std
	DMM	FUI	870	26.6	199	1328	972	877	731	371	---	56	0	0.0%	Std
	WWT	OR	3145	691	2185	8036	4720	2206	1511	1373	---	10	0	0.0%	Std
	WWT	FUI	6280	1066	3014	11860	7797	6326	3957	2041	---	8	0	0.0%	Std
	NPS	OR	1510	275	777	2478	2241	1466	1203	6	---	8	0	0.0%	Std
	NPS	FUI	1724	183	578	2421	2292	1863	1050	942	---	10	0	0.0%	Std
	CON	OR	7907	1814	5132	15141	13510	6839	3577	1060	---	8	0	0.0%	Std
	CON	FUI	7601	1493	5585	15483	13520	6167	2260	919	---	14	0	0.0%	Std
Antimony (Sb)	DMM	OR	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	---
	DMM	FUI	0.112	0.012	0.074	0.500	0.128	0.098	0.080	0.048	0.076-0.760	56	41	73.2%	ROS
	WWT	OR	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	---
	WWT	FUI	*	*	*	ND	*	*	*	ND	0.48-0.70	8	8	100.0%	---
	NPS	OR	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	---
	NPS	FUI	*	*	*	ND	*	*	*	ND	0.49-0.73	10	10	100.0%	---
	CON	OR	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	---
	CON	FUI	0.120	0.014	0.031	0.160	0.145	0.130	0.089	0.078	0.08-0.75	14	9	64.3%	ROS
Arsenic (As)	DMM	OR	3.67	0.384	1.99	7.58	5.29	3.95	2.22	0.113	---	27	0	0.0%	Std
	DMM	FUI	1.75	0.127	0.948	3.50	2.50	1.90	1.20	ND	0.13-1.1	56	10	17.9%	K-M
	WWT	OR	2.76	0.651	2.06	6.82	3.77	3.10	1.13	0.000	---	10	0	0.0%	Std
	WWT	FUI	2.52	0.401	1.14	4.15	3.80	2.60	1.80	ND	0.72-1.0	8	1	12.5%	K-M
	NPS	OR	3.51	0.938	2.65	6.25	5.59	4.78	0.305	0.000	---	8	0	0.0%	Std
	NPS	FUI	3.74	0.559	1.77	6.20	5.23	3.83	1.88	1.20	0.74-1.1	10	0	0.0%	Std
	CON	OR	12.1	2.04	5.77	20.1	16.5	12.5	9.19	1.09	---	8	0	0.0%	Std
	CON	FUI	9.52	2.01	7.52	20.0	17.0	10.6	3.10	ND	0.12-1.1	14	2	14.3%	K-M
Barium (Ba)	DMM	OR	5.18	0.556	2.89	14.3	5.11	4.51	3.87	1.77	---	27	0	0.0%	Std
	DMM	FUI	5.13	0.709	5.31	34.0	4.40	3.90	3.70	3.00	0.069-0.680	56	0	0.0%	Std
	WWT	OR	10.4	2.50	7.91	24.7	18.5	7.54	4.74	0.130	---	10	0	0.0%	Std
	WWT	FUI	5.38	0.383	1.08	6.90	6.38	5.18	4.65	3.70	0.43-0.63	8	0	0.0%	Std
	NPS	OR	5.70	0.391	1.11	7.25	6.29	6.10	4.87	3.72	---	8	0	0.0%	Std
	NPS	FUI	4.96	0.232	0.734	6.40	5.50	4.85	4.38	3.95	0.44-0.65	10	0	0.0%	Std
	CON	OR	14.6	2.68	7.57	23.9	23.1	12.0	8.23	5.29	---	8	0	0.0%	Std
	CON	FUI	5.61	0.389	1.46	8.80	6.63	5.65	4.40	3.55	0.072-0.670	14	0	0.0%	Std
Cadmium (Cd)	DMM	OR	0.195	0.077	0.402	1.82	0.199	0.008	0.000	0.000	---	27	0	0.0%	Std
	DMM	FUI	0.113	0.012	0.089	0.750	0.119	0.102	0.087	0.066	0.038-0.380	56	37	66.1%	ROS
	WWT	OR	0.202	0.117	0.371	1.01	0.344	0.009	0.004	0.000	---	10	0	0.0%	Std
	WWT	FUI	*	*	*	0.250	*	*	*	ND	0.24-0.35	8	7	87.5%	---
	NPS	OR	0.310	0.150	0.424	1.25	0.408	0.212	0.000	0.000	---	8	0	0.0%	Std

Table 3-1: Statistical summary of pre-ROUMRS (2009 UH OR Study) and post-ROUMRS (Follow-Up Investigation) sediment data (all units are in mg/kg-dw)

Analyte	Strata	Study	Mean	Std Error	Std Dev	Max	75th Pctl	Median	25th Pctl	Min	DL Range	n	# of NDs	%NDs	Method
	NPS	FUI	*	*	*	ND	*	*	*	ND	0.25-0.36	10	10	100.0%	---
	CON	OR	0.068	0.048	0.135	0.399	0.050	0.027	0.000	0.000	---	8	0	0.0%	Std
	CON	FUI	0.292	0.051	0.192	0.620	0.488	0.165	0.160	0.115	0.04-0.37	14	7	50.0%	ROS
Calcium (Ca)	DMM	OR	327690	4216	21907	367642	340352	334009	323900	264558	---	27	0	0.0%	Std
	DMM	FUI	337534	2381	17818	358861	345480	340152	335196	230707	---	56	0	0.0%	Std
	WWT	OR	307102	11728	37087	339131	333768	321340	288955	219864	---	10	0	0.0%	Std
	WWT	FUI	332652	3686	10425	349023	340561	332653	326524	314837	---	8	0	0.0%	Std
	NPS	OR	274692	40564	114733	342124	340814	312861	269552	331	---	8	0	0.0%	Std
	NPS	FUI	344490	5715	18074	352818	352102	349617	348656	293321	---	10	0	0.0%	Std
	CON	OR	304825	9681	27382	339275	325445	308211	283225	259115	---	8	0	0.0%	Std
	CON	FUI	322735	4221	15795	340829	335227	326663	305506	292648	---	14	0	0.0%	Std
Chromium (Cr)	DMM	OR	14.3	0.976	5.07	30.7	17.0	11.9	10.7	9.36	---	27	0	0.0%	Std
	DMM	FUI	10.7	0.252	1.89	15.0	12.0	10.3	9.39	7.20	0.076-0.760	56	0	0.0%	Std
	WWT	OR	32.5	6.26	19.8	71.9	45.7	31.1	12.6	7.96	---	10	0	0.0%	Std
	WWT	FUI	16.8	1.86	5.25	23.0	22.0	17.5	12.2	8.80	0.48-0.70	8	0	0.0%	Std
	NPS	OR	16.8	2.82	7.98	26.6	23.4	17.0	12.7	1.36	---	8	0	0.0%	Std
	NPS	FUI	11.2	0.450	1.42	13.3	12.3	11.0	10.1	9.00	0.49-0.73	10	0	0.0%	Std
	CON	OR	63.8	12.6	35.5	113	95.4	64.6	34.5	11.1	---	8	0	0.0%	Std
	CON	FUI	19.6	2.68	10.0	33.0	30.3	18.4	9.02	6.70	0.08-0.75	14	0	0.0%	Std
Cobalt (Co)	DMM	OR	3.54	0.201	1.05	6.29	4.40	3.20	2.71	2.16	---	27	0	0.0%	Std
	DMM	FUI	1.05	0.044	0.329	1.60	1.30	1.10	0.688	0.500	0.0076-0.0760	56	0	0.0%	Std
	WWT	OR	5.74	0.896	2.84	11.6	7.53	4.53	3.85	3.15	---	10	0	0.0%	Std
	WWT	FUI	2.56	0.375	1.06	4.20	3.40	2.65	1.65	1.00	0.048-0.070	8	0	0.0%	Std
	NPS	OR	4.80	0.473	1.34	7.72	4.99	4.65	4.24	2.96	---	8	0	0.0%	Std
	NPS	FUI	1.14	0.092	0.290	1.60	1.30	1.15	0.948	0.740	0.049-0.073	10	0	0.0%	Std
	CON	OR	11.0	2.09	5.91	18.6	17.5	9.41	5.79	4.21	---	8	0	0.0%	Std
	CON	FUI	4.38	0.858	3.21	9.90	6.85	3.55	1.39	0.890	0.008-0.075	14	0	0.0%	Std
Copper (Cu)	DMM	OR	399	104	541	2500	601	215	107	3.00	---	27	0	0.0%	Std
	DMM	FUI	241	89.3	669	4100	77.0	18.6	9.10	1.90	0.076-0.760	56	0	0.0%	Std
	WWT	OR	23.4	8.87	28.0	95.4	34.7	15.4	3.99	3.08	---	10	0	0.0%	Std
	WWT	FUI	6.19	1.13	3.20	12.0	7.96	6.17	3.48	1.80	0.48-0.70	8	0	0.0%	Std
	NPS	OR	2.18	0.176	0.498	2.80	2.63	2.26	1.73	1.39	---	8	0	0.0%	Std
	NPS	FUI	1.52	0.248	0.784	3.65	1.55	1.30	1.15	0.860	0.49-0.73	10	0	0.0%	Std
	CON	OR	10.6	2.71	7.66	24.3	16.7	7.84	4.04	3.82	---	8	0	0.0%	Std
	CON	FUI	3.70	0.583	2.18	7.30	6.03	3.45	1.54	1.20	0.08-0.75	14	0	0.0%	Std
Iron (Fe)	DMM	OR	2453	300	1558	8984	2743	1991	1605	1116	---	27	0	0.0%	Std
	DMM	FUI	2287	138	1036	8908	2516	2154	1721	1266	---	56	0	0.0%	Std

Table 3-1: Statistical summary of pre-ROUMRS (2009 UH OR Study) and post-ROUMRS (Follow-Up Investigation) sediment data (all units are in mg/kg-dw)

Analyte	Strata	Study	Mean	Std Error	Std Dev	Max	75th Pctl	Median	25th Pctl	Min	DL Range	n	# of NDs	%NDs	Method
	WWT	OR	3930	949	3001	10915	5594	2790	1912	1368	---	10	0	0.0%	Std
	WWT	FUI	7762	1200	3395	13411	9995	7529	4991	2984	---	8	0	0.0%	Std
	NPS	OR	1669	264	747	2264	2200	1895	1457	8.00	---	8	0	0.0%	Std
	NPS	FUI	2617	225	711	3636	3166	2693	1833	1537	---	10	0	0.0%	Std
	CON	OR	10600	2708	7659	22245	19178	8266	5493	875	---	8	0	0.0%	Std
	CON	FUI	9950	1727	6461	19482	18850	8058	5103	1812	---	14	0	0.0%	Std
Lead (Pb)	DMM	OR	44.4	21.0	109	549	17.7	11.3	9.60	1.70	---	27	0	0.0%	Std
	DMM	FUI	11.1	4.08	30.6	228	7.77	4.80	2.87	1.80	0.044-0.450	56	0	0.0%	Std
	WWT	OR	7.12	1.61	5.11	18.2	9.26	5.61	3.10	2.08	---	10	0	0.0%	Std
	WWT	FUI	2.66	0.581	1.64	5.60	4.03	1.93	1.35	1.10	0.29-0.42	8	0	0.0%	Std
	NPS	OR	5.05	1.18	3.33	11.0	7.91	4.45	2.23	1.20	---	8	0	0.0%	Std
	NPS	FUI	2.83	0.300	0.949	3.80	3.65	3.05	2.08	1.20	0.30-0.44	10	0	0.0%	Std
	CON	OR	26.0	15.8	44.8	136	19.8	9.50	5.80	4.30	---	8	0	0.0%	Std
	CON	FUI	3.74	0.557	2.08	8.80	4.59	3.45	2.28	1.20	0.048-0.450	14	0	0.0%	Std
Magnesium (Mg)	DMM	OR	20788	528	2744	25748	22747	20439	19271	14494	---	27	0	0.0%	Std
	DMM	FUI	21258	348	2601	30766	22091	20969	19925	14734	---	56	0	0.0%	Std
	WWT	OR	16637	819	2589	21686	18758	15728	14498	14284	---	10	0	0.0%	Std
	WWT	FUI	17887	496	1404	19606	19272	18054	16424	15866	---	8	0	0.0%	Std
	NPS	OR	14267	2064	5838	17480	16844	16601	14468	49.0	---	8	0	0.0%	Std
	NPS	FUI	16553	349	1105	17902	17374	16741	15780	14098	---	10	0	0.0%	Std
	CON	OR	20591	1506	4258	26520	25127	19017	16719	15891	---	8	0	0.0%	Std
	CON	FUI	20626	689	2577	25241	22335	21123	19065	15237	---	14	0	0.0%	Std
Manganese (Mn)	DMM	OR	25.9	0.782	4.06	37.8	28.0	26.1	22.7	17.9	---	27	0	0.0%	Std
	DMM	FUI	33.9	6.89	51.6	403	34.3	25.1	21.3	3.30	---	56	0	0.0%	Std
	WWT	OR	63.5	10.3	32.6	129	93.0	48.5	38.7	36.4	---	10	0	0.0%	Std
	WWT	FUI	111	14.3	40.3	177	134	109	91.6	37.7	---	8	0	0.0%	Std
	NPS	OR	47.1	6.93	19.6	60.9	57.0	54.1	46.9	0.110	---	8	0	0.0%	Std
	NPS	FUI	63.8	4.99	15.8	95.9	72.8	61.3	52.7	39.4	---	10	0	0.0%	Std
	CON	OR	154	32.7	92.6	290	252	146	88.1	27.9	---	8	0	0.0%	Std
	CON	FUI	136	20.6	76.9	248	235	129	70.0	34.7	---	14	0	0.0%	Std
Nickel (Ni)	DMM	OR	33.6	2.31	12.0	62.9	38.8	30.0	25.9	14.7	---	27	0	0.0%	Std
	DMM	FUI	6.55	0.594	4.44	15.5	9.40	7.60	1.40	ND	0.076-3.60	56	15	26.8%	K-M
	WWT	OR	50.9	8.03	25.4	105	65.2	37.3	33.4	27.3	---	10	0	0.0%	Std
	WWT	FUI	12.8	3.20	9.06	30.0	17.6	12.0	5.22	1.60	0.48-0.70	8	0	0.0%	Std
	NPS	OR	40.5	5.59	15.8	59.8	54.2	41.9	29.6	14.0	---	8	0	0.0%	Std
	NPS	FUI	1.58	0.395	1.25	3.70	2.90	1.09	0.550	0.550	0.49-3.5	10	5	50.0%	ROS
	CON	OR	61.1	9.86	27.9	103	87.8	52.3	34.7	32.3	---	8	0	0.0%	Std

Table 3-1: Statistical summary of pre-ROUMRS (2009 UH OR Study) and post-ROUMRS (Follow-Up Investigation) sediment data (all units are in mg/kg-dw)

Analyte	Strata	Study	Mean	Std Error	Std Dev	Max	75th Pctl	Median	25th Pctl	Min	DL Range	n	# of NDs	%NDs	Method
	CON	FUI	26.2	6.65	24.9	84.0	38.5	17.1	3.72	1.40	0.08-0.75	14	0	0.0%	Std
Selenium (Se)	DMM	OR	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	---
	DMM	FUI	1.10	0.072	0.540	2.60	1.50	0.990	0.680	ND	0.076-0.760	56	3	5.4%	K-M
	WWT	OR	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	---
	WWT	FUI	1.06	0.197	0.557	1.90	1.80	1.05	0.690	ND	0.48-0.70	8	1	12.5%	K-M
	NPS	OR	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	---
	NPS	FUI	1.02	0.089	0.282	1.50	1.15	1.10	0.920	ND	0.49-0.73	10	1	10.0%	K-M
	CON	OR	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	---
	CON	FUI	1.17	0.080	0.300	1.75	1.43	0.995	0.910	0.880	0.08-0.75	7	0	0.0%	Std
Strontium (Sr)	DMM	OR	2646	39.1	203	3106	2776	2659	2464	2280	---	27	0	0.0%	Std
	DMM	FUI	2385	24.9	186	2810	2476	2394	2327	1620	---	56	0	0.0%	Std
	WWT	OR	2721	180	571	3230	3142	2923	2348	1618	---	10	0	0.0%	Std
	WWT	FUI	3170	113	320	3652	3403	3155	2867	2829	---	8	0	0.0%	Std
	NPS	OR	2806	405	1146	3554	3260	3190	2975	4.00	---	8	0	0.0%	Std
	NPS	FUI	2878	74.9	237	3171	3047	2946	2714	2453	---	10	0	0.0%	Std
	CON	OR	3209	150	423	4009	3467	3177	2929	2614	---	8	0	0.0%	Std
	CON	FUI	2675	57.2	214	2976	2846	2673	2499	2269	---	14	0	0.0%	Std
Titanium (Ti)	DMM	OR	294	8.81	45.8	411	322	294	266	210	---	27	0	0.0%	Std
	DMM	FUI	266	5.86	43.8	367	294	268	232	161	---	56	0	0.0%	Std
	WWT	OR	829	164	520	1977	1238	613	409	403	---	10	0	0.0%	Std
	WWT	FUI	1527	264	747	2974	1853	1492	948	546	---	8	0	0.0%	Std
	NPS	OR	333	50.1	142	431	428	375	315	2.00	---	8	0	0.0%	Std
	NPS	FUI	418	35.3	112	601	489	426	309	262	---	10	0	0.0%	Std
	CON	OR	1730	410	1158	3477	3030	1440	836	326	---	8	0	0.0%	Std
	CON	FUI	1568	264	987	3126	2822	1299	797	276	---	14	0	0.0%	Std
Uranium (U)	DMM	OR	0.703	0.081	0.423	1.20	1.02	0.891	0.230	0.000	---	27	0	0.0%	Std
	DMM	FUI	0.813	0.027	0.203	1.20	0.955	0.840	0.615	0.430	0.0073-0.2300	56	0	0.0%	Std
	WWT	OR	1.05	0.110	0.348	1.52	1.34	1.04	0.880	0.338	---	10	0	0.0%	Std
	WWT	FUI	1.23	0.146	0.414	1.80	1.70	1.18	0.886	0.700	0.048-0.210	8	0	0.0%	Std
	NPS	OR	0.911	0.213	0.602	1.70	1.38	1.11	0.299	0.001	---	8	0	0.0%	Std
	NPS	FUI	1.08	0.086	0.271	1.50	1.40	0.943	0.875	0.760	0.049-0.220	10	0	0.0%	Std
	CON	OR	1.29	0.109	0.308	1.50	1.49	1.37	1.27	0.555	---	8	0	0.0%	Std
	CON	FUI	0.933	0.077	0.290	1.40	1.20	0.905	0.686	0.470	0.008-0.220	14	0	0.0%	Std
Vanadium (V)	DMM	OR	8.61	0.232	1.20	11.2	9.29	8.53	7.88	6.51	---	27	0	0.0%	Std
	DMM	FUI	6.16	0.198	1.48	9.90	7.35	6.10	4.95	3.10	0.23-2.3	56	0	0.0%	Std
	WWT	OR	16.6	2.91	9.21	36.2	23.5	12.9	9.21	7.67	---	10	0	0.0%	Std
	WWT	FUI	11.8	1.26	3.55	17.5	14.0	12.3	8.32	6.80	1.4-2.1	8	0	0.0%	Std

Table 3-1: Statistical summary of pre-ROUMRS (2009 UH OR Study) and post-ROUMRS (Follow-Up Investigation) sediment data (all units are in mg/kg-dw)

Analyte	Strata	Study	Mean	Std Error	Std Dev	Max	75th Pctl	Median	25th Pctl	Min	DL Range	n	# of NDs	%NDs	Method
	NPS	OR	10.4	0.425	1.20	12.5	11.2	10.5	9.33	8.87	---	8	0	0.0%	Std
	NPS	FUI	8.02	0.509	1.61	10.5	9.23	8.45	6.36	5.80	1.5-2.2	10	0	0.0%	Std
	CON	OR	39.4	8.58	24.3	75.0	65.9	30.7	23.9	6.15	---	8	0	0.0%	Std
	CON	FUI	23.6	3.97	14.9	43.0	38.3	21.6	8.50	5.65	0.24-2.2	14	0	0.0%	Std
Zinc (Zn)	DMM	OR	146	16.9	88.1	408	210	131	90.9	12.6	---	27	0	0.0%	Std
	DMM	FUI	71.9	14.8	111	676	73.9	32.0	16.8	4.70	0.46-4.5	56	0	0.0%	Std
	WWT	OR	29.0	5.64	17.8	55.4	45.6	29.0	13.3	5.21	---	10	0	0.0%	Std
	WWT	FUI	16.7	9.65	27.3	84.0	10.0	9.00	4.70	ND	2.9-4.2	8	1	12.5%	K-M
	NPS	OR	6.50	1.43	4.03	12.4	10.3	5.71	2.54	1.42	---	8	0	0.0%	Std
	NPS	FUI	5.44	0.766	2.42	11.5	5.80	4.90	3.90	ND	3.0-4.4	10	3	30.0%	K-M
	CON	OR	24.9	4.89	13.8	49.2	35.6	22.3	13.3	8.54	---	8	0	0.0%	Std
	CON	FUI	13.3	3.15	11.8	48.0	16.6	11.4	4.60	3.20	0.48-4.5	14	0	0.0%	Std
2,4-Dinitrotoluene (2,4-DNT)	DMM	OR	0.387	0.193	0.819	3.30	0.300	0.120	*	ND	0.20	18	7	38.9%	K-M
	DMM	FUI	2.54	1.97	14.7	110	0.420	0.038	*	ND	0.019-0,20	56	25	44.6%	K-M
	WWT	OR	0.048	0.037	0.103	0.300	0.044	0.003	0.000	0.000	0.02	8	5	62.5%	ROS
	WWT	FUI	*	*	*	0.027	*	*	*	ND	0.019-0.020	8	7	87.5%	---
	NPS	OR	*	*	*	ND	*	*	*	ND	0.02	8	8	100.0%	---
	NPS	FUI	*	*	*	<0.063	*	*	*	ND	0.02	10	9	90.0%	---
	CON	OR	*	*	*	ND	*	*	*	ND	0.02	8	8	100.0%	---
	CON	FUI	*	*	*	ND	*	*	*	ND	0.019-0.020	14	14	100.0%	---
2,6-Dinitrotoluene (2,6-DNT)	DMM	OR	*	*	*	0.380	*	*	*	ND	0.029-0.030	18	16	88.9%	---
	DMM	FUI	0.233	0.178	1.336	10.0	0.033	0.004	0.001	0.000	0.028-0.031	56	44	78.6%	ROS
	WWT	OR	*	*	*	ND	*	*	*	ND	0.029-0.030	8	8	100.0%	---
	WWT	FUI	*	*	*	ND	*	*	*	ND	0.028-0.030	8	8	100.0%	---
	NPS	OR	*	*	*	ND	*	*	*	ND	0.029-0.030	8	8	100.0%	---
	NPS	FUI	*	*	*	ND	*	*	*	ND	0.029-0.030	10	10	100.0%	---
	CON	OR	*	*	*	ND	*	*	*	ND	0.03	8	8	100.0%	---
	CON	FUI	*	*	*	ND	*	*	*	ND	0.029-0.030	14	14	100.0%	---
Glyceryl Trinitrate (GTN)	DMM	OR	*	*	*	ND	*	*	*	ND	0.13	18	18	100.0%	---
	DMM	FUI	*	*	*	1.70	*	*	*	ND	0.12-0.13	56	54	96.4%	---
	WWT	OR	*	*	*	ND	*	*	*	ND	0.13	8	8	100.0%	---
	WWT	FUI	*	*	*	ND	*	*	*	ND	0.12-0.13	8	8	100.0%	---
	NPS	OR	*	*	*	ND	*	*	*	ND	0.13	8	8	100.0%	---
	NPS	FUI	*	*	*	ND	*	*	*	ND	0.13	10	10	100.0%	---
	CON	OR	*	*	*	ND	*	*	*	ND	0.13	8	8	100.0%	---
	CON	FUI	*	*	*	ND	*	*	*	ND	0.12-0.13	14	14	100.0%	---
2-Nitrotoluene (2-NT)	DMM	OR	*	*	*	ND	*	*	*	ND	0.078-0.080	18	18	100.0%	---

Table 3-1: Statistical summary of pre-ROUMRS (2009 UH OR Study) and post-ROUMRS (Follow-Up Investigation) sediment data (all units are in mg/kg-dw)

Analyte	Strata	Study	Mean	Std Error	Std Dev	Max	75th Pctl	Median	25th Pctl	Min	DL Range	n	# of NDs	%NDs	Method
	DMM	FUI	*	*	*	1.10	*	*	*	ND	0.075-0.082	56	54	96.4%	---
	WWT	OR	*	*	*	ND	*	*	*	ND	0.078-0.080	8	8	100.0%	---
	WWT	FUI	*	*	*	ND	*	*	*	ND	0.076-0.079	8	8	100.0%	---
	NPS	OR	*	*	*	ND	*	*	*	ND	0.078-0.080	8	8	100.0%	---
	NPS	FUI	*	*	*	ND	*	*	*	ND	0.078-0.081	10	10	100.0%	---
	CON	OR	*	*	*	ND	*	*	*	ND	0.079-0.080	8	8	100.0%	---
	CON	FUI	*	*	*	ND	*	*	*	ND	0.077-0.080	14	14	100.0%	---
4-Nitrotoluene (4-NT)	DMM	OR	*	*	*	ND	*	*	*	ND	0.078-0.080	18	18	100.0%	---
	DMM	FUI	*	*	*	0.490	*	*	*	ND	0.075-0.082	56	55	98.2%	---
	WWT	OR	*	*	*	ND	*	*	*	ND	0.078-0.080	8	8	100.0%	---
	WWT	FUI	*	*	*	ND	*	*	*	ND	0.076-0.079	8	8	100.0%	---
	NPS	OR	*	*	*	ND	*	*	*	ND	0.078-0.080	8	8	100.0%	---
	NPS	FUI	*	*	*	ND	*	*	*	ND	0.078-0.081	10	10	100.0%	---
	CON	OR	*	*	*	ND	*	*	*	ND	0.079-0.080	8	8	100.0%	---
	CON	FUI	*	*	*	ND	*	*	*	ND	0.077-0.080	14	14	100.0%	---
Royal Demolition Explosive (RDX)	DMM	OR	*	*	*	ND	*	*	*	ND	0.039-0.040	18	18	100.0%	---
	DMM	FUI	*	*	*	0.140	*	*	*	ND	0.038-0.041	56	55	98.2%	---
	WWT	OR	*	*	*	ND	*	*	*	ND	0.039-0.040	8	8	100.0%	---
	WWT	FUI	*	*	*	ND	*	*	*	ND	0.038-0.040	8	8	100.0%	---
	NPS	OR	*	*	*	ND	*	*	*	ND	0.039-0.040	8	8	100.0%	---
	NPS	FUI	*	*	*	ND	*	*	*	ND	0.039-0.040	10	10	100.0%	---
	CON	OR	*	*	*	ND	*	*	*	ND	0.04	8	8	100.0%	---
	CON	FUI	*	*	*	ND	*	*	*	ND	0.038-0.040	14	14	100.0%	---

* Insufficient data to calculate statistic; ND = not detected (i.e., <DL); and NA = not analyzed; %NDs = the percent of nondetects; and a < means one replicate was ND and the other was the value.

Note: J-flagged data (i.e., data between DL and RL) treated as quantitative data; if one of two replicate samples was ND, the mean result was counted as an ND because the indicator variable was coded as "less than"

Statistical Method: Std = *standard* Minitab summary statistics; K-M = Kaplan-Meier method (NDs <50 %); ROS = regression on order statistics (NDs ≥50 % and <80 %); and -- not calculated (NDs ≥80 %)

Table 3-2: Statistical summary of pre-ROUMRS (2009 UH OR Study) post-ROUMRS (Follow-Up Investigation) biota data (all units are in mg/kg wet or fresh weight)

Analyte	Organism	Study	Mean	Std Error	Std Dev	Max	75th Pctl	Median	25th Pctl	Min	DL Range	n	# of NDs	%NDs	Method
Aluminum (Al)	Limu	OR	111	21.1	84.4	248	180	128	19.4	7.00	3	16	0	0.0%	Std
	Limu	FUI	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	---
	Crab	OR	5.81	0.664	2.66	11.8	7.3	5.3	4.3	ND	3	16	3	18.8%	K-M
	Crab	FUI	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	---
	Octopus	OR	*	*	*	16.7	*	*	*	ND	3	18	16	88.9%	---
	Octopus	FUI	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	---
	Fish	OR	*	*	*	25.1	*	*	*	ND	3	39	37	94.9%	---
	Fish	FUI	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	---
Arsenic (As)	Limu	OR	0.854	0.064	0.380	1.50	1.20	0.880	0.550	ND	0.15	35	2	5.7%	K-M
	Limu	FUI	1.03	0.117	0.561	2.67	1.05	0.850	0.720	0.520	0.14-0.21	23	0	0.0%	Std
	Crab	OR	36.5	1.71	9.06	52.4	43.2	36.3	31.1	14.9	0.15	28	0	0.0%	Std
	Crab	FUI	46.9	3.23	12.5	65.8	56.7	48.0	33.2	28.2	0.15	15	0	0.0%	Std
	Octopus	OR	25.9	0.928	5.49	37.8	29.8	24.8	21.2	18.7	0.15	35	0	0.0%	Std
	Octopus	FUI	23.9	0.885	4.51	37.0	26.6	24.2	21.4	14.0	0.14-0.16	26	0	0.0%	Std
	Fish	OR	15.7	0.782	6.95	38.8	18.5	15.0	10.7	4.40	0.15	79	0	0.0%	Std
	Fish	FUI	12.7	0.682	4.52	24.0	15.9	12.0	9.71	4.40	0.14-0.16	44	0	0.0%	Std
Barium (Ba)	Limu	OR	1.28	0.264	1.56	7.85	1.30	0.910	0.430	0.210	0.09	35	0	0.0%	Std
	Limu	FUI	1.43	0.173	0.828	4.50	1.60	1.30	0.980	0.440	0.09-0.12	23	0	0.0%	Std
	Crab	OR	0.172	0.053	0.283	1.60	0.135	0.110	*	ND	0.09	28	9	32.1%	K-M
	Crab	FUI	0.153	0.009	0.034	0.240	0.170	0.140	0.120	0.120	0.09	15	0	0.0%	Std
	Octopus	OR	0.149	0.065	0.385	1.90	0.120	0.027	0.010	ND	0.09	35	21	60.0%	ROS
	Octopus	FUI	0.107	0.015	0.077	0.350	0.133	0.082	0.052	0.031	0.09	26	13	50.0%	ROS
	Fish	OR	0.120	0.006	0.055	0.420	0.120	0.095	*	ND	0.09	79	35	44.3%	K-M
	Fish	FUI	0.118	0.011	0.074	0.530	0.140	*	*	ND	0.09	44	21	47.7%	K-M
Cadmium (Cd)	Limu	OR	*	*	*	ND	*	*	*	ND	0.05	35	35	100.0%	---
	Limu	FUI	*	*	*	0.086	*	*	*	ND	0.05-0.07	23	19	82.6%	---
	Crab	OR	0.077	0.022	0.12	0.510	0.099	0.029	0.010	ND	0.05	28	19	67.9%	ROS
	Crab	FUI	0.074	0.009	0.034	0.150	0.091	*	*	ND	0.05	15	7	46.7%	K-M
	Octopus	OR	0.463	0.114	0.673	3.50	0.710	0.176	0.075	ND	0.05	35	18	51.4%	ROS
	Octopus	FUI	*	*	*	ND	*	*	*	ND	0.05	26	26	100.0%	---

Table 3-2: Statistical summary of pre-ROUMRS (2009 UH OR Study) post-ROUMRS (Follow-Up Investigation) biota data (all units are in mg/kg wet or fresh weight)

Analyte	Organism	Study	Mean	Std Error	Std Dev	Max	75th Pctl	Median	25th Pctl	Min	DL Range	n	# of NDs	%NDs	Method
	Fish	OR	*	*	*	ND	*	*	*	ND	0.05	79	79	100.0%	---
	Fish	FUI	*	*	*	ND	*	*	*	ND	0.05	44	44	100.0%	---
Chromium (Cr)	Limu	OR	1.09	0.116	0.689	2.65	1.70	1.10	0.420	ND	0.10	35	2	5.7%	K-M
	Limu	FUI	1.41	0.288	1.38	5.20	1.20	0.941	0.710	0.460	0.10-0.14	23	0	0.0%	Std
	Crab	OR	0.582	0.015	0.078	0.710	0.648	0.575	0.506	0.480	0.10	28	0	0.0%	Std
	Crab	FUI	0.628	0.013	0.050	0.740	0.660	0.620	0.590	0.550	0.10	15	0	0.0%	Std
	Octopus	OR	0.347	0.038	0.223	1.00	0.520	0.260	0.140	ND	0.10	35	4	11.4%	K-M
	Octopus	FUI	0.640	0.020	0.101	0.990	0.701	0.615	0.550	0.510	0.10	26	0	0.0%	Std
	Fish	OR	0.458	0.030	0.266	0.860	0.680	0.490	0.250	ND	0.10	79	17	21.5%	K-M
	Fish	FUI	0.632	0.027	0.182	1.10	0.708	0.597	0.510	0.170	0.10	44	0	0.0%	Std
Cobalt (Co)	Limu	OR	0.109	0.014	0.083	0.345	0.160	0.100	0.036	ND	0.01	35	2	5.7%	K-M
	Limu	FUI	0.195	0.055	0.266	0.886	0.160	0.096	0.065	0.029	0.01	23	0	0.0%	Std
	Crab	OR	0.020	0.004	0.020	0.110	0.021	0.014	*	ND	0.01	28	8	28.6%	K-M
	Crab	FUI	0.032	0.007	0.026	0.082	0.040	0.020	0.016	ND	0.01	15	1	6.7%	K-M
	Octopus	OR	0.053	0.010	0.062	0.230	0.095	0.012	*	ND	0.01	35	16	45.7%	K-M
	Octopus	FUI	*	*	*	0.012	*	*	*	ND	0.01	26	21	80.8%	---
	Fish	OR	0.007	0.001	0.005	0.036	0.008	0.005	0.003	ND	0.01	79	61	77.2%	ROS
	Fish	FUI	*	*	*	0.029	*	*	*	ND	0.01	44	36	81.8%	---
Copper (Cu)	Limu	OR	1.51	0.716	4.23	25.0	0.920	0.620	0.230	0.081	0.01	35	0	0.0%	Std
	Limu	FUI	1.56	0.667	3.20	16.0	1.40	0.750	0.420	0.250	0.01	23	0	0.0%	Std
	Crab	OR	8.42	0.790	4.18	16.2	12.1	7.85	5.55	0.300	0.01	28	0	0.0%	Std
	Crab	FUI	8.28	0.674	2.61	12.8	10.2	8.40	7.20	2.60	0.01	15	0	0.0%	Std
	Octopus	OR	14.2	2.70	16.0	90.3	20.4	8.60	6.00	2.60	0.01	35	0	0.0%	Std
	Octopus	FUI	5.42	0.31	1.60	9.10	6.14	5.40	3.80	3.40	0.01	26	0	0.0%	Std
	Fish	OR	0.294	0.016	0.141	0.755	0.340	0.240	0.205	0.130	0.01	79	0	0.0%	Std
	Fish	FUI	0.527	0.076	0.501	2.90	0.564	0.385	0.303	0.130	0.01	44	0	0.0%	Std
Lead (Pb)	Limu	OR	0.415	0.042	0.247	1.10	0.590	0.440	0.190	ND	0.06	35	3	8.6%	K-M
	Limu	FUI	0.459	0.066	0.318	1.40	0.530	0.380	0.275	0.140	0.06-0.08	23	0	0.0%	Std
	Crab	OR	*	*	*	2.40	*	*	*	ND	0.06	28	27	96.4%	---
	Crab	FUI	*	*	*	ND	*	*	*	ND	0.06	15	15	100.0%	---

Table 3-2: Statistical summary of pre-ROUMRS (2009 UH OR Study) post-ROUMRS (Follow-Up Investigation) biota data (all units are in mg/kg wet or fresh weight)

Analyte	Organism	Study	Mean	Std Error	Std Dev	Max	75th Pctl	Median	25th Pctl	Min	DL Range	n	# of NDs	%NDs	Method
	Octopus	OR	*	*	*	0.200	*	*	*	ND	0.06	35	28	80.0%	---
	Octopus	FUI	*	*	*	ND	*	*	*	ND	0.06	26	26	100.0%	---
	Fish	OR	0.045	0.005	0.041	0.310	0.060	0.033	0.020	ND	0.06	79	58	73.4%	ROS
	Fish	FUI	0.167	0.136	0.903	6.00	0.013	0.002	0.000	0.000	0.06	44	35	79.5%	ROS
Mercury (Hg)	Limu	OR	*	*	*	0.031	*	*	*	ND	0.020-0.061	35	33	94.3%	---
	Limu	FUI	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	---
	Crab	OR	0.051	0.005	0.025	0.140	0.060	0.050	*	ND	0.029-0.055	28	13	46.4%	K-M
	Crab	FUI	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	---
	Octopus	OR	*	*	*	0.050	*	*	*	ND	0.024-0.055	35	30	85.7%	---
	Octopus	FUI	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	---
	Fish	OR	0.079	0.004	0.032	0.170	0.100	0.076	0.055	ND	0.025-0.061	79	9	11.4%	K-M
	Fish	FUI	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	---
Nickel (Ni)	Limu	OR	0.751	0.091	0.536	2.20	0.910	0.615	0.360	ND	0.10	35	2	5.7%	K-M
	Limu	FUI	1.42	0.362	1.74	6.91	1.20	0.980	0.420	0.300	0.10-0.14	23	0	0.0%	Std
	Crab	OR	*	*	*	ND	*	*	*	ND	0.10	28	28	100.0%	---
	Crab	FUI	*	*	*	ND	*	*	*	ND	0.10	15	15	100.0%	---
	Octopus	OR	*	*	*	0.160	*	*	*	ND	0.10	35	31	88.6%	---
	Octopus	FUI	*	*	*	0.110	*	*	*	ND	0.10	26	23	88.5%	---
	Fish	OR	*	*	*	0.800	*	*	*	ND	0.10	79	73	92.4%	---
	Fish	FUI	*	*	*	0.130	*	*	*	ND	0.10	44	42	95.5%	---
Selenium (Se)	Limu	OR	0.139	0.036	0.215	0.910	0.140	0.049	0.017	ND	0.10	35	24	68.6%	ROS
	Limu	FUI	0.119	0.015	0.072	0.330	0.171	0.097	0.067	0.034	0.10-0.14	23	14	60.9%	ROS
	Crab	OR	0.334	0.019	0.102	0.595	0.360	0.320	0.280	0.160	0.10	28	0	0.0%	Std
	Crab	FUI	0.520	0.064	0.248	1.10	0.680	0.41	0.300	0.250	0.10	15	0	0.0%	Std
	Octopus	OR	0.256	0.017	0.098	0.590	0.280	0.230	0.190	0.150	0.10	35	0	0.0%	Std
	Octopus	FUI	0.162	0.006	0.031	0.230	0.185	0.160	0.130	ND	0.10	26	1	3.8%	K-M
	Fish	OR	0.321	0.020	0.182	1.20	0.400	0.290	0.200	ND	0.10	79	2	2.5%	K-M
	Fish	FUI	0.270	0.023	0.149	0.580	0.400	0.270	0.110	ND	0.10	44	9	20.5%	K-M
Strontium (Sr)	Limu	OR	136	20.4	120	425	212	108	13.2	7.20	0.10	35	0	0.0%	Std
	Limu	FUI	211	28.1	135	470	321	160	110	67.5	0.10-0.14	23	0	0.0%	Std

Table 3-2: Statistical summary of pre-ROUMRS (2009 UH OR Study) post-ROUMRS (Follow-Up Investigation) biota data (all units are in mg/kg wet or fresh weight)

Analyte	Organism	Study	Mean	Std Error	Std Dev	Max	75th Pctl	Median	25th Pctl	Min	DL Range	n	# of NDs	%NDs	Method
	Crab	OR	13.5	2.44	12.9	66.5	14.5	9.90	7.12	0.360	0.10	28	0	0.0%	Std
	Crab	FUI	19.2	4.37	16.9	78.5	16.8	13.9	12.4	9.20	0.10	15	0	0.0%	Std
	Octopus	OR	3.86	0.142	0.839	7.00	4.10	3.67	3.20	2.90	0.10	35	0	0.0%	Std
	Octopus	FUI	3.69	0.086	0.438	4.80	4.07	3.70	3.30	2.80	0.10	26	0	0.0%	Std
	Fish	OR	2.15	0.369	3.28	15.2	2.60	0.530	0.370	0.240	0.10	79	0	0.0%	Std
	Fish	FUI	3.60	0.852	5.66	35.0	3.99	1.70	0.987	0.280	0.10	44	0	0.0%	Std
Uranium (U)	Limu	OR	*	*	*	0.205	*	*	*	ND	0.10	35	29	82.9%	---
	Limu	FUI	0.098	0.009	0.043	0.190	0.120	0.085	0.067	0.040	0.10-0.14	23	16	69.6%	ROS
	Crab	OR	*	*	*	ND	*	*	*	ND	0.10	28	28	100.0%	---
	Crab	FUI	*	*	*	ND	*	*	*	ND	0.10	15	15	100.0%	---
	Octopus	OR	*	*	*	ND	*	*	*	ND	0.10	35	35	100.0%	---
	Octopus	FUI	*	*	*	ND	*	*	*	ND	0.10	26	26	100.0%	---
	Fish	OR	*	*	*	ND	*	*	*	ND	0.10	79	79	100.0%	---
	Fish	FUI	*	*	*	ND	*	*	*	ND	0.10	44	44	100.0%	---
Vanadium (V)	Limu	OR	1.47	0.208	1.23	6.60	2.10	1.30	0.450	ND	0.30	35	3	8.6%	K-M
	Limu	FUI	2.45	0.406	1.95	7.60	3.30	1.90	1.20	0.480	0.29-0.41	23	0	0.0%	Std
	Crab	OR	*	*	*	ND	*	*	*	ND	0.30	28	28	100.0%	---
	Crab	FUI	*	*	*	ND	*	*	*	ND	0.30	15	15	100.0%	---
	Octopus	OR	0.286	0.010	0.058	0.410	0.310	0.278	0.244	ND	0.30	35	23	65.7%	ROS
	Octopus	FUI	*	*	*	0.890	*	*	*	ND	0.29-0.31	26	23	88.5%	---
	Fish	OR	0.424	0.014	0.123	0.680	0.473	0.397	0.329	ND	0.30	79	57	72.2%	ROS
	Fish	FUI	*	*	*	1.30	*	*	*	ND	0.29-0.31	44	42	95.5%	---
Zinc (Zn)	Limu	OR	9.62	7.46	44.1	263	2.70	1.80	1.10	ND	0.60	35	3	8.6%	K-M
	Limu	FUI	3.08	0.567	2.72	14.0	4.20	2.20	1.50	ND	0.57-0.82	23	1	4.3%	K-M
	Crab	OR	43.1	2.37	12.5	56.8	49.4	45.5	40.9	3.20	0.60	28	0	0.0%	Std
	Crab	FUI	46.4	1.27	4.90	57.7	49.1	46.5	43.4	38.7	0.60	15	0	0.0%	Std
	Octopus	OR	15.6	1.15	6.83	51.6	16.3	14.4	13.1	9.00	0.60	35	0	0.0%	Std
	Octopus	FUI	12.7	0.159	0.808	15.0	13.0	12.9	12.2	11.2	0.57-0.63	26	0	0.0%	Std
	Fish	OR	3.67	0.115	1.02	7.80	4.20	3.40	3.00	2.20	0.60	79	0	0.0%	Std
	Fish	FUI	7.82	0.834	5.53	35.0	9.08	5.90	4.73	2.00	0.57-0.63	44	0	0.0%	Std

Table 3-2: Statistical summary of pre-ROUMRS (2009 UH OR Study) post-ROUMRS (Follow-Up Investigation) biota data (all units are in mg/kg wet or fresh weight)

Analyte	Organism	Study	Mean	Std Error	Std Dev	Max	75th Pctl	Median	25th Pctl	Min	DL Range	n	# of NDs	%NDs	Method
3,5-Dinitroaniline (3,5-DNA)	Limu	OR	*	*	*	ND	*	*	*	ND	0.460-0.500	19	19	100.0%	---
	Limu	FUI	*	*	*	ND	*	*	*	ND	0.093-0.500	23	23	100.0%	---
	Crab	OR	*	*	*	ND	*	*	*	ND	0.056-0.076	28	28	100.0%	---
	Crab	FUI	*	*	*	ND	*	*	*	ND	0.073-0.076	15	15	100.0%	---
	Octopus	OR	*	*	*	ND	*	*	*	ND	0.028-0.038	35	35	100.0%	---
	Octopus	FUI	*	*	*	ND	*	*	*	ND	0.035-0.039	26	26	100.0%	---
	Fish	OR	*	*	*	0.053	*	*	*	ND	0.027-0.040	79	76	96.2%	---
	Fish	FUI	*	*	*	ND	*	*	*	ND	0.035-0.038	44	44	100.0%	---
2,4-Dinitrotoluene (2,4-DNT)	Limu	OR	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	---
	Limu	FUI	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	---
	Crab	OR	*	*	*	ND	*	*	*	ND	0.028-0.039	28	28	100.0%	---
	Crab	FUI	*	*	*	ND	*	*	*	ND	0.037-0.038	15	15	100.0%	---
	Octopus	OR	*	*	*	ND	*	*	*	ND	0.028-0.038	35	35	100.0%	---
	Octopus	FUI	*	*	*	ND	*	*	*	ND	0.004-0.038	26	26	100.0%	---
	Fish	OR	*	*	*	0.180	*	*	*	ND	0.027-0.040	79	70	88.6%	---
	Fish	FUI	*	*	*	0.039	*	*	*	ND	0.035-0.038	44	43	97.7%	---
2,6-Dinitrotoluene (2,6-DNT)	Limu	OR	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	---
	Limu	FUI	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	---
	Crab	OR	*	*	*	ND	*	*	*	ND	0.056-0.076	28	28	100.0%	---
	Crab	FUI	*	*	*	ND	*	*	*	ND	0.073-0.076	15	15	100.0%	---
	Octopus	OR	*	*	*	ND	*	*	*	ND	0.028-0.038	35	35	100.0%	---
	Octopus	FUI	*	*	*	ND	*	*	*	ND	0.035-0.039	26	26	100.0%	---
	Fish	OR	*	*	*	ND	*	*	*	ND	0.027-0.040	79	79	100.0%	---
	Fish	FUI	*	*	*	0.140	*	*	*	ND	0.035-0.038	44	43	97.7%	---
High Melting Explosive (HMX)	Limu	OR	*	*	*	ND	*	*	*	ND	0.460-0.500	19	19	100.0%	---
	Limu	FUI	*	*	*	ND	*	*	*	ND	0.110-0.500	23	23	100.0%	---
	Crab	OR	*	*	*	ND	*	*	*	ND	0.056-0.076	28	28	100.0%	---
	Crab	FUI	*	*	*	ND	*	*	*	ND	0.073-0.076	15	15	100.0%	---
	Octopus	OR	*	*	*	0.062	*	*	*	ND	0.028-0.038	35	34	97.1%	---
	Octopus	FUI	*	*	*	ND	*	*	*	ND	0.035-0.039	26	26	100.0%	---

Table 3-2: Statistical summary of pre-ROUMRS (2009 UH OR Study) post-ROUMRS (Follow-Up Investigation) biota data (all units are in mg/kg wet or fresh weight)

Analyte	Organism	Study	Mean	Std Error	Std Dev	Max	75th Pctl	Median	25th Pctl	Min	DL Range	n	# of NDs	%NDs	Method
	Fish	OR	*	*	*	0.420	*	*	*	ND	0.027-0.040	79	66	83.5%	---
	Fish	FUI	*	*	*	ND	*	*	*	ND	0.035-0.038	44	44	100.0%	---
2-Nitrophenol (2-NP)	Limu	OR	*	*	*	ND	*	*	*	ND	0.460-0.500	19	19	100.0%	---
	Limu	FUI	*	*	*	ND	*	*	*	ND	0.300-0.500	23	23	100.0%	---
	Crab	OR	*	*	*	ND	*	*	*	ND	0.060-0.082	28	28	100.0%	---
	Crab	FUI	*	*	*	ND	*	*	*	ND	0.078-0.081	15	15	100.0%	---
	Octopus	OR	*	*	*	ND	*	*	*	ND	0.058-0.079	35	35	100.0%	---
	Octopus	FUI	*	*	*	ND	*	*	*	ND	0.073-0.082	26	26	100.0%	---
	Fish	OR	*	*	*	0.092	*	*	*	ND	0.058-0.084	79	78	98.7%	---
	Fish	FUI	*	*	*	ND	*	*	*	ND	0.074-0.081	44	44	100.0%	---
2-Nitrotoluene (2-NT)	Limu	OR	*	*	*	ND	*	*	*	ND	0.460-0.500	19	19	100.0%	---
	Limu	FUI	*	*	*	ND	*	*	*	ND	0.300-0.500	23	23	100.0%	---
	Crab	OR	*	*	*	ND	*	*	*	ND	0.056-0.076	28	28	100.0%	---
	Crab	FUI	*	*	*	ND	*	*	*	ND	0.073-0.076	15	15	100.0%	---
	Octopus	OR	*	*	*	ND	*	*	*	ND	0.028-0.038	35	35	100.0%	---
	Octopus	FUI	*	*	*	ND	*	*	*	ND	0.035-0.039	26	26	100.0%	---
	Fish	OR	*	*	*	0.055	*	*	*	ND	0.027-0.040	79	77	97.5%	---
	Fish	FUI	*	*	*	ND	*	*	*	ND	0.035-0.038	44	44	100.0%	---
4-Nitrotoluene (4-NT)	Limu	OR	*	*	*	ND	*	*	*	ND	0.460-0.500	19	19	100.0%	---
	Limu	FUI	*	*	*	ND	*	*	*	ND	0.300-0.500	23	23	100.0%	---
	Crab	OR	*	*	*	ND	*	*	*	ND	0.056-0.076	28	28	100.0%	---
	Crab	FUI	*	*	*	ND	*	*	*	ND	0.073-0.076	15	15	100.0%	---
	Octopus	OR	*	*	*	ND	*	*	*	ND	0.055-0.074	35	35	100.0%	---
	Octopus	FUI	*	*	*	ND	*	*	*	ND	0.069-0.077	26	26	100.0%	---
	Fish	OR	*	*	*	0.092	*	*	*	ND	0.054-0.079	79	78	98.7%	---
	Fish	FUI	*	*	*	ND	*	*	*	ND	0.070-0.076	44	44	100.0%	---
Royal Demolition Explosive (RDX)	Limu	OR	*	*	*	ND	*	*	*	ND	0.460-0.500	19	19	100.0%	---
	Limu	FUI	*	*	*	ND	*	*	*	ND	0.150-0.500	23	23	100.0%	---
	Crab	OR	*	*	*	ND	*	*	*	ND	0.056-0.076	28	28	100.0%	---
	Crab	FUI	*	*	*	ND	*	*	*	ND	0.073-0.076	15	15	100.0%	---

Table 3-2: Statistical summary of pre-ROUMRS (2009 UH OR Study) post-ROUMRS (Follow-Up Investigation) biota data (all units are in mg/kg wet or fresh weight)

Analyte	Organism	Study	Mean	Std Error	Std Dev	Max	75th Pctl	Median	25th Pctl	Min	DL Range	n	# of NDs	%NDs	Method
	Octopus	OR	*	*	*	ND	*	*	*	ND	0.028-0.038	35	35	100.0%	---
	Octopus	FUI	*	*	*	ND	*	*	*	ND	0.035-0.039	26	26	100.0%	---
	Fish	OR	*	*	*	1.60	*	*	*	ND	0.054-0.079	79	78	98.7%	---
	Fish	FUI	*	*	*	ND	*	*	*	ND	0.070-0.076	44	44	100.0%	---
Tetryl	Limu	OR	*	*	*	ND	*	*	*	ND	0.460-0.500	19	19	100.0%	---
	Limu	FUI	*	*	*	ND	*	*	*	ND	0.190-0.500	23	23	100.0%	---
	Crab	OR	*	*	*	ND	*	*	*	ND	0.225-0.310	28	28	100.0%	---
	Crab	FUI	*	*	*	ND(R)	*	*	*	ND	0.290-0.300	14	14	100.0%	---
	Octopus	OR	*	*	*	ND	*	*	*	ND	0.055-0.074	35	35	100.0%	---
	Octopus	FUI	*	*	*	ND	*	*	*	ND	0.069-0.077	26	26	100.0%	---
	Fish	OR	*	*	*	0.850	*	*	*	ND	0.220-0.320	79	77	97.5%	---
	Fish	FUI	*	*	*	ND(R)	*	*	*	ND	0.280-0.300	43	43	100.0%	---
1,3,5-Trinitrobenzene (135-TNB)	Limu	OR	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	---
	Limu	FUI	*	*	*	ND	*	*	*	ND	0.019-0.081	23	23	100.0%	---
	Crab	OR	*	*	*	0.067	*	*	*	ND	0.028-0.039	28	27	96.4%	---
	Crab	FUI	*	*	*	ND	*	*	*	ND	0.037-0.038	15	15	100.0%	---
	Octopus	OR	*	*	*	ND	*	*	*	ND	0.028-0.038	35	35	100.0%	---
	Octopus	FUI	*	*	*	0.055	*	*	*	ND	0.035-0.039	26	25	96.2%	---
	Fish	OR	*	*	*	0.076	*	*	*	ND	0.027-0.040	79	78	98.7%	---
	Fish	FUI	*	*	*	0.063	*	*	*	ND	0.035-0.038	44	41	93.2%	---

* Insufficient data to calculate statistic; ND = not detected (i.e., <DL); and NA = not analyzed; %NDs = the percent of nondetects; and a < means one replicate was ND and the other was the value.

Note: J-flagged data (i.e., data between DL and RL) treated as quantitative data; if one of two replicate samples was ND, the mean result was counted as an ND because the indicator variable was coded as "less than"

Statistical Method: Std = *standard* Minitab summary statistics; K-M = Kaplan-Meier method (NDs <50 %); ROS = regression on order statistics (NDs ≥50 % and <80 %); and -- not calculated (NDs ≥80 %)

The maximum value was rejected by the data validator (flagged as R) and discarded; *n* adjusted accordingly.

Several of the statistics presented in Tables 3-1 and 3-2 warrant further explanation. Both the mean and the median are measures of what is called central tendency; however, how this central tendency is measured and how the mean and median are used differ. The mean is simply the sum of all concentrations (in this case) divided by the number of samples (or by using one of the estimation techniques described in Section 2.0). As a result, the mean is affected by extreme values or outliers, which are not unusual in environmental data of this type. The median (or 50th percentile), on the other hand, represents the concentration at which one half of the data are less than this value and one half of the data are greater than this value (or by using one of the estimation techniques described in Section 2.0). The application of mean and median differs. For example, if you are interested in the frequency you might expect for a given concentration, the median will give you some idea of how often this concentration occurs in the dataset. Combined with the 25th and 75th percentile (also known as the interquartile range or IQR), you know that half of all concentrations will fall within the IQR, and that 25% of the concentrations of a given analyte will be greater than the 75th percentile and 25% of the concentrations will be less than the 25th percentile. Moreover, these measures are not affected by outliers.

Sometimes, however, it is important to include the effect of the outliers. The mean is the ideal statistic in this case. For example, if you wanted to estimate the total mass of copper in the top inch or so of sediment across the study area (assuming the concentration is constant with depth of sediment), then the mean, which is affected by outliers, is a better statistic to use because the effect of outliers, in this case, is important.

The laboratory analytical reports are provided in Appendix E and the analytical data are summarized on tables provided in Appendix F. Also, it should be noted that sediment analyte concentrations are reported in milligrams per kilogram – dry weight (mg/kg-dw) whereas the analyte concentrations for biota are reported in milligrams per kilogram – wet or fresh weight (mg/kg-ww).

The Follow-Up Investigation results of each analyte group in each matrix are discussed in detail below. Table 3-3 provides a list of the sites within the DMM stratum sampled and indicates what DMM types were present, which types of samples were collected, and the proximity of the samples to where the DMM at Ordnance Reef (HI-06) were removed. Table 3-3 is a subset of Table 2-1 in a simplified format to provide the reader with information on the DMM samples, which for this investigation, are particularly important.

Table 3-3: Munitions found and samples collected within the DMM stratum

Site Name[1]	Date	Ordnance Removed during ROUMRS Demonstration	Depth[2]	Sample Field ID	Sample Lab ID	Distance from Ordnance (Removed) & Sample	Sample Observation
DMM31	8/6/2011	Small arms site, ARA Item 81 location, many 20mm remain on location	*~70.2 ft* (21.4 m)	DMM31	ORD201S, ORD202S	Series of samples amongst multiple rounds of small arms, no distance function	
				DMM32			
				DMM33			
DMM34	8/6/2011	Small arms site, ARA Item 97 location, 50 caliber DMM remain on location	*~55.8 ft* (17.0 m)	DMM34	ORD203S	Series of samples amongst multiple rounds of small arms, no distance function	
				DMM35			
				DMM36			
DMM37	8/6/2011	5" x 20" projectile,	~70 ft	DMM37	ORD204S	0 ft	

Table 3-3: Munitions found and samples collected within the DMM stratum

Site Name[1]	Date	Ordnance Removed during ROUMRS Demonstration	Depth[2]	Sample Field ID	Sample Lab ID	Distance from Ordnance (Removed) & Sample	Sample Observation
		ARA Item 93 location	(*21.3 m*)	DMM38	ORD205S	3 ft (0.9 m)	
				DMM39	ORD206S	6 ft (1.8 m)	
DMM40	8/6/2011	5" x 18" projectile site, ARA Item 126 location	~70 ft (*21.3 m*)	DMM40	ORD207S	0 ft	
				DMM41	ORD208S	3 ft (0.9 m)	
				DMM42	ORD209S	6 ft (1.8 m)	
DMM43	8/6/2011	Small arms site, ARA Item 154 location	~70 ft (*21.3 m*)	DMM43	ORD210S	Series of samples amongst multiple rounds of small arms, no distance function	
				DMM44			
				DMM45			
DMM46	8/6/2011	12" x 16" projectile, ARA Item 160 location	~135 ft (*41.1 m*)	DMM46	ORD211S	0 ft	
				DMM47	ORD212S	3 ft (0.9 m)	
				DMM48	ORD213S	6 ft (1.8 m)	
DMM49	8/6/2011	5" x 7" projectile, ARA Item 156 location	~76 ft (*23.2 m*)	DMM49	ORD214S	0 ft	
				DMM50	ORD215S	3 ft (0.9 m)	
				DMM51	ORD216S	6 ft (1.8 m)	
DMM52	7/16/2012	Small arms site, ARA Item 81 location, many 20mm remain on location	~*70.2 ft* (21.4 m)	DMM52	ORD319S, ORD322S	0 ft	
				DMM53	ORD320S	3 ft (0.9 m)	
				DMM54	ORD321S	6 ft (1.8 m)	
				DMM52-O001	--	/*	
				DMM52-O002	--	/*	
				DMM52-O003	ORD316O	/*	
				DMM52-L001	ORD306L	/*	
DMM55	7/16/2012	Small arms site, ARA Item 97 location, 50 caliber DMM remain on location	~*55.8 ft* (17.0 m)	DMM55	ORD323S	0 ft	One 50-caliber in sample bag
				DMM56	ORD324S	3 ft (0.9 m)	Munitions shell fragment found during process (at the UH laboratory)
				DMM57	ORD325S	6 ft (1.8 m)	50-caliber and other small arms in bag
				DMM55-O004	ORD311O	/*	
				DMM55-L002	ORD307L	/*	
DMM58	7/16/2012	5" x 20" projectile, ARA Item 93 location	~ *73.2 ft* (22.3 m)	DMM58	ORD326S	0 ft	
				DMM59	ORD327S	3 ft (0.9 m)	
				DMM60	ORD328S, ORD329S	6 ft (1.8 m)	
				DMM58-O005	ORD314O	/*	
DMM61	7/16/2012	5" x 18" projectile site, ARA Item 126 location	~ *73.4 ft* (22.4 m)	DMM61	ORD330S	0 ft	
				DMM62	ORD331S	3 ft (0.9 m)	

Table 3-3: Munitions found and samples collected within the DMM stratum

Site Name[1]	Date	Ordnance Removed during ROUMRS Demonstration	Depth[2]	Sample Field ID	Sample Lab ID	Distance from Ordnance (Removed) & Sample	Sample Observation
				DMM63	ORD332S	6 ft (1.8 m)	
				DMM61-O006	ORD313O	/*	Propellant grain and one 50-caliber in sample bag
				DMM61-L003	ORD308L	/*	
DMM64	7/16/2012	Small arms site, ARA Item 154 location	*~79.0 ft* (24.1 m)	DMM64	ORD333S	0 ft	
				DMM65	ORD334S	3 ft (0.9 m)	
				DMM66	ORD335S	6 ft (1.8 m)	
				DMM64-O007	ORD315O	/*	
				DMM64-L004	ORD309L	/*	
DMM67	7/16/2012	5" x 7" projectile, ARA Item 156 location	*~72.5 ft* (22.1 m)	DMM67	ORD336S	0 ft	
				DMM68	ORD337S	3 ft (0.9 m)	
				DMM69	ORD338S	6 ft (1.8 m)	
				DMM67-O008	ORD310O	/*	
				DMM67-L005	ORD310L	/*	
DMM70	7/17/2012	12" x 16" projectile, ARA Item 160 location	*~ 141 ft* (43.0 m)	DMM70	ORD339S	0 ft	
				DMM71	ORD301S	3 ft (0.9 m)	
				DMM72	ORD340S	6 ft (1.8 m)	
				DMM70-L006	ORD311L	/*	
DMM[3]	7/19/2012	/	~50 ft (*15.2 m*)	DMM-F010	ORD318F	/	
DMM[3]	7/19/2012	/	~50 ft (*15.2 m*)	DMM-F011	ORD319F	/	
				DMM-F012	ORD320F	/	
				DMM-F013	--	/	
DMM[3]	7/19/2012	/	~50 ft (*15.2 m*)	DMM-F014	--	/	
DMM[3]	7/19/2012	/	~50 ft (*15.2 m*)	DMM-F015	ORD323F	/	
				DMM-F016	--	/	
DMM[3]	7/19/2012	/	~50 ft (*15.2 m*)	DMM-F017	ORD325F	/	
DMM[3]	7/19/2012	/	~50 ft (*15.2 m*)	DMM-F018	ORD326F	/	
DMM[3]	7/19/2012	/	~50 ft *(15.2 m)*	DMM-F019	ORD327F	/	
DMM[3]	7/19/2012	/	~50 ft (*15.2 m*)	DMM-F020	--	/	
				DMM-F021	ORD329F	/	
				DMM-F022	--	/	
				DMM-F023	--	/	
DMM[3]	7/19/2012	/	~50 ft (*15.2 m*)	DMM-F020	--	/	
				DMM-F021	ORD329F	/	
				DMM-F022	--	/	

Table 3-3: Munitions found and samples collected within the DMM stratum

Site Name[1]	Date	Ordnance Removed during ROUMRS Demonstration	Depth[2]	Sample Field ID	Sample Lab ID	Distance from Ordnance (Removed) & Sample	Sample Observation
				DMM-F023	--	/	
DMM[3]	7/31/2012	/	~110 ft (*33.5 m*)	DMM-C005	ORD305C	/	
DMM[3]	7/31/2012	/	~100 ft (*30.5 m*)	DMM-C006	ORD306C	/	
				DMM-C007	--	/	
DMM[3]	7/31/2012	/	~120 ft (*36.6 m*)	DMM-C008	ORD307C	/	
DMM[3]	7/31/2012	/	~90 ft (*27.4 m*)	DMM-C009	ORD308C	/	
DMM[3]	7/31/2012	/	~110 ft (*33.5 m*)	DMM-C010	ORD309C	/	
DMM[3]	7/31/2012	/	~90 ft (*27.4 m*)	DMM-C011	ORD310C		
DMM73	6/3/2013	Small arms site, ARA Item 81 location, many 20mm remain on location	*~70.2 ft* (21.4 m)	DMM73	ORD411S, ORD412S	0 ft	Munition Fragments
				DMM74	ORD401S	3 ft (0.9 m)	
				DMM75	ORD402S	6 ft (1.8 m)	
				DMM73-O001	ORD401O	/*	
				DMM73-L001	ORD401L	/*	
DMM 76	6/3/2013	Small arms site, ARA Item 97 location, 50 caliber DMM remain on location	*~55.8 ft* (17.0 m)	DMM76	ORD403S, ORD404S	0 ft	
				DMM77	ORD413S	3 ft (0.9 m)	
				DMM78	ORD405S	6 ft (1.8 m)	
				DMM76-O002	ORD402O	/*	
				DMM76-L002	ORD402L	/*	
DMM79	6/3/2013	5" x 20" projectile, ARA Item 93 location	*~73.2 ft* (22.3 m)	DMM79	ORD406S	0 ft	Some munitions Fragments
				~~DMM80~~[4]	--	--	
				DMM81	ORD414S	6 ft (1.8 m)	Some munitions Fragments
				DMM79-O003	ORD403O	/*	Found under a case of 50-caliber
				DMM79-L003	ORD403L	/*	
DMM82	6/3/2013	5" x 18" projectile site, ARA Item 126 location	*~73.5 ft* (22.4 m)	DMM82	ORD407S	0 ft	
				DMM83	ORD408S	3 ft (0.9 m)	Possible munitions pins
				DMM684	ORD409S	6 ft (1.8 m)	
				DMM82-O004	ORD404O	/*	
				DMM82-L004	ORD404L	/*	
DMM85	6/3/2013	Small arms site, ARA Item 154 location	*~79.1 ft* (24.1 m)	DMM85	ORD410S	0 ft	
				DMM86	ORD415S	3 ft (0.9 m)	
				DMM87	ORD416S	6 ft (1.8 m)	
				DMM85-O005	ORD405O	/*	

Table 3-3: Munitions found and samples collected within the DMM stratum

Site Name[1]	Date	Ordnance Removed during ROUMRS Demonstration	Depth[2]	Sample Field ID	Sample Lab ID	Distance from Ordnance (Removed) & Sample	Sample Observation
				DMM85-L005	ORD405L	/*	
DMM88	6/7/2013	12" x 16" projectile, ARA Item 160 location	*~141.1 ft* (43.0 m)	DMM88	ORD425S	0 ft	
				DMM89	ORD426S	3 ft (0.9 m)	
				DMM90	ORD427S	6 ft (1.8 m)	
				DMM88-O006	ORD411O	/*	
				DMM88-L006	ORD412L	/*	
DMM91	6/7/2013	5" x 7" projectile, ARA Item 156 location	*~72.25 ft* (22.1 m)	DMM91	ORD417S	0 ft	
				DMM92	ORD418S	3 ft (0.9 m)	
				DMM93	ORD428S	6 ft (1.8 m)	
				DMM91-O007	ORD412O	/*	
				DMM91-L007	ORD413L	/*	
DMM[3]	6/19/2013	/	~60 ft *(18.3 m)*	DMM-F028	ORD418F	/	
DMM[3]	6/19/2013	/	~60 ft *(18.3 m)*	DMM-F029	ORD424F	/	
				DMM-F030	--	/	
DMM[3]	6/19/2013	/	~60 ft *(18.3 m)*	DMM-F031	ORD419F	/	
DMM[3]	6/19/2013	/	~60 ft *(18.3 m)*	DMM-F032	ORD420F	/	
DMM[3]	6/19/2013	/	~60 ft *(18.3 m)*	DMM-F033	ORD421F	/	
DMM[3]	6/19/2013	/	~60 ft *(18.3 m)*	DMM-F034	ORD422F	/	
DMM[3]	6/19/2013	/	~60 ft *(18.3 m)*	DMM-F035	ORD423F	/	
DMM[3]	6/19/2013	/	~60 ft *(18.3 m)*	DMM-F036	ORD425F	/	
DMM[3]	6/19/2013	/	~60 ft *(18.3 m)*	DMM-F037	ORD426F	/	
DMM[3]	6/19/2013	/	~60 ft *(18.3 m)*	DMM-F038	ORD427F	/	
DMM[3]	6/19/2013	/	~60 ft *(18.3 m)*	DMM-F039	ORD428F	/	
DMM[3]	6/19/2013	/	~60 ft *(18.3 m)*	DMM-F040	ORD429F	/	
DMM[3]	6/19/2013	/	~60 ft *(18.3 m)*	DMM-F041	ORD430F	/	
				DMM-F042	--	/	
				DMM-F043	--	/	
DMM[3]	6/19/2013	/	~60 ft *(18.3 m)*	DMM-F044	ORD431F	/	
				DMM-F045	--	/	
				DMM-F046	--	/	
				DMM-F047	--	/	
DMM[3]	6/19/2013	/	~60 ft *(18.3 m)*	DMM-F048	ORD432F	/	
DMM[3]	6/19/2013	/	~60 ft	DMM-F049	ORD433F	/	

Table 3-3: Munitions found and samples collected within the DMM stratum

Site Name[1]	Date	Ordnance Removed during ROUMRS Demonstration	Depth[2]	Sample Field ID	Sample Lab ID	Distance from Ordnance (Removed) & Sample	Sample Observation
			(18.3 m)	DMM-F050	--	/	
DMM[3]	6/19/2013	/	~60 ft *(18.3 m)*	DMM-F051	ORD434F	/	
				DMM-F052	--	/	
DMM[3]	6/19/2013	/	~60 ft *(18.3 m)*	DMM-F053	ORD435F	/	
				DMM-F054	--	/	
				DMM-F055	--	/	
DMM[3]	6/19/2013	/	~60 ft *(18.3 m)*	DMM-F056	ORD436F	/	
				DMM-F057	--	/	
				DMM-F058	--	/	
				DMM-F059	--	/	
				DMM-F060	--	/	
				DMM-F061	--	/	
				DMM-F062	ORD437F	/	
				DMM-F063	--	/	
				DMM-F064	--	/	
				DMM-F065	--	/	
				DMM-F066	--	/	
				DMM-F067	--	/	
				DMM-F068	--	/	
				DMM-F069	--	/	
				DMM-F070	--	/	
				DMM-F071	--	/	
				DMM-F072	--	/	
				DMM-F073	--	/	
				DMM-F074	--	/	

Notes: / = information not available
-- = Extra sample. Sample not submitted to the laboratory.
* = Biota specimens were caught/collected as close as possible to the targeted sediment sampling location.
[1] = Site names were designated by the sample field ID of the first sediment sample collected at a location.
[2] = Converted depth measurements are italicized.
[3] = Specimen were caught from various locations within the DMM stratum.
[4] = Divers attempted to collect sediment from the 3 ft distance at site DMM79 but due to the lack of sediment, no sample was collected.
ID - identification
ft - feet
m - meters

Before proceeding, a brief summary discussion of the UH sample IDs would be helpful. Sediment samples from the different strata include the strata designation (CON, NPS, WWT, or DMM) and a consecutive number and if samples were collected at different distances (nominally 0, 3, and 6 feet), the UH ID included an A, B, and C, respectively. The lab IDs always included "ORD" followed by a sequential number and the letter "S" to indicate sediment. Biota samples were labeled somewhat differently. If a biota sample was specifically identified with a sediment sample, the label includes the stratum designation followed by the corresponding sediment sequential number; if there was no sediment sample associated with the biota sample, the UH ID included the stratum from whence the sample was collected followed by a hyphen, the organism designation ("L" for limu, "C" for crab, "O" for octopus, and "F" for fish); letters A-D (OR1, OR2, FUI2, and FUI3, respectively); and finally, a sequential letter designation. The lab IDs always included "ORD" followed by a sequential number and the organism designation described above.

3.1 Fate and Transport

The potential fate and transport of COPCs were discussed in the 2009 UH OR Study (UH, 2014) report; nevertheless, given that an understanding of these processes is essential to understanding what is seen in the Follow-Up Investigation, this information is repeated below.

Primary factors affecting transport of COPCs include ambient temperature, solubility (in seawater), density, and available transport methods within a given medium once COPCs are dissolved, suspended, or deposited. Bottom temperatures within the study area were in the range of 76.6 to 78.8°F (24.8 to 26.0°C) during the Follow-Up Investigation. Temperature affects the solubility, rate of chemical reactions, and the physical state. The primary factors affecting fate are chemical degradation mechanics, biouptake, transport through the food chain, and/or sequestration by natural means. Table 3-4 provides a summary of COPCs along with parameters important to their fate and transport in the marine ecosystem. The octanol-water partition coefficient (K_{ow}) and organic carbon partition coefficient (K_{oc}) give indications of the potential for bioaccumulation and the subsequent biomagnification of constituents, including MC, in an ecosystem.

Table 3-4: Properties of constituents of potential concern detected at least once in sediments or biota.

Constituent of Potential Concern	CAS Registry Number	Molecular Weight (g/mol)	Density (g/mL)	Melting Point (°C)	Octanol-Water Partition Coefficient (Log K_{ow})	Organic Carbon – Water Partition Coefficient (Log K_{oc})	Vapor Pressure (mm Hg)	Aqueous Solubility (mg/L)
Energetics								
2,4,6-Trinitrotoluene (TNT)[a]	118-96-7[a]	227.131[a]	1.654 @ 20°C[a]	80.5[a]	1.60 – 2.05[a,b,e]	3.20[b]	8.02E-6 @ 25°C[b]	96.7 – 120 @ 20°C[a]
2,4-Dinitrotoluene (2,4-DNT)	121-14-2[a]	182.134[a]	1.521 @ 15°C[a]	70.5[a]	1.98 – 2.04[a,b]	4.04 – 3.30[b]	1.47E-4 @ 22° C[b]	188 – 300 @ 22°C[a,b]
2,6-Dinitrotoluene (2,6-DNT)	606-20-2[a]	182.134[a]	1.283 @ 111°C[b]	64.0 - 66.0[a,e]	1.72 – 2.10[a,b,e]	1.28 – 2.31[a,b]	5.67E-4 @ 25°C[b]	204 – 300 @ 25°C[a,b,e]
2-Nitrotoluene (2-NT)	88-72-2[a]	137.137[a]	1.157 @ 20°C[a]	-10.4[a]	2.30 – 2.46[a,b]	2.09 – 2.63[a,b]	1.85E-1 @ 25°C[b]	609 @ 20°C[a,b]
4-Nitrotoluene (4-NT)	99-99-0[a]	137.137[a]	1.163 @ 20°C[a]	51.6[a]	2.10 – 2.61[a,b]	2.14 – 2.67[a,b]	1.57E-2 @ 25°C[b]	242 – 288 @ 20°C[a,b]
Hexahydro-1,3,5-trinitro-1,3,5-triazine (RDX)	121-82-4[b]	222.116[b]	1.82 @ 20°C[b]	206[b]	0.87 – 0.90[b,e]	ND	4.10E-9 @ 20°C[b]	56.3 – 59.7 @ 25°C[e,b]
Octahydro-1,3,5,7-tetranitro-1,3,5,7-tetrazocine (HMX)	2691-41-0[b]	296.15[b]	1.83 (mean of β, α, γ, δ)[b]	281 - 286[b,e]	0.16 – 0.17[b,e]	1.48 – 2.83[b]	2.4E-8 @ 25°C[b]	4.5 @ 25°C[e]
Tetryl	479-45-8[b]	287.14[b]	1.57 @ 19°C[c]	130-132[b,c]	0.17[e]	3.32[b]	1.2E-7 – 3.3E-14 @ 25°C[b,e]	74 @ 25°C
1,3,5-Trinitrobenzene (1,3,5-TNB)	99-35-4[b]	213.11[b]	1.688 @ 20°C[b]	121.5[b]	1.18[b,e]	2.02[b]	6.44E-6 @ 25°C[b]	278 @ 15°C[b]
Nitroglycerin	55-63-0[b]	227.09[b]	1.592 @ 25°C[b]	13.5[b,e]	1.62[b,e]	2.26[b]	2.0E-4 @ 20°C[b]	1800 @ 20°C[d,e]

Table 3-4: Properties of constituents of potential concern detected at least once in sediments or biota.

Constituent of Potential Concern	CAS Registry Number	Molecular Weight (g/mol)	Density (g/mL)	Melting Point (°C)	Octanol-Water Partition Coefficient (Log K_{ow})	Organic Carbon – Water Partition Coefficient (Log K_{oc})	Vapor Pressure (mm Hg)	Aqueous Solubility (mg/L)
Metalloids & Metals								
Arsenic	7440-38-2[b]	74.922[b]	5.778 @ 25°C (β-metallic form)[b]	613 (sub-limes)[c]	0.68	13.22		
Copper	7440-50-8	63.55	8.96	1083	-0.57	13.22		
Lead	7439-92-1	207.2	11.3	327.5	0.73	13.22		

References
[a] *Physical-Chemical Properties and Environmental Fate for Organic Chemicals* (Mackay *et al*., 2006) and all references contained therein.
[b] Hazardous Substances Database (NLM at http://toxnet.nlm.nih.gov/ (last accessed, 26-July-2014) and all references contained therein.
[c] *Hawley's Condensed Chemical Dictionary* (Lewis, 2007).
[d] *Handbook of Environmental Data on Organic Chemicals* (Verschueren, 1996).
[e] *Site Characterizations for Munitions Constituents* (USEPA, 2012)

Notes
Properties for metalloids (arsenic) and metals (copper and lead) are for elemental As, Cu, and Pb.
Composition B is a mixture of TNT and RDX, Torpex is a mixture of TNT, RDX and aluminum, and amatol is a mixture of ammonium nitrate and TNT.
Arsenic is a possible carcinogen by the United States Occupational Safety and Health Administration (OSHA), IARC, and the NTP.

Units & Abbreviations

° C	degrees Celsius
CAS	Chemical Abstract Service
mm Hg	millimeters of mercury
g/mL	grams per milliliter
g/mol	grams per mole
IARC	International Agency for Research on Cancer
mg/L	milligram per liter
MW	molecular weight
ND	no data
NTP	National Toxicology Program

Bioaccumulation is the process by which chemicals are incorporated by an organism either from the direct exposure to a contaminated medium or through consumption of food containing the chemical. Bioaccumulation occurs when a chemical is taken up and stored faster than it is eliminated (i.e., metabolized, transformed, and/or excreted) (Corl, 2001).

Among the more important aspects of bioaccumulation is the process of biomagnification. Biomagnification occurs when the concentration of a chemical increases at each successive trophic level in the food chain. Because an organism at each higher trophic level theoretically consumes many organisms in the level below it, the consumer effectively becomes exposed to the amount of a chemical from all trophic levels below it (Corl, 2001).

The once-released COPCs may be deposited on the seafloor as free product, dissolved in the water column, or sorbed to sediment particles. COPCs sorbed to suspended particles may settle from the water column and accumulate in sediment. Therefore, sediment can act as the ultimate sink for COPCs from DMM and other sources. The behavior and effect of chemicals in the marine environment depend on their chemical and physical properties and external factors. The properties include water solubility, tendency to transform or degrade (e.g., a compound's half-life), and chemical affinity for solids or organic matter (partition coefficient).

Predictions regarding the fate and transport of chemicals, including MC, and any breakdown products require detailed information about the integrity of the munitions or containers (relates to rate and duration of release), impurities present, temperature, pH, oxidation-reduction potential (ORP), degree of burial in sediment, currents at the disposal site, and on the physical and chemical nature of the chemicals themselves (Helsinki Commission [HELCOM], 1994). Density is a determining factor as to whether a compound will sink or rise to the surface when released (U.S. Army, 2005). The seawater density data from our FUI2 and FUI3 hydrocasts (discussed in Section 3.3 of this report) indicate that seawater density throughout the water column in the vicinity of Ordnance Reef (HI-06) ranged from 8.5298 to 8.5440 pounds per gallon (lbs/gal) (1.0221 to 1.0238 grams per milliliter [g/mL]). Because all of the COPCs are denser than seawater, they are anticipated to sink; however, when dissolved in seawater, the COPCs will diffuse and disperse throughout the water column.

The K_{ow} is the ratio of the concentration of a chemical in octanol and in water at equilibrium and at a specified temperature. This measure indicates the affinity of the compound to accumulate in fatty tissue and is used to help determine the fate of chemicals in the environment – the greater the partitioning to octanol (i.e., the greater the K_{ow}), the greater the potential for bioaccumulation. A compound with a K_{ow} >1,000 (or a log K_{ow} >3) would be expected to accumulate in the food chain in fatty tissue, while a compound with a K_{ow} of <500 (or a log K_{ow} of <2.70) is not expected to bioaccumulate (Daugherty, 1998).

K_{ow} is typically determined at a temperature of 68 or 77°F (20 or 25°C) and at standard atmospheric pressure. The Ordnance Reef (HI-06) study area is approximately 33 to 121 ft (10 to 37 m) deep, resulting in pressures of 14 to 59 pounds per square inch (psi) (one to 4 atmospheres) or more and bottom water temperatures ranging from about 73.9 to 78.8°F (23.3 to 26.0°C), based on data collected in April and September 2009 during the 2009 UH OR Study. It is not known how pressure at the study site alters the effective K_{ow} and hence bioaccumulation.

None of the Ordnance Reef (HI-06) COPCs has a log K_{ow} ≥2.7 at standard temperature and pressure (STP), i.e., none of the COPCs are expected to bioaccumulate. Therefore, in shallow water, none of the constituents is anticipated to significantly bioaccumulate or biomagnify in living tissue. As reported in the USCHPPM Health Risk Evaluation (USACHPPM, 2007), past research has indicated that explosives are rapidly biotransformed even in worst-case laboratory studies and it would not be likely to detect them in fish tissue. Contrary to this conclusion, we did detect energetics in biota, including fish tissue during both the 2009 Environmental Study and the 2011-2013 Follow-Up Investigation. Nevertheless, as reported in Lotufo and Lydy (2005) explosives and related compounds have low potential to bioconcentrate in aquatic organisms, as expected from their weak hydrophobicity.

K_{oc} is a measure of the degree to which a contaminant in water will be adsorbed to organic carbon in the environment. Often this leads to sequestration of the contaminant in sediments containing high concentrations of organic carbon.

The degree of risk associated with release of MC (e.g., energetics, metals) into seawater depends on numerous factors. The potential for harm is a function of the rates of release, degradation or sequestration, the extent to which a constituent is diluted, toxicity, dose and the duration of exposure.

3.1.1 Energetics

The 2009 UH OR Study (UH, 2014) evaluated the potential effect of conventional DMM on the composition of sediment, seawater, and human food item biota by analyzing for energetics (i.e., explosives) and their degradation products. This Follow-Up Investigation was designed to quantify the changes in MC in sediment and biota, possibly resulting from the ROUMRS technology demonstration.

The corrosion of the metal casings of conventional munitions and consequent leaking of the fill can release energetics and their degradation products into the environment. The fate and transport processes believed most applicable to energetics in sediment and marine environments are biotic transformation, oxidation or reduction, covalent bonding, and sorption to sediment substrates. Most energetics are relatively polar, but have low solubility in water and low vapor pressure (Table 3-4).

Commonly occurring energetics include explosives, propellants, impurities, and degradation compounds. As a group, military explosives have relatively low water solubilities and are relatively immobile in water. The degradation and dissolution of these materials may be slowed by the physical structure and composition of blended explosives (e.g., in Composition B, the dissolution rate of RDX controls the dissolution rate of TNT).

TNT transforms via a sequential reduction of its nitro groups (Yost et al., 2007). It has been noted that dissolution rates of TNT are somewhat slower in saline water than in fresh water. TNT is rapidly removed from solution in sediment slurries with half-lives ranging from 2.8 to 7.3 hours in both fresh and saline solutions. Formation of the TNT transformation products 2-Am-DNT and 4-Am-DNT was noted in the sediments tested. A rapid drop in aqueous concentration appears related to the sorption of the compounds to sediment. The rate is related to the cation exchange capacity (CEC), organic carbon content, and particle size (Brannon et al., 2005).

Experiments on the fate and effects of TNT on fish and invertebrates in field studies showed no significant impacts on body indices, hematological variables, hepatic detoxification, and antioxidant enzyme activities in fish (Ek et al., 2006; Lotufo et al., 2013). In the same study, no detectable levels of TNT or its degradates were found in sediments, bile, and blood plasma of fish, and hepatopancreas of mussels (Ek et al., 2006). Dissolution rates of TNT from munitions casings appeared to be relatively slow, with no continuous increase in acute sediment toxicity over time (Ek et al., 2006). Laboratory studies of rainbow trout exposed to TNT indicated that these fish were able to detoxify and excrete TNT (Ek et al., 2005; Lotufo et al., 2013).

A study of microbial degradation of RDX in tropical marine sediments collected in Hawai‘i indicated that cyclic nitramine contaminants are likely to be degraded upon release from munitions into tropical marine sediment (Bhatt et al., 2005), suggesting natural attenuation *in situ*.

Explosive D (ammonium picrate) is an ammonium salt of picric acid and under normal aqueous conditions will dissociate to ammonium and picrate ions. In sediment slurry tests, picric acid was found to remain in the aqueous phase with little partitioning to the sediments. Transformation to picramic acid was limited (Yost et al., 2007). It is likely that the ions would transform further depending on the ORP. For this study and the 2009 UH OR Study, picric acid was included in the list of COPCs as a conservative measure.

Nitroglycerin (glycerl trinitrate) is a common energetic material used in double base (nitroglycerin and nitrocellulose) gun propellants, and will leach out of the nitrocellulose matrix in the propellants. Nitroglycerin has a moderate range of aqueous solubility, with a half-life range of 37 to 96 days at pH 9 (Mirecki et al., 2006); typically seawater is about pH 8. The predominant products of nitroglycerin via hydrolysis are calcium nitrate and calcium nitrite. Nitroglycerin has a low log K_{ow} value, suggesting hydrophilic behavior and a low log K_{oc} value and indicating limited sorption, thus it is mobile in soil environments. Nitroglycerin has been documented to transform via microbial mediation in both aerobic and anaerobic conditions, ultimately forming glycerol (Mirecki et al., 2006).

Noblis (2011) discussed the possible fate of selected energetic MCs (specifically, TNT, RDX, HMX, Explosive D (ammonium picrate), and 2,4-DNT at Ordnance Reef (HI-06). For additional details, reference the Noblis (2011) document.

3.1.2 Elements

The elements of potential concern have relatively low solubility and are likely to accumulate in sediment and, due to their elemental nature, may oxidize or react with other materials but will not break down.

Element concentrations in sediments vary in relation to grain size and primary mineralogy. The sediment fraction under 7.87×10^{-5} in (2 micrometers [µm]) is a major sink for contaminants introduced into natural waters, due to the high surface area available for adsorption, and the associated coatings of organic material and iron and manganese oxyhydroxide precipitates (Horowitz, 1991). These substances scavenge dissolved trace metals from the water column and deposit them with the sediments (Stumm and Morgan, 1996).

3.1.2.1 Arsenic

The sediment characteristics, namely pH, organic matter content, clay content, iron oxide content, aluminum oxide content, and CEC, have an effect on the adsorption of arsenic. Arsenic may be adsorbed from water onto sediments or soils, especially clays, iron oxides, aluminum hydroxides, manganese compounds, and organic material. Iron content has a significant influence on arsenic adsorption; however, arsenic that is adsorbed to iron and manganese oxides may be released under reducing conditions (Stoeppler 1992; Fuller et al., 1993; Francesconi and Kuehnelt 2002; Plant et al., 2005; O'Day, 2006; ATSDR, 2007). Transport and partitioning of arsenic in water depends upon the chemical form (oxidation state and presence of complexing agents ion) of the arsenic and on interactions with other materials present. One source of arsenic in the water column can be re-suspended sediment. While arsenic bioaccumulates in animals, biomagnification in aquatic food chains does not appear to be significant (ATSDR, 2007).

3.1.2.2 Copper

In sediment, copper is generally associated with mineral matter or is tightly bound to organic material (Moffett et al, 1997; Burton et al., 2005). Copper is usually associated with fine as opposed to coarse sediment. The fate of copper in the aquatic environment is determined by the formation of complexes, sorption to hydrous metal oxides and organic matter. The formation of complexes with organic ligands modifies the solubility and precipitation behavior of copper. Between a pH 5 and 6, adsorption is the primary process for removing copper from the water column; above pH 6, formation and precipitation of hydroxy complexes becomes dominant (World Health Organization, 2003; Langmuir et al., 2004; Burton et al., 2005). Typically, seawater is about pH 8 thus, copper is expected to precipitate at Ordnance Reef (HI-06). According to Rainbow (2002) "[t]race metal concentrations are not as a rule biomagnified along food chains, the concentration at each trophic level being determined by the trace metal accumulation pattern of the particular species at each trophic level."

3.1.2.3 Lead

Sorption sequesters soluble lead in water. The tendency for lead to form complexes with organic matter increases its adsorptive affinity for clays and mineral surfaces (Langmuir et al., 2004; Burton et al., 2005). Benthic microbes can methylate lead to a volatile and more toxic form. According to Eisler (1988), "[N]o significant biomagnification of Pb [lead] occurs in aquatic food chains" which agrees with the findings of Rainbow (2002) cited above.

3.2 Results of Energetics Analysis

3.2.1 Energetics in Sediment

Of the 88 sediment samples (replicate samples were averaged) analyzed during the Follow-Up Investigation, the following MC compounds were detected in certain strata, primarily the DMM stratum (Table 3-1 and Appendix F, Table F-1):

	# & % of Total	# per Stratum
2,4-dinitrotoluene (2,4-DNT)	33 (37.5%)	31 DMM, 1 WWT, 1 NPS;
2,6-dinitrotoluene (2,6-DNT)	12 (13.6%)	12 DMM;
nitroglycerin (glyceryl trinitrate)	2 (2.3%)	2 DMM;
2-nitrotoluene (2-NT)	2 (2.3%)	2 DMM;
4-nitrotoluene (4-NT)	1 (1.1%)	1 DMM; and
Royal Demolition Explosive (RDX)	1 (1.1%)	1 DMM.

The median concentration of 2,4-DNT in sediments was 0.038 mg/kg-dw and 75% of the samples had concentrations <0.420 mg/kg-dw. The maximum 2,4-DNT concentration was 110 mg/kg-dw (FUI1). This particular set of samples (DMM-49A through C) actually revealed a gradient with the highest concentration occurring at the site (DMM-49A [ORD214S]), with the 2,4-DNT concentration decreasing with increasing distance so that it was 6.7 mg/kg-dw at a distance of 3 feet (0.9 m) and 2.3 mg/kg-dw at a distance of 6 feet (1.8 m). Oddly, the gradient was reversed in the case of DMM-40A through C (ORD207S through ORD209S – 0.28, 2.5, and 5.9 mg/kg-dw). In addition to the five detections exceeding 1.6 mg/kg during FUI1, this concentration was exceeded once during FUI2 (July 2012) and three times during FUI3 (June 2013). In the case of the FUI3, one of the 2,4-DNT concentrations was 2.1 mg/kg-dw but the replicate sample was only 0.60 mg/kg-dw. Of the energetics detected, only 2,4-DNT was detected in strata other than the DMM stratum – once each in the WWT (FUI1 – WWT-32 [ORD219S], estimated at 0.027 mg/kg-dw) and NPS (FUI2 – NPS-49 [ORD312S and ORD313S], <0.063 mg/kg-dw) strata.

The last energetic with a substantial number of detects (12), 2,6-DNT, had median and maximum concentrations (0.004 and 10.0 mg/kg-dw, respectively) considerably lower than 2,4-DNT and they were all associated with the DMM stratum. Of the 12 detects, half were between 0.001 and 0.033 mg/kg-dw. The remaining detects were nitroglycerin, 2-NT, 4-NT, and RDX, with maximum concentrations of 1.70, 1.10, 0.490, and 0.140 mg/kg-dw, respectively. These detects were also associated solely with the DMM stratum.

3.2.2 Energetics in Biota

Biota samples consisted of four types of organisms, arranged by order of increasing trophic level, they were: limu (seaweed), crab, octopus, and fish. All of the limu and octopus (minus beak and ink sac) were analyzed, whereas only the edible tissue of the crabs and fish were analyzed; the methods used to process these samples were detailed in Section 2.0 of this report. In addition to the Method 8330 COPC energetics, biota samples were also analyzed for additional 8330 energetics (e.g., 3,5-dinitroaniline, 2-nitrophenol, and 4-nitrophenol). Although these energetic are not considered COPCs, the data are presented in the laboratory report (see Appendix E) and the results are summarized on Appendix F, Table F-2.

During the Follow-Up Investigation, only three energetics (2,4-DNT, 2,6-DNT, and 1,3,5-TNB) were detected in biota samples collected from Ordnance Reef (HI-06) and only in the higher trophic level organisms, namely octopus and fish. (Table 3-2 and Appendix F, Table F-2). The energetics 2,4-DNT and 2,6-DNT were detected at estimated concentrations of 0.039 and 0.14 mg/kg, respectively, in a fish collected during FUI3 (June 2013, DMM-FDA [for an explanation of biota sample naming conventions, refer to the paragraph just before Section 3.1 above]). The energetic 1,3,5-trinitrobenzene (1,3,5-TNB) was detected once in an octopus during FUI3 at an estimated concentration of 0.055 mg/kg; it was detected in three fish, also during FUI3, at estimated concentrations ranging from 0.053 to 0.063 mg/kg.

3.3 Results of Elemental Analysis (Sediment and Biota)

3.3.1 Elemental Composition of Sediment Samples

Sediment samples from the different strata collected during the three Follow-Up Investigation sampling events (FUI1 - 2011, FUI2 - 2012, and FUI3 - 2013) were sieved into two grain-size fractions. These grain size categories were: a) clay-silt-sand (<2 mm) and (b) gravel (>2 mm). This approach differs slightly from the 2009 UH OR Study, during which three size fractions were obtained. Based on results of the latter study, it was decided that analysis of only the fraction <2 mm (i.e., combined sand, silt, and clay) would be necessary. All gravel fractions were retained; however, they were not analyzed.

Summary statistics for the representative major and minor elements (aluminum, calcium, iron, magnesium, manganese, strontium, and titanium) and trace elements (antimony, arsenic, barium, cadmium, chromium, cobalt, copper, lead, nickel, selenium, uranium, vanadium, and zinc) of the combined fractions of clay-silt and sand sediment samples from each of the four strata (CON, DMM, WWT, and NPS) during all three Follow-Up Investigation sampling events are presented in Table 3-1. The compiled sediment element table for all three sampling events is included in Appendix F, Table F-3; the validation reports are provided in Appendix G. The elemental composition of the gravel fraction was not determined as visual examination during sample processing indicated this size fraction consisted primarily of larger coral rubble and fragments and volcanic pebbles, neither of which were expected to be important carriers of COPC elements. The following discussion will concentrate primarily on the statistical summary presented in Table 3-1, which is based on the pooled Follow-Up Investigation (post-ROUMRS) data. These data were pooled in order to increase the power of the statistical tests used during this study. A detailed discussion of variations in element concentration between all sampling events and the pooled pre- and post-ROUMRS data are presented in Section 4.0 of this report.

Not every element detected during the Follow-Up Investigation is discussed in the report, but instead refer the reader to Table 3-1; however, a discussion of the COPC elements (arsenic, copper, and lead) in included in this section.

3.3.1.1 Arsenic

Of the 88 sediment samples collected (replicates were averaged), arsenic was detected in 75 (85.2%) of the samples. While arsenic was detected in all four strata, the highest median and maximum concentrations (10.6 and 20.0 mg/kg-dw, respectively) were found in samples from the CON (control) stratum. The median arsenic concentrations increased by stratum in the following order: DMM (1.90 mg/kg-dw) < WWT (2.60 mg/kg-dw) < NPS (3.83 mg/kg-dw) < CON (10.6 mg/kg-dw). These median concentrations are not particularly high for marine sediments (Francesconi and Edmonds 1998; Maher and Butler 1988; Reimann et al. 2009); nevertheless, the source of the arsenic remains uncertain (De Carlo et al., 2013). Within a fairly large range of detection limits (0.12 – 1.1 mg/kg-dw), there were 10 NDs (17.9%) in the DMM stratum, one ND (12.5%) in the WWT stratum, and two NDs (14.3%) in the CON stratum; arsenic was detected in all 10 of the samples from the NPS stratum.

Using the IQR (i.e., between the 25th and 75th percentiles in Table 3-1) within the DMM stratum, 50% of the arsenic concentrations were between 1.20 and 2.50 mg/kg, 25% were >2.50 mg/kg-dw and 25% were <1.20 mg/kg-dw; the maximum arsenic concentration in the DMM sediments during the Follow-Up Investigation was 3.50 mg/kg-dw. These concentrations are considerably lower than those observed from the CON stratum where 50% of the arsenic concentrations were between 3.10 and 17.0 mg/kg-dw with a maximum concentration of 20.0 mg/kg-dw.

3.3.1.2 Copper

Copper, unlike arsenic, was detected in all Follow-Up Investigation samples. Unlike arsenic, copper was higher in the DMM stratum than any other strata with median and maximum concentrations of 18.6 and 4,100 mg/kg-dw, respectively. Li (2000) reported the average copper concentration for pelagic clay was 250 mg/kg-dw. Closer to Ordnance Reef (HI-06), NOAA (1991) reported grain-size adjusted mean copper concentrations of 66 mg/kg-dw in fine-grained sediments from Barbers Point; for Honolulu Harbor they reported 70 mg/kg-dw of copper in fine-grained sediments. Clays, as noted earlier have the capability to adsorb more copper than the silt-clay-sand sediments collected at Ordnance Reef (HI-06), especially given that the sand fraction was generally the most abundant (UH, 2014). The median copper concentrations increased by stratum in the following order: NPS (1.30 mg/kg-dw) < CON (3.45 mg/kg-dw) < WWT (6.17 mg/kg-dw) < DMM (18.6 mg/kg-dw). Certainly the copper concentrations in the DMM stratum are considerably higher than the concentrations in any of the other strata sampled.

3.3.1.3 Lead

Like copper, lead was detected in all Follow-Up Investigation samples. While the median lead concentration of samples from the DMM stratum was higher than the other strata, the differences between strata were not as pronounced with the median concentrations by strata increasing in the following order: WWT (1.93 mg/kg-dw) < NPS (3.05 mg/kg-dw) < CON (3.45 mg/kg-dw) < DMM (4.80 mg/kg-dw). The maximum lead concentration in the DMM stratum (228 mg/kg-dw, FUI3 – DMM-73A [ORD411S and ORD412S]), however, was substantially higher than the next highest maximum concentration (8.80 mg/kg-dw) found in a sample from the CON stratum. Li (2000) reported an average lead concentration for pelagic clays of 80 mg/kg-dw. NOAA (1991) reported a grain-size adjusted mean lead concentration of 14 mg/kg-dw in fine-grained sediments from Barbers Point. Not surprisingly, the mean lead concentration in Honolulu Harbor was 58 mg/kg-dw.

3.3.2 Elemental Composition of Biota Samples

Like the sediment samples, biota samples were analyzed for the three COPCs (arsenic, copper, and lead) and a suite of other elements not considered to be COPCs (aluminum, antimony, barium, cadmium, chromium, cobalt, mercury, nickel, selenium, strontium, thallium, uranium, vanadium, and zinc). The summary statistics for the post-ROUMRS (FUI2 and FUI3) sampling (by organism) are presented in Table 3-2 (summary statistics for pre-ROUMRS are also included in this table but discussed in Section 4.0). Arsenic was also speciated into organic and inorganic forms for selected samples (Appendix H, Table H-1); the summary statistics for the post-ROUMRS (FUI2 and FUI3) arsenic speciation data by organism are included in Table 3-5.

As with the sediments, not every element detected in biota samples during the Follow-Up Investigation will be discussed, but instead refer the reader to Table 3-2; however, a discussion of the COPC elements (arsenic, copper, and lead) is included in this section.

3.3.2.1 Arsenic

Arsenic was detected in all biota samples with overall DLs ranging from 0.14 to 0.21 mg/kg. The statistics presented in Table 3-2 for arsenic are for total arsenic, i.e., the sum of both the inorganic and organic forms. The median arsenic concentration varied by organism as follows: limu (0.850 mg/kg) < fish (12.0 mg/kg) < octopus (24.2 mg/kg) < crab (48.0 mg/kg). This ordering of the median concentrations does not follow trophic levels except limu is at the lowest trophic level. There are, however, many factors that can control element concentrations in organisms including maturity, feeding habits, metabolism, etc., in addition to trophic level.

The maximum arsenic concentration for limu (2.67 mg/kg) is well within the range reported for various forms of algae (1.4 to 28.1 mg/kg) according to Eisler (2010a). It should be noted that “limu” is a Hawaiian word that encompasses a variety of algal (and other plant) types. Eisler (2010a) reported that “…arsenic concentrations are significantly higher in marine plants and animals than in freshwater counterparts…” and “…in general, total arsenic concentrations in brown algae were higher than those in red algae…”

Crab not only had the highest median total arsenic concentration (48.0 mg/kg) but the highest maximum concentration as well at 65.8 mg/kg. According to Eisler (2010a), arsenic exhibits a wide range of concentrations in crustaceans, with the highest concentrations occurring in lipids, liver, and muscle. Eisler goes on to state that “[e]dible tissues of crustaceans from the coastal waters of the United States usually contained 3.0-10.0 mg As/kg FW [milligrams of arsenic per kilogram fresh weight]…” however, most of this arsenic is primarily in the nontoxic organic form of arsenic. Half (i.e., within the IQR) of 15 crab tissue samples (replicates were averaged) analyzed during the Follow-Up Investigation (FUI2 only) had concentrations ranging from 33.2 to 56.7 mg/kg of total arsenic in their edible tissue.

According to Eisler (2010a), “…seafoods, especially *molluscs and crustaceans* [emphasis added], were unusually rich in arsenic compounds, although these were present almost always in the nontoxic form, that is, arsenobetaine or as organic pentavalent compounds, with *little risk to human consumers* [emphasis added].” Certainly our limited data support the statement that arsenic is highest in crustaceans such as the Kona crab and in molluscs such as the octopus; the latter organism (minus beak and ink sac) had a median concentration of 24.2 mg/kg and a maximum concentration of 37.0 mg/kg in data from the Follow-Up Investigation. In fact, half (again, within the IQR) of the 26 octopus sampled during the Follow-Up Investigation had concentrations ranging from 21.4 to 26.6 mg/kg.

Fish, on the other hand, had the second lowest median arsenic concentration (12.0 mg/kg) which was still well above the median concentration for limu. Eisler (2010b) reported that arsenic concentrations in fish varied widely but with most falling within 2.0 to 5.0 mg/kg and that fish with elevated arsenic concentrations came from areas with high arsenic concentrations in invertebrates suggesting that food uptake was an important factor. Half of the 44 Follow-Up Investigation fish samples had arsenic concentrations ranging from 9.71 to 15.9 mg/kg, which is elevated compared to most of the data reported by Eisler (2010b).

As stated previously, however, much of the arsenic found in marine organisms is reported to be in the form of the nontoxic organic arsenic compounds. In order to confirm this, arsenic speciation analyses were conducted on subsamples of biota. The summary statistics from these analyses for total, organic, and inorganic arsenic, conducted by Brooks Rand Laboratories (BRL), are presented in Table 3-5; the statistics for the total arsenic concentration determined by TestAmerica were also included in this table for comparison. Crabs, with the highest median BRL determined total arsenic concentration (49.9 mg/kg, n = 12) had a median organic arsenic concentration that was virtually identical to the total arsenic value. The maximum concentration of inorganic arsenic in crabs was only an estimated 0.005 mg/kg; most values were below the DL that ranged from 0.003 to 0.004 mg/kg.

Table 3-5: Arsenic speciation summary statistics by arsenic species and organism for the post-ROUMRS (FUI2 and FUI3) sampling

Variable	Organism	n	%ND	DL Range	Mean	SE	SD	Min	Q1	Median	Q3	Max
Total As (TA)	Crab	5	0.0%	0.15	44.9	6.26	14.0	28.5	30.9	46.0	58.3	61.2
	Fish	12	0.0%	0.14-0.15	13.3	1.85	6.40	5.40	8.55	11.1	20.5	24.0
	Limu	21	0.0%	0.14-0.16	1.06	0.126	0.576	0.580	0.730	0.850	1.13	2.67
	Octopus	10	0.0%	0.14-0.16	25.1	1.70	5.4	16.9	20.9	25.5	27.2	37.0
Total As (BRL)	Crab	5	0.0%	0.04-0.05	49.7	6.70	15.0	32.0	35.2	49.9	64.1	68.7
	Fish	12	0.0%	0.04-0.14	14.7	2.05	7.10	5.91	8.69	13.0	23.4	24.8
	Limu	21	0.0%	0.04-0.11	2.40	0.436	2.0	0.670	1.02	1.56	3.31	6.89
	Octopus	10	0.0%	0.04-0.11	27.1	1.61	5.09	18.3	24.8	26.5	29.7	37.7
Organic As (BRL)	Crab	5	0.0%	0.044-0.050	49.7	6.70	15.0	32.0	35.2	49.9	64.1	68.7
	Fish	12	0.0%	0.043-0.141	14.7	2.05	7.10	5.91	8.68	13.0	23.4	24.8
	Limu	21	0.0%	0.044-0.154	1.83	0.318	1.46	0.526	0.784	1.06	2.93	4.92
	Octopus	10	0.0%	0.044-0.109	27.1	1.61	5.09	18.3	24.8	26.5	29.7	37.7
Inorganic As (BRL)	Crab	5	60.0%	0.003-0.004	*	*	*	ND	*	*	*	0.005 J
	Fish	12	91.7%	0.004	*	*	*	ND	*	*	*	0.013
	Limu	21	0.0%	0.004-0.154	0.564	0.135	0.618	0.122	0.168	0.357	0.589	2.262
	Octopus	10	90.0%	0.003-0.004	*	*	*	ND	*	*	*	0.004 J

* Insufficient data to calculate statistic

All units are mg/kg wet or fresh weight unless otherwise indicated

ND = not detected, J = estimated value (i.e., between DL and RL)

The concentration of inorganic arsenic was virtually undetectable in the other organisms with the exception of limu (Table 3-5). According to the arsenic speciation results from BRL, limu had a median total, organic, and inorganic arsenic concentration of 1.56, 1.06, and 0.357 mg/kg, respectively. Half of the 21 limu samples (i.e., within the IQR) had inorganic arsenic concentrations ranging from 0.168 to 0.589 mg/kg; 25% of the samples had inorganic concentrations >0.589 mg/kg with the maximum concentration being 2.26 mg/kg. These findings also provide an excellent example of when a median and mean might be used. If the question concerns the frequency with which a concentration can be expected, then the median (in this example, 0.357 mg/kg) is a better statistic; half of the time the concentration will be higher than this value and half of the time it will be lower. If, however, the question is how much arsenic might be ingested by someone eating limu, then the mean concentration of inorganic arsenic (in this example, 0.564 mg/kg), which is affected by outliers, is arguably a better statistic to use.

3.3.2.2 Copper

Copper was detected in all biota samples. Not surprisingly, the median concentration of copper was highest in crabs and octopus (8.40 and 5.40 mg/kg, respectively for the Follow-Up Investigation) – the blood of both organisms contains copper-based hemocyanin rather than iron-based hemoglobin. In fact, it is the copper in hemocyanin that gives the blue crab (*Callinectes sapidus*) its name. Moreover, according to White and Rainbow (1985), "… metabolically functional copper and zinc often make up significant proportions of the total content of these metals in molluscs [e.g., octopus] and crustaceans [e.g., Kona crab] from non-polluted environments, especially the open ocean." For example, White and Rainbow (1985) calculated that the total theoretical metabolic and respiratory requirements for copper in cephalopod molluscs and decapod crustaceans were 91.8 and 83.7 ppm-dry weight, respectively.

According to Kumar et al. (2014), "[c]opper serves as an essential component in metabolic processes of algae [as well as animals], playing vital functions in the electron transport and various enzyme systems (e.g., amineoxidase, cytochrome c oxidase), and particularly works as a prosthetic group of the…enzyme Cu/Zn superoxide dismutase [Cu/Zn-SOD]." According to Mallick and Mohn (2000), "… SOD [superoxide dismutase] consists of a group of metalloisoenzymes that neutralize the very reactive superoxide radicals (O_2^-) into oxygen (O_2) and hydrogen peroxide (H_2O_2).

$$2O_2^- + 2H^+ \xrightarrow{SOD} O_2 + H_2O_2$$

One of the types of SOD…is a copper-zinc-containing protein." Paradoxically, excess copper and zinc (and other heavy metals) can induce oxidative stress (Mellado et al., 2012).

The fact that all biota copper concentrations were below the theoretical limit in the octopus and crab (White and Rainbow, 1985) was most likely due to the fact that the Follow-Up Investigation reported concentrations as parts per million – wet weight, whereas White and Rainbow (1985) report the trace element concentrations as parts per million – dry weight.

Interestingly, during the Follow-Up Investigation, the highest maximum copper concentration was measured in a sample of limu (16.0 mg/kg) and not the crabs (12.8 mg/kg) or octopus (9.10

mg/kg). Not surprisingly, this sample of limu was collected from the DMM stratum, specifically, DMM-73A (ORD401L), a site with a high copper concentration in the sediment (average of two replicates = 355 mg/kg-dw [ORD411S and ORD412S]); not the highest copper concentration observed in sediment but most definitely well above the 75^{th} percentile for copper in sediments (77.0 mg/kg, refer to Table 3-1).

The lowest median and maximum copper concentration (0.385 and 2.90 mg/kg, respectively) for the Follow-Up Investigation was measured in a sample of fish tissue. Unlike the limu, the motility of fish makes it difficult to attribute concentrations of copper to a specific stratum such as DMM. Half of the 44 fish samples analyzed (i.e., within the IQR) had copper concentrations ranging from 0.303 to 0.564 mg/kg, whereas half of the 15 crabs ranged from 7.20 to 10.2 mg/kg and half of 26 octopus ranged from 3.80 to 6.14 mg/kg. In fact, the minimum copper concentration for octopus (3.40 mg/kg) was greater than the maximum copper concentration for fish (2.90 mg/kg), no doubt in part due to the hemocyanin in the octopus blood.

3.3.2.3 Lead

Unlike arsenic and copper, lead was not always detected in the biota. DLs for lead ranged from 0.06 to 0.08 mg/kg. Lead was not detected in any of the 15 crab or 26 octopus samples analyzed during the Follow-Up Investigation. Lead, however, was detected in limu at median concentration of 0.380 mg/kg. Half of the 23 limu samples had concentrations between 0.275 and 0.530 mg/kg, with a maximum of 1.40 mg/kg which was found in the CON stratum at CON-56 (ORD409L). Interestingly, lead in the sediments was not particularly elevated at CON-56 (ORD423S) – 3.30 mg/kg-dw, i.e., less than the CON sediment median of 3.45 mg/kg-dw. Unfortunately, most of the lead data reported by Eisler (2010a) is expressed in dry weight making it difficult to compare with the data from the Follow-Up Investigation. The one range expressed as fresh (or wet) weight reported by Eisler (2010a) for seaweed from Korea extended from 0.05 to 0.3 mg/kg which is somewhat lower than what UH observed.

A total of 44 fish samples was analyzed for lead, of which, 35 (79.5%) were NDs with a DL of 0.06 mg/kg. Regression on order statistics (ROS) were used to estimate the various statistics presented in Table 3-2 and, unlike the other methods use, ROS will estimate a minimum which, in this case was 0.000 mg/kg at the reported precision. The estimated median concentration for lead in fish was 0.002 mg/kg, i.e., below the laboratory DL; 25% of the samples were estimated to have a lead concentration >0.013 mg/kg. The maximum lead concentration for fish was 6.00 mg/kg (DMM-FDQ [ORD434F]).

3.4 Possible Sources of Various Analytes

While the occurrence and concentrations of various analytes, as discussed above, are important, they beg the question – where did these analytes come from? The energetics, by their very nature, identify their origin, i.e., explosives, propellants, and degradation products of these explosives and propellants. Elements, on the other hand, being ubiquitous, make the identification of the sources more challenging. This is where multivariate statistical analysis is useful. We used the various exploratory techniques described in Section 2.0 in order to understand better the sources of these elements and the energetics served to confirm some of the conclusions reached.

As explained in Section 2.0 of this report, NMDS is an exploratory nonparametric ordination technique for examining complex data and discerning patterns within the data that may not be readily apparent when simply looking at tables of numbers or even summary statistics. NMDS cannot be used to test hypotheses, e.g., does one group of samples differ significantly from another group; however, NMDS can help identify different groups of samples and variables (analytes). Being a nonparametric ordination technique, NMDS does not require a specific data distribution (e.g., normal, log-normal, etc.) and, unlike principal components analysis (PCA), NMDS does not require that the relationships between the variables (analytes) be linear.

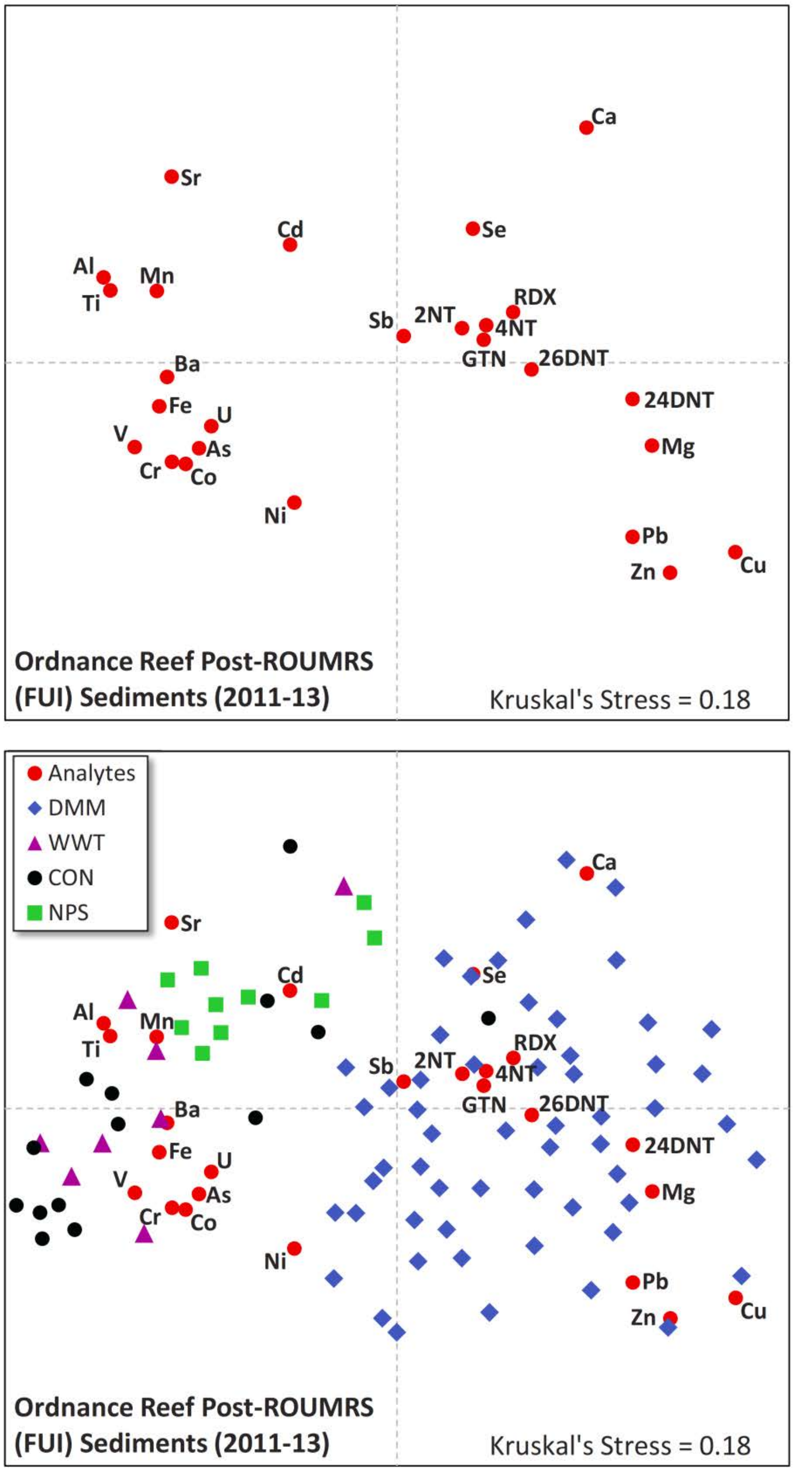
We examined both the sediment and biota data using NMDS to look for patterns and relationships within the data. The NMDS plot for sediments is presented in Figure 3-16. Normally, NMDS plots include the variables (analytes) and the samples; however, given that not everyone is familiar with NMDS plots, only the analytes are shown first in the top panel of Figure 3-16. The bottom panel combines the analytes and samples together.

Although the plot may look complicated, it is not. Of primary interest are the patterns, if any, that appear and if these patterns are real or simply random. Kruskal's stress, in this case 0.18, is an indicator of randomness. While there are no hard and fast rules, generally, if Kruskal's stress is <0.20, then the pattern is not necessarily random. In the case of the pooled post-ROUMRS (FUI1, FUI2, and FUI3) sediment data, the pattern is not quite random. There does appear to be some clustering of data. Moreover, the clusters appear to make sense. For example, the energetics are all on the right side center of the figure. In addition, the elements (zinc [Zn], copper [Cu], lead [Pb], and magnesium [Mg]) that might be associated with munitions seem to cluster in the lower right quadrant and closer to the energetics (e.g., 2,4-DNT, nitroglycerin [GTN], 2,6-DNT) than most of the other elements. Elements like zinc and copper might be expected to cluster with munitions because of brass casings. Lead and magnesium would cluster with munitions because they could be associated with SAA slugs and tracer rounds, respectively. The fact that these elements seem to cluster with the energetics simply adds credence to this interpretation.

Many of the other elements cluster on the left side of the NMDS plot and, for the most part, they are elements that would be associated with Hawaiian basalts which are rich in iron (Fe), aluminum (Al), chromium (Cr), etc. Hawaiian basalts are quite poor in arsenic (As) and yet arsenic clusters with these so-called petrogenic elements suggesting that perhaps arsenic may be associated with terrestrial runoff and certainly not DMMs.

Overlaying the samples (normally performed automatically in NMDS plotting) helps confirm our conclusions about the analytes (bottom panel of Figure 3-16). The individual samples are not identified to reduce clutter; however, the stratum from which they were collected is indicated by the symbol assigned to each datum. Notice that most of the DMM samples (blue diamonds) cluster to the right side of the NMDS plot with the analytes associated with DMMs. The other samples generally cluster to the left side of the plot with the petrogenic elements. The pattern shown, while not very strong (Kruskal's stress = 0.18), does seem to support our conclusions about the sources for the various analytes.

Figure 3-16: NMDS plot of post-ROUMRS (FUI1-3) sediment analytes (red dots) and sediment samples for different strata: DMM (blue diamonds), WWT (magenta triangles), CON (black dots), and NPS (green squares); top panel shows only the analytes. A Kruskal's stress < 0.20 suggests the pattern is not random.



The NMDS plot does not provide any indication of the strength of the relationship between the various analytes and, in fact, note that there are no labels or scales assigned to the axes. In order to determine the strength of the relationship between the various analytes, we conducted correlation analyses using Kendall's tau (τ). As discussed in Section 2.0 of this report, Kendall's τ is the nonparametric analog of Pearson's r. A correlation matrix using Kendall's τ is shown in Table 3-6, below. The table lists each analyte for which a correlation could be calculated on the top and sides of the table. In addition to the analytes, the leftmost column indicates Kendall's tau (τ), the probability value (p), and the number of samples (n). The format of the table quickly highlights correlations that are significant at a significance level $\alpha = 0.05$ (a correlation is significant if $p < 0.05$) through the use of bold text; whether a significant correlation is positive or negative is indicated with green or red font, respectively. Arsenic (As) for example, is strongly correlated with the petrogenic (rock-based) elements with Kendall's τ generally >0.3, which is roughly equivalent to a Pearson's r of about 0.5 (refer to Section 2.0). On the other hand, aluminum (Al) has a relatively strong and significant negative relationship with analytes associated with DMMs such as Cu (τ = -0.335), Pb (τ = -0.193), Mg (τ = -0.235), Zn (τ = -0.210), and 2,4-DNT (τ = -0.178). This means that as aluminum concentration (associated with Hawaiian basalts) increases, the concentrations of the analytes associated with DMMs decrease. In other words, sites with high aluminum (and other petrogenic elements) are under the influence of terrestrial runoff. It is patterns like those seen in the NMDS plot and the Kendall's τ correlations, that lead us to believe that arsenic is associated with terrestrial runoff and not DMMs (note that there are no significant correlations between arsenic and any of the analytes associated with DMMs).

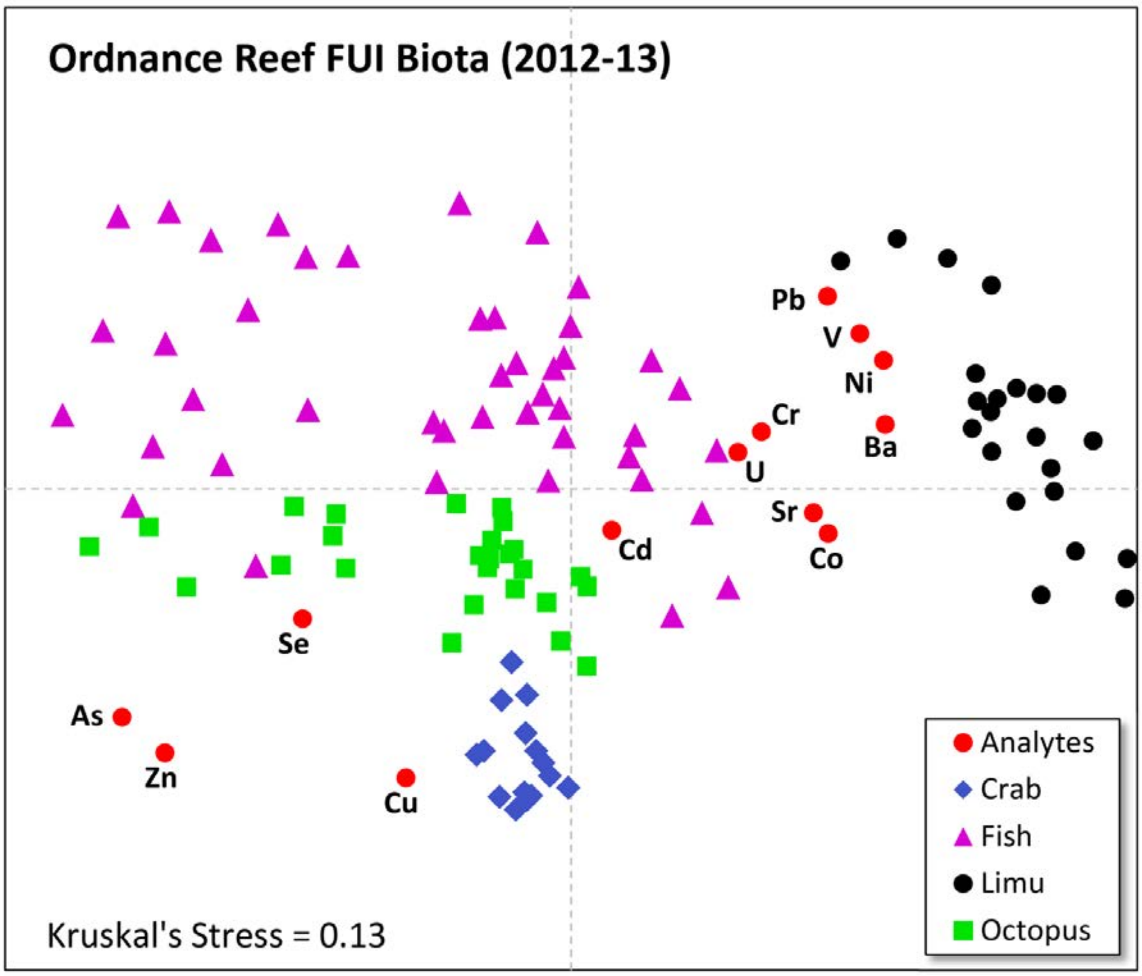
Table 3-6: Kendall's τ correlation matrix for sediment element and energetics data from the Ordnance Reef post-ROUMRS (FUI1-3) sampling during 2011-2013. Significant correlations (α = 0.05) are indicated with bold font; green indicates a positive correlation and red indicates a negative correlation.

Variable		Al	As	Ba	Cd	Ca	Cr	Co	Cu	Fe	Pb	Mg	Mn	Ni	Sr	Ti	U	V	Zn	2,4-DNT	2,6-DNT
Al	τ		0.406	0.346	0.141	-0.147	0.323	0.384	-0.335	0.635	-0.193	-0.235	0.505	0.180	0.519	0.799	0.268	0.398	-0.210	-0.178	-0.094
	p		0.000	0.000	0.047	0.043	0.000	0.000	0.000	0.000	0.008	0.001	0.000	0.013	0.000	0.000	0.000	0.000	0.004	0.008	0.158
	n		88	88	88	88	88	88	88	88	88	88	88	88	88	88	88	88	88	88	88
As	τ	0.406		0.310	0.127	-0.147	0.395	0.309	-0.140	0.456	0.072	-0.059	0.323	0.171	0.228	0.409	0.324	0.440	-0.013	-0.068	-0.031
	p	0.000		0.000	0.072	0.042	0.000	0.000	0.053	0.000	0.319	0.417	0.000	0.018	0.002	0.000	0.000	0.000	0.862	0.313	0.640
	n	88		88	88	88	88	88	88	88	88	88	88	88	88	88	88	88	88	88	88
Ba	τ	0.346	0.310		0.101	-0.166	0.445	0.342	-0.247	0.284	-0.091	-0.230	0.360	0.229	0.330	0.328	0.382	0.503	-0.195	-0.218	-0.072
	p	0.000	0.000		0.154	0.022	0.000	0.000	0.001	0.000	0.207	0.001	0.000	0.002	0.000	0.000	0.000	0.000	0.007	0.001	0.282
	n	88	88		88	88	88	88	88	88	88	88	88	88	88	88	88	88	88	88	88
Cd	τ	0.141	0.127	0.101		-0.121	0.136	0.102	-0.058	0.131	-0.015	0.026	0.126	0.105	0.050	0.141	0.120	0.123	-0.009	-0.033	-0.015
	p	0.047	0.072	0.154		0.087	0.054	0.149	0.417	0.064	0.831	0.718	0.077	0.139	0.479	0.047	0.090	0.084	0.906	0.618	0.821
	n	88	88	88		88	88	88	88	88	88	88	88	88	88	88	88	88	88	88	88
Ca	τ	-0.147	-0.147	-0.166	-0.121		-0.246	-0.312	-0.055	-0.202	-0.050	-0.047	-0.200	-0.345	0.176	-0.158	-0.146	-0.301	-0.049	-0.016	0.009
	p	0.043	0.042	0.022	0.087		0.001	0.000	0.449	0.005	0.493	0.519	0.006	0.000	0.016	0.029	0.044	0.000	0.498	0.817	0.891
	n	88	88	88	88		88	88	88	88	88	88	88	88	88	88	88	88	88	88	88
Cr	τ	0.323	0.395	0.445	0.136	-0.246		0.420	-0.166	0.341	-0.089	-0.134	0.361	0.400	0.171	0.339	0.418	0.598	-0.065	-0.109	-0.036
	p	0.000	0.000	0.000	0.054	0.001		0.000	0.022	0.000	0.219	0.064	0.000	0.000	0.018	0.000	0.000	0.000	0.368	0.107	0.592
	n	88	88	88	88	88		88	88	88	88	88	88	88	88	88	88	88	88	88	88
Co	τ	0.384	0.309	0.342	0.102	-0.312	0.420		-0.082	0.416	-0.040	-0.075	0.327	0.574	0.201	0.379	0.311	0.547	-0.059	-0.211	-0.122
	p	0.000	0.000	0.000	0.149	0.000	0.000		0.255	0.000	0.579	0.298	0.000	0.000	0.005	0.000	0.000	0.000	0.417	0.002	0.066
	n	88	88	88	88	88	88		88	88	88	88	88	88	88	88	88	88	88	88	88
Cu	τ	-0.335	-0.140	-0.247	-0.058	-0.055	-0.166	-0.082		-0.117	0.435	0.289	-0.312	0.065	-0.381	-0.312	-0.170	-0.213	0.674	0.290	0.119
	p	0.000	0.053	0.001	0.417	0.449	0.022	0.255		0.108	0.000	0.000	0.000	0.374	0.000	0.000	0.019	0.003	0.000	0.000	0.074
	n	88	88	88	88	88	88	88		88	88	88	88	88	88	88	88	88	88	88	88
Fe	τ	0.635	0.456	0.284	0.131	-0.202	0.341	0.416	-0.117		-0.033	-0.068	0.532	0.244	0.338	0.699	0.217	0.437	-0.001	-0.061	0.013
	p	0.000	0.000	0.000	0.064	0.005	0.000	0.000	0.108		0.655	0.347	0.000	0.001	0.000	0.000	0.003	0.000	0.994	0.370	0.853
	n	88	88	88	88	88	88	88	88		88	88	88	88	88	88	88	88	88	88	88
Pb	τ	-0.193	0.072	-0.091	-0.015	-0.050	-0.089	-0.040	0.435	-0.033		0.281	-0.216	-0.002	-0.233	-0.186	-0.050	-0.093	0.458	0.150	0.073
	p	0.008	0.319	0.207	0.831	0.493	0.219	0.579	0.000	0.655		0.000	0.003	0.986	0.001	0.010	0.493	0.202	0.000	0.026	0.273
	n	88	88	88	88	88	88	88	88	88		88	88	88	88	88	88	88	88	88	88
Mg	τ	-0.235	-0.059	-0.230	0.026	-0.047	-0.134	-0.075	0.289	-0.068	0.281		-0.126	0.039	-0.425	-0.231	-0.140	-0.187	0.364	0.138	0.105
	p	0.001	0.417	0.001	0.718	0.519	0.064	0.298	0.000	0.347	0.000		0.082	0.593	0.000	0.001	0.054	0.010	0.000	0.041	0.115
	n	88	88	88	88	88	88	88	88	88	88		88	88	88	88	88	88	88	88	88
Mn	τ	0.505	0.323	0.360	0.126	-0.200	0.361	0.327	-0.312	0.532	-0.216	-0.126		0.188	0.305	0.514	0.223	0.444	-0.239	-0.157	-0.003
	p	0.000	0.000	0.000	0.077	0.006	0.000	0.000	0.000	0.000	0.003	0.082		0.010	0.000	0.000	0.002	0.000	0.001	0.020	0.966
	n	88	88	88	88	88	88	88	88	88	88	88		88	88	88	88	88	88	88	88
Ni	τ	0.180	0.171	0.229	0.105	-0.345	0.400	0.574	0.065	0.244	-0.002	0.039	0.188		0.002	0.161	0.275	0.363	0.079	-0.139	-0.079
	p	0.013	0.018	0.002	0.139	0.000	0.000	0.000	0.374	0.001	0.986	0.593	0.010		0.983	0.027	0.000	0.000	0.274	0.040	0.235
	n	88	88	88	88	88	88	88	88	88	88	88	88		88	88	88	88	88	88	88
Sr	τ	0.519	0.228	0.330	0.050	0.176	0.171	0.201	-0.381	0.338	-0.233	-0.425	0.305	0.002		0.476	0.143	0.227	-0.325	-0.246	-0.104
	p	0.000	0.002	0.000	0.479	0.016	0.018	0.005	0.000	0.000	0.001	0.000	0.000	0.983		0.000	0.049	0.002	0.000	0.000	0.119
	n	88	88	88	88	88	88	88	88	88	88	88	88	88		88	88	88	88	88	88
Ti	τ	0.799	0.409	0.328	0.141	-0.158	0.339	0.379	-0.312	0.699	-0.186	-0.231	0.514	0.161	0.476		0.237	0.400	-0.192	-0.134	-0.052
	p	0.000	0.000	0.000	0.047	0.029	0.000	0.000	0.000	0.000	0.010	0.001	0.000	0.027	0.000		0.001	0.000	0.008	0.048	0.434
	n	88	88	88	88	88	88	88	88	88	88	88	88	88	88		88	88	88	88	88
U	τ	0.268	0.324	0.382	0.120	-0.146	0.418	0.311	-0.170	0.217	-0.050	-0.140	0.223	0.275	0.143	0.237		0.420	-0.098	-0.177	-0.117
	p	0.000	0.000	0.000	0.090	0.044	0.000	0.000	0.019	0.003	0.493	0.054	0.002	0.000	0.049	0.001		0.000	0.175	0.009	0.079
	n	88	88	88	88	88	88	88	88	88	88	88	88	88	88	88		88	88	88	88
V	τ	0.398	0.440	0.503	0.123	-0.301	0.598	0.547	-0.213	0.437	-0.093	-0.187	0.444	0.363	0.227	0.400	0.420		-0.131	-0.207	-0.097
	p	0.000	0.000	0.000	0.084	0.000	0.000	0.000	0.003	0.000	0.202	0.010	0.000	0.000	0.002	0.000	0.000		0.072	0.002	0.144
	n	88	88	88	88	88	88	88	88	88	88	88	88	88	88	88	88		88	88	88
Zn	τ	-0.210	-0.013	-0.195	-0.009	-0.049	-0.065	-0.059	0.674	-0.001	0.458	0.364	-0.239	0.079	-0.325	-0.192	-0.098	-0.131		0.290	0.133
	p	0.004	0.862	0.007	0.906	0.498	0.368	0.417	0.000	0.994	0.000	0.000	0.001	0.274	0.000	0.008	0.175	0.072		0.000	0.046
	n	88	88	88	88	88	88	88	88	88	88	88	88	88	88	88	88	88		88	88
2,4-DNT	τ	-0.178	-0.068	-0.218	-0.033	-0.016	-0.109	-0.211	0.290	-0.061	0.150	0.138	-0.157	-0.139	-0.246	-0.134	-0.177	-0.207	0.290		0.250
	p	0.008	0.313	0.001	0.618	0.817	0.107	0.002	0.000	0.370	0.026	0.041	0.020	0.040	0.000	0.048	0.009	0.002	0.000		0.000
	n	88	88	88	88	88	88	88	88	88	88	88	88	88	88	88	88	88	88		88
2,6-DNT	τ	-0.094	-0.031	-0.072	-0.015	0.009	-0.036	-0.122	0.119	0.013	0.073	0.105	-0.003	-0.079	-0.104	-0.052	-0.117	-0.097	0.133	0.250	
	p	0.158	0.640	0.282	0.821	0.891	0.592	0.066	0.074	0.853	0.273	0.115	0.966	0.235	0.119	0.434	0.079	0.144	0.046	0.000	
	n	88	88	88	88	88	88	88	88	88	88	88	88	88	88	88	88	88	88	88	

τ = Kendall's correlation coefficient; *p* = probability, if *p* < α = 0.05 → correlation is significant; n = number of samples; 0.500 = significant positive correlation; -0.500 = significant negative correlation; τ ± (0.15-0.20) = *r*

The NMDS plot of the biota data (Figure 3-17), however, leads us to different conclusions. Although the pattern is not random (Kruskal's stress = 0.13), it is apparent that there is no readily apparent relationship between the analytes. What is readily apparent, and not totally unexpected, is that the samples cluster by organism with limu on the right side of the plot and, progressing leftward and downward, fish, octopus, and crab. According to Rainbow (2002), "[a]ny meaningful comparison of relative concentrations [of elements] in aquatic invertebrates should be *intraspecies, and certainly not between families* [emphasis added] (e.g. between mussels and oysters), or higher systematic divisions such as between decapod and cirripede crustaceans." Notice that the octopus and especially the crab cluster near copper (Cu) which is expected given the copper-based hemocyanin in the blood of these organisms. There is no clustering of samples by stratum.

Figure 3-17: NMDS Plot of post-ROUMRS biota data; analytes are indicated with red dots and the different organisms are represented by the other symbols indicated in the key.



3.5 Water Column Profiles

The last products created from the data collected during the Follow-Up Investigation were the water column vertical profile plots created from the hydrocast data collected by the CTD and associated sensors. Unfortunately, during FUI1 (2011), the data were not recorded as the instrument was lowered through the water column. This malfunction was not discovered until the CTD was returned to UH and an attempt was made to download the data.

During the FUI2 (2012) sampling effort, the CTD did record the data as it was lowered through the water column. The hydrocast (water column) data and basic statistics are included in Appendix I, Table I-1; vertical profile plots are shown in Figure 3-18. Most of the profiles were to water depths of around 65 feet (20 m) and show relatively well mixed waters with a slight decrease in temperature with increasing depth. Hydrocast 3 on 17-July-2012 went to a maximum depth of 115 feet (35 m) and showed a pronounced thermocline (depth at which temperature changes rapidly with depth) and halocline (depth at which salinity changes rapidly with depth) at around 40 feet (12 m). Water temperature remained relatively constant at around 78.0°F (25.5°C) down to a depth of 40 feet (12 m) and then started to rapidly decrease, ultimately to a temperature of around 76.6°F (24.8°C). Salinity, on the other hand, was around 35.1 ppt near the surface and increased to a little over 35.2 ppt near the bottom. A similar trend was seen for Hydrocast 6. Interestingly, during Hydrocast 8 (18-July-2012), the same general decrease in temperature and increase in salinity was seen but the change was more gradual with depth and the thermocline and halocline were less evident.

Hydrocasts were again conducted during FUI3 (2013) and the profile plots are shown in Figure 3-19. Due to a possible sensor malfunction the dissolved oxygen data were considered to be erroneous. The thermocline and halocline that were so evident in the deeper hydrocasts during FUI2 were not evident in these profile plots even though Hydrocast 2 almost seems to show both a thermocline and a halocline. The salinity record in this hydrocast suggests, however, that the sensors may not have reached equilibrium before the CTD was lowered.

Figure 3-18: Water column profiles from Post-ROUMRS hydrocasts (FUI2 – 2012); color connects the variables to appropriate axes.

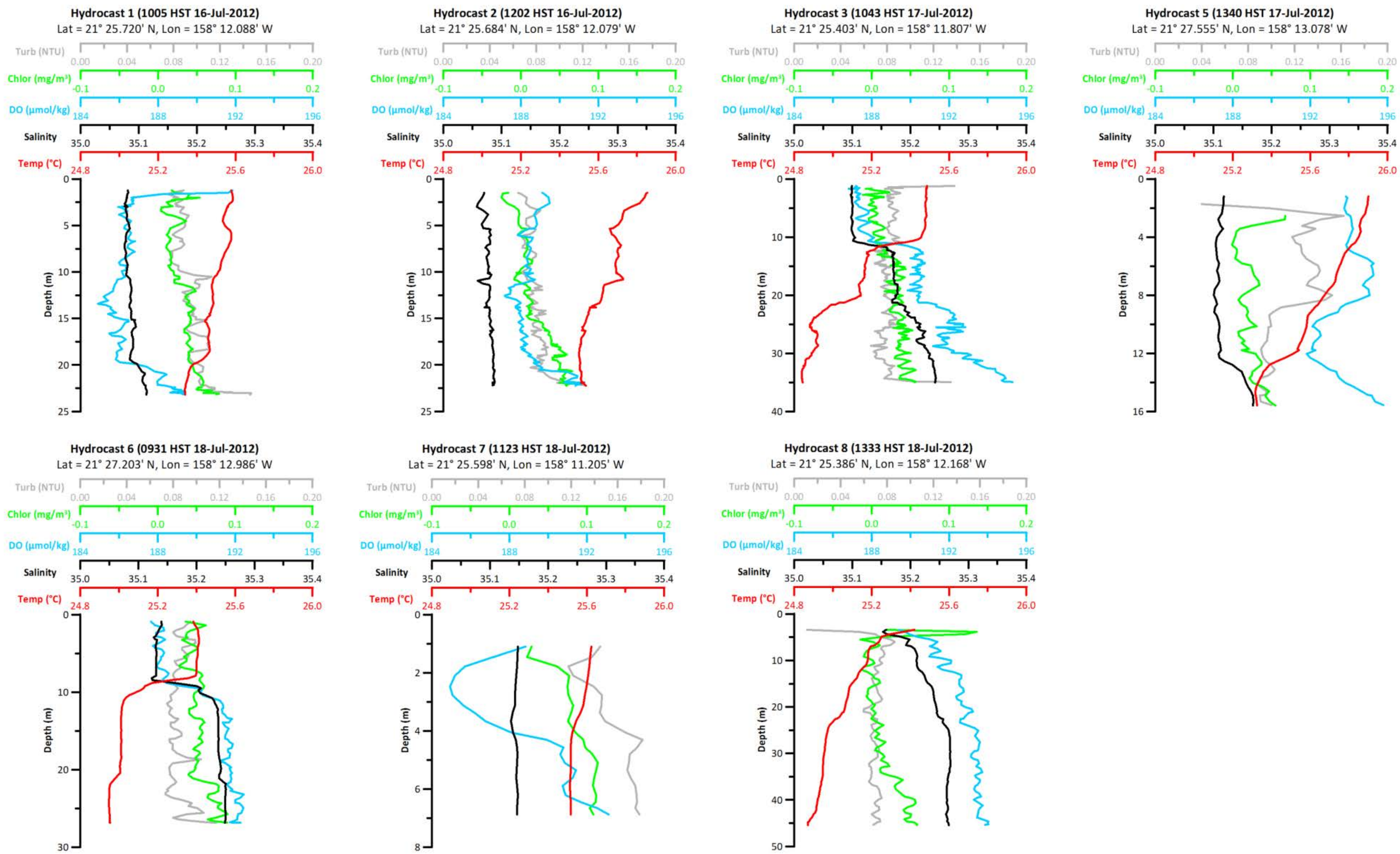
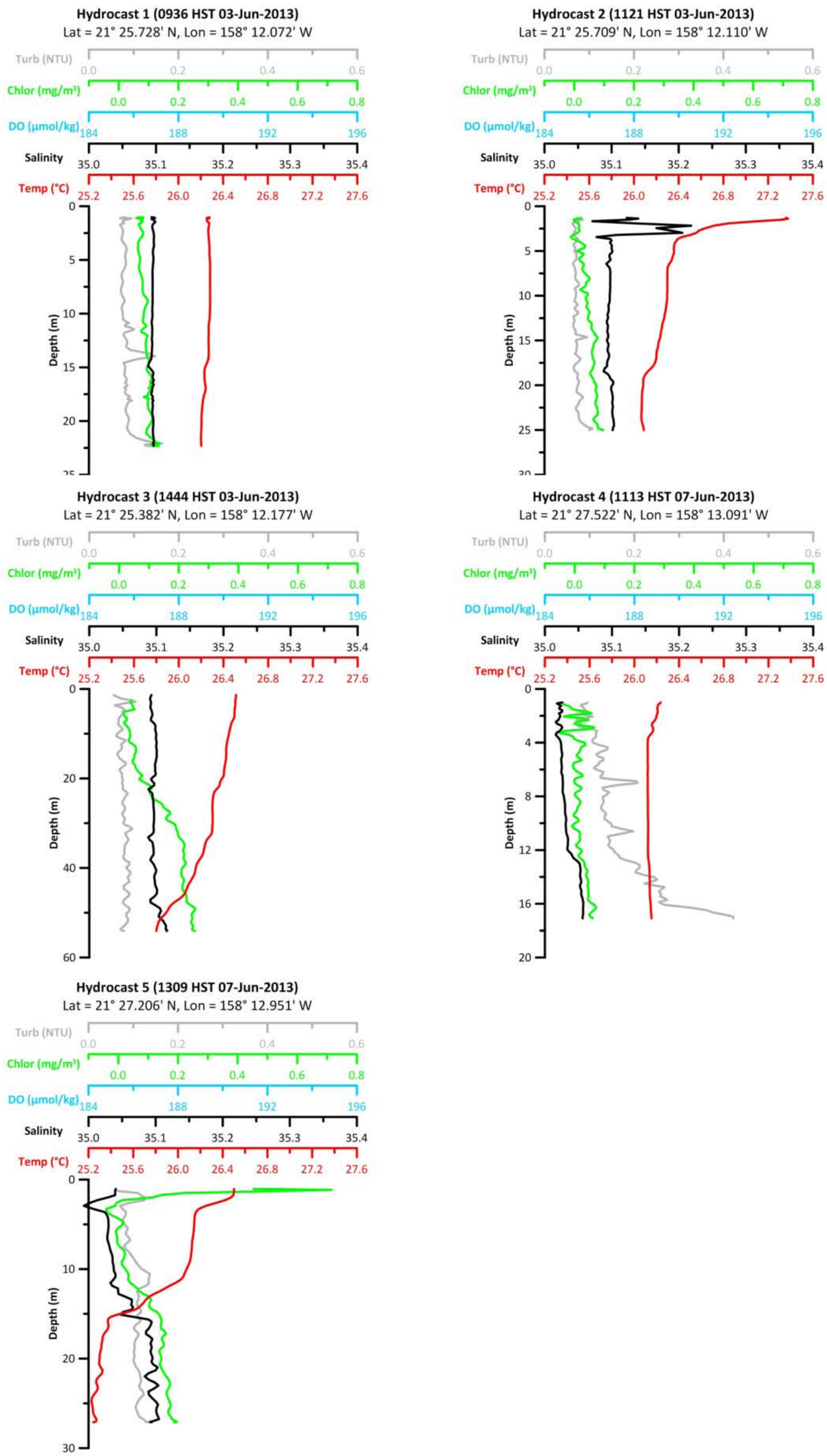


Figure 3-19: Water column profiles from Post-ROUMRS hydrocasts (FUI3 – 2013); color connects the variables to appropriate axes.



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Section 4 *Comparison of Pre- and Post-ROUMRS Data*

Ultimately, the question comes down to: "What effect, if any, did the ROUMRS technology demonstration have on the chemical composition of the surrounding sediments and biota of Ordnance Reef (HI-06)?" Before answering this question, however, the data collected during the 2009 UH OR Study and the 2011-2013 Follow-Up investigation needed to be reviewed. One of the best ways to look at these data and their distribution through time is by creating a series of boxplots, each representing a single sampling event. Some of these data, however, were left-censored, i.e., below the detection limits or NDs. Previously in the report, the summary statistics that can be estimated using a variety of techniques based on the percentage of NDs (refer back to Tables 3-1 and 3-2) were discussed. Although these statistics are very helpful, sometimes it helps to visualize data distributions with boxplots, even when some of the data are censored. Therefore, each section of the sediment and biota results begins with an overview of the data by sampling event. This is followed by a comparison of the censored boxplots for the pooled pre- and post-ROUMRS data by strata and organism and the results of the hypothesis testing to determine if there are statistically significant differences.

4.1 Sediments

Figure 4-1 presents boxplots showing the sediment data distribution for each sampling event with all strata pooled. These boxplots simply show how the distribution of each analyte varied with time. While pooling the data for each event obscures the differences that might exist in strata, it increases the number of samples (without pooling the strata, some individual strata would have an n <5) and, hence, the power of the statistics. It is always important to examine data before proceeding with any statistical analysis and boxplots are an excellent way to examine the distribution of data. There are two boxplots for the 2009 pre-ROUMRS sampling (OR1 and OR2) and three boxplots for the 2011-2013 post-ROUMRS sampling (FUI1, FUI2, and FUI3). The heavy bold line located within the box represents the median value (50^{th} percentile or 2^{nd} quartile); the top and bottom of the box (sometimes referred to as "hinges") represent the 75^{th} and 25^{th} percentiles (3^{rd} and 1^{st} quartiles), respectively, and define the interquartile range or IQR (one half of the data lie within the IQR). The *whiskers* on the top and bottom of the boxes represent data that are within one "step" (somewhat confusingly defined as 1½ × IQR) of the ends of the boxes. Finally, the dots represent extreme, but valid, data.

The boxplots incorporate one more feature due to the fact that some of the data are left-censored and that is the addition of a red line that extends across the series of boxes and represents the maximum DL measured throughout the pre- and post-ROUMRS analyses. **Any statistics provided in the boxplot should be ignored if they lie below this red line**. For example, if the red line is above the median line, then the median (50^{th} percentile or 2^{nd} quartile), 25^{th} percentile (1^{st} quartile), the lower whisker, and any extremes should be ignored. Much of this information can be estimated from the techniques described in Section 2.0 and these results were presented in Tables 3-1 and 3-2. The censoring of the boxplots represents a rather conservative approach because DLs change from sampling event to sampling event and sometimes from sample to sample but the maximum DL is used to define the red line. Nevertheless, in most cases the boxplots still help us visualize the distribution of the data. If there is no red line, then there were no NDs and all statistics provided by the boxplot are valid. Of course, there are extreme versions such as the boxplots for 2,4-DNT for which none of the quartiles shown in the boxplots are valid except for the 75th percentile (3rd quartile) and only for OR2, FUI1, and FUI3.

Figure 4-1: Boxplots showing the distribution of the pre- and post-ROUMRS sediment data by sampling event. The portions of the boxplots below the red line are censored by the maximum detection limit and should be ignored. The first panel indicates the number of samples (*n*).

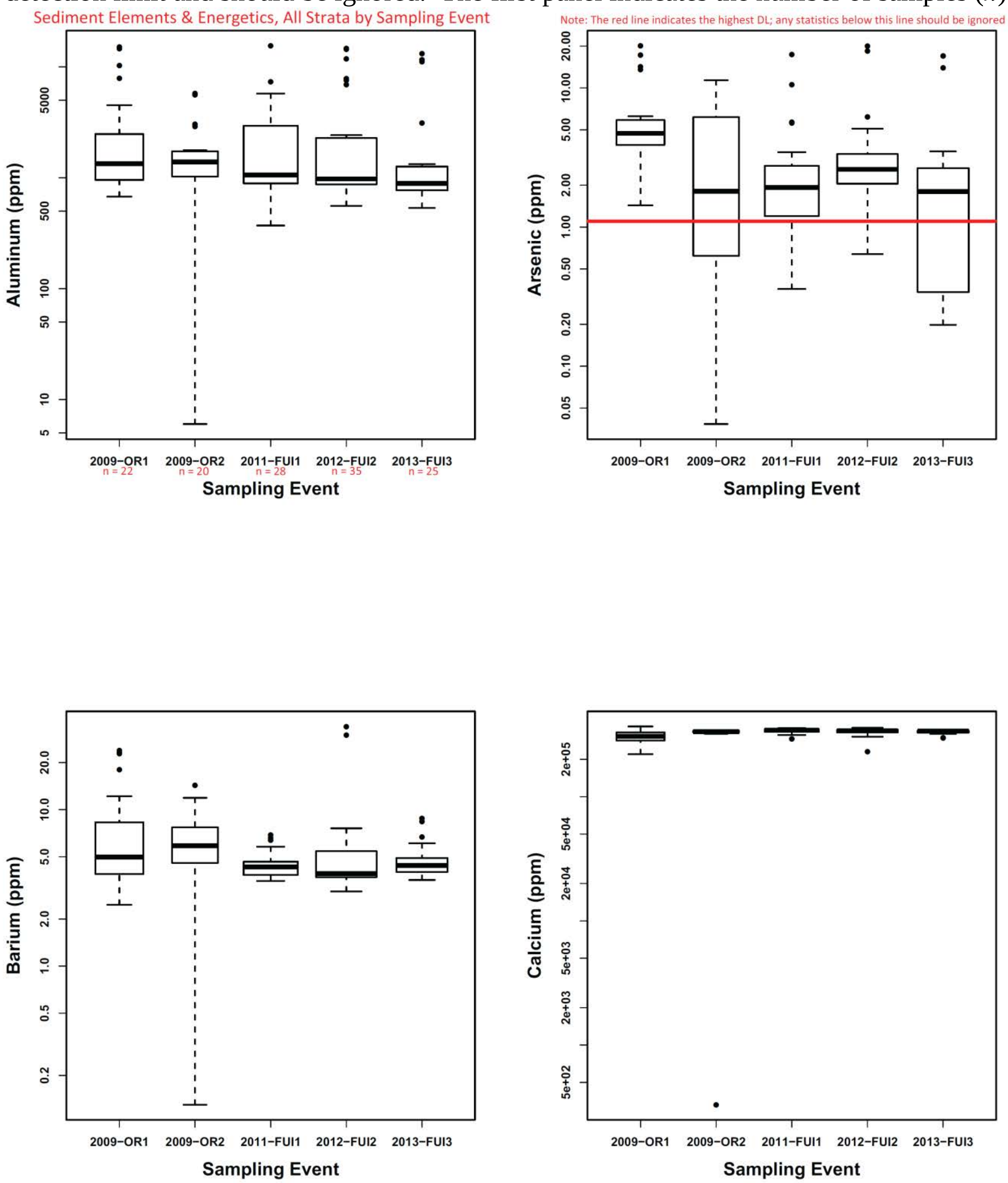


Figure 4-1 (continued): Boxplots showing the distribution of the pre- and post-ROUMRS sediment data. The portions of the boxplots below the red line are censored by the maximum detection limit and should be ignored. The first panel indicates the number of samples (*n*).

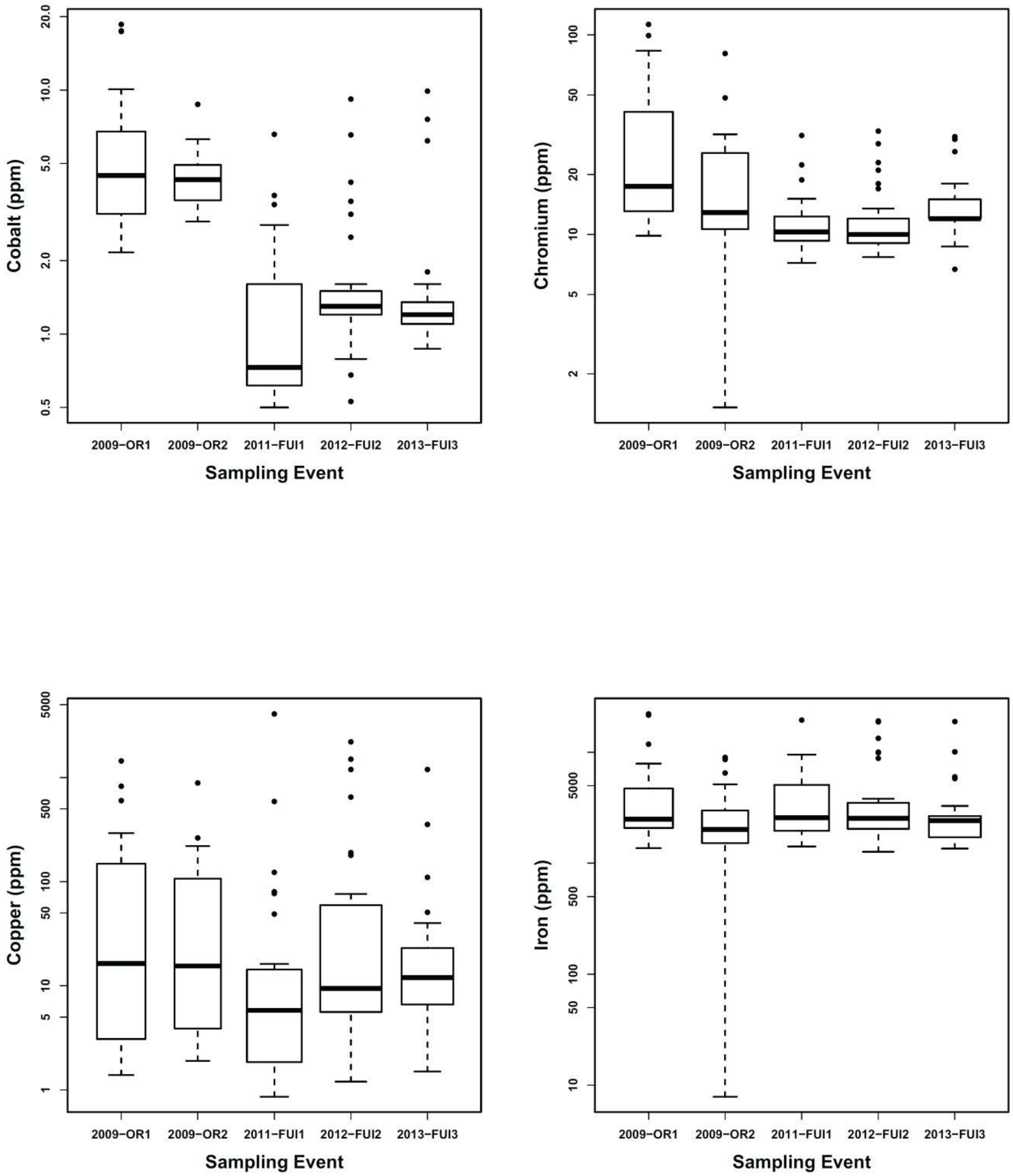


Figure 4-1 (continued): Boxplots showing the distribution of the pre- and post-ROUMRS sediment data. The portions of the boxplots below the red line are censored by the maximum detection limit and should be ignored. The first panel indicates the number of samples (*n*).

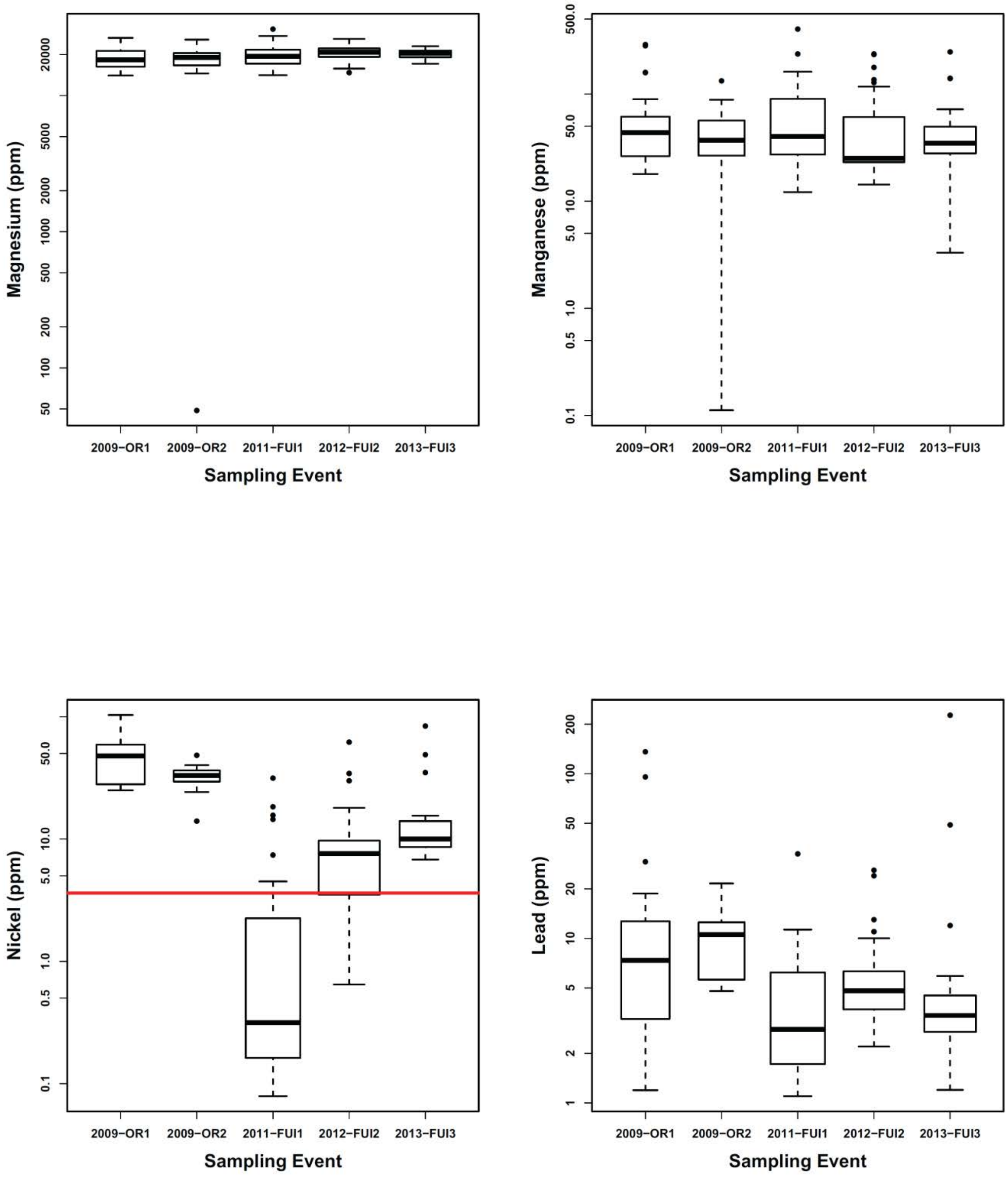


Figure 4-1 (continued): Boxplots showing the distribution of the pre- and post-ROUMRS sediment data. The portions of the boxplots below the red line are censored by the maximum detection limit and should be ignored. The first panel indicates the number of samples (*n*).

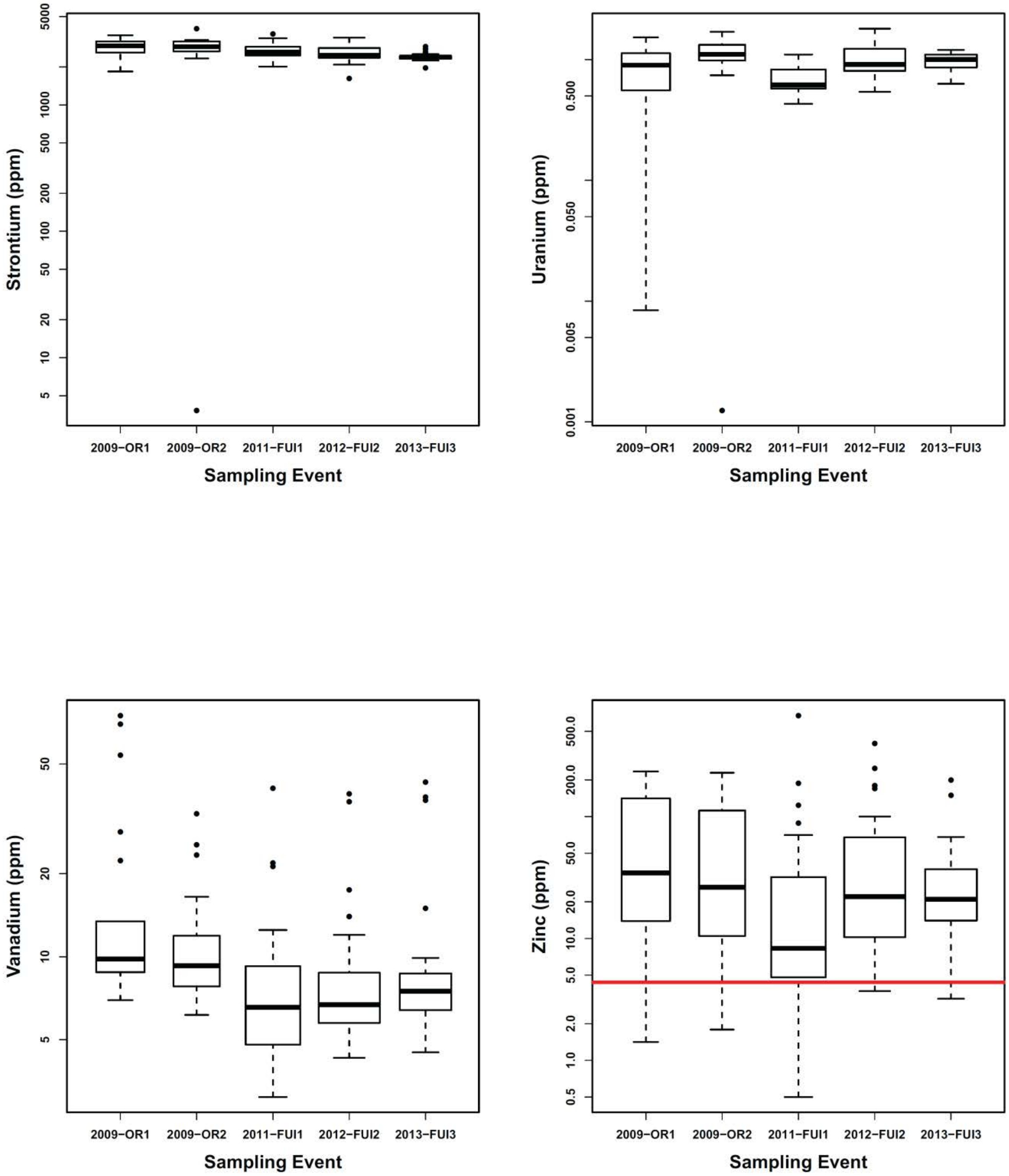
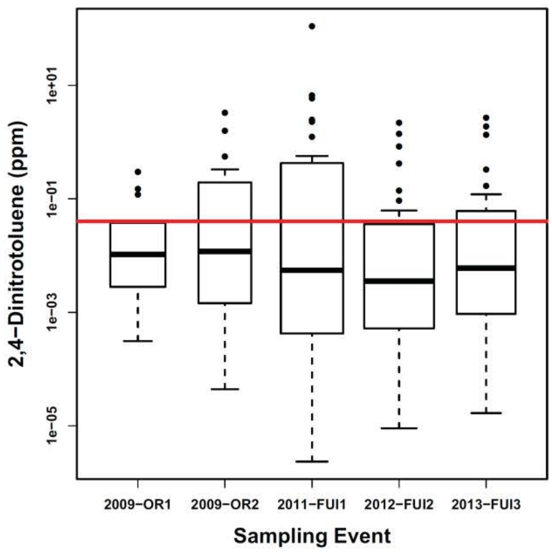


Figure 4-1 (continued): Boxplots showing the distribution of the pre- and post-ROUMRS sediment data. The portions of the boxplots below the red line are censored by the maximum detection limit and should be ignored. The first panel indicates the number of samples (*n*).



It is apparent from Figure 4-1 that certain analytes such as aluminum, barium, calcium, iron, magnesium, and strontium generally appeared relatively constant (bearing in mind that the Y axes of the plots are logarithmic). The boxplots for calcium, magnesium, and strontium, in particular, were compressed as a result of a single outlier that affected the Y axis. The sampling log, lab report, and validator report were all consulted and there was no indication that this outlier was a bad datum, merely extreme. This point demonstrates the effect of extreme data on the mean whereby the pooled OR mean was affected considerably by this point, whereas the median was not (Table 3-1).

Other analytes such as arsenic, cobalt, nickel, lead, zinc, and 2,4-DNT, and possibly chromium and copper, to a lesser degree, varied considerably from sampling event to sampling event. These boxplots in themselves, however, do not answer the question of whether or not there were statistically significant differences between the pre- and post-ROUMRS data.

In order to answer the latter question, the 2009 OR Study (UH, 2014) sediment data were pooled into a single pre-ROUMRS dataset (consisting of OR1 and OR2) and the Follow-Up Investigation data (consisting of FUI1 through FUI3) into a single post-ROUMRS dataset. The pooling of the data helped increase the power of the test that was applied to these data. We prepared a new set of censored boxplots for the DMM and CON strata only (Figures 4-2 and 4-3, respectively). To answer the question of whether or not the pre- and post-ROUMRS were statistically different, interval-censored data were used (and, hence, did not require any substitution such as ½DL) and an analog to the nonparametric generalized Wilcoxon test. Using interval-censored data and the nonparametric score test outlined by Helsel (2012), we compared the pooled pre-ROUMRS data with the post-ROUMRS data as described in Section 2.0 of this report. After conducting this test between the two groups of data for each analyte, if the p value was ≤ 0.05 (α), then we concluded that there was a statistically significant difference between the two groups. This was indicated in a note (in red text) added to all boxplots for which there was a significant difference.

In running the Wilcoxon test analog, the energetics data could not be analyzed (possibly too few samples above the DL), but we were successful in comparing most of the element data. If only those elements initially considered COPCs (i.e., arsenic, copper, and lead) were compared, the results indicate that, not only were there significant differences between the pre- and post-ROUMRS dataset, but in each case as seen in the boxplots, the post-ROUMRS concentrations were lower. Zinc, which we established was associated with DMM even though it is not a COPC, exhibited statistically significant lower concentrations in the post-ROUMRS dataset as well. The initial reaction might be to say that the ROUMRS technology demonstration did lower COPCs and other DMM-related analytes. Nonetheless, caution should be exercised in reaching this conclusion given that a number of analytes that were not associated with DMM were also significantly lower in post-ROUMRS dataset. These analytes included aluminum, barium, calcium, cobalt, chromium, nickel, strontium, titanium, and vanadium. In fact, given that arsenic, in all likelihood, was not associated with DMM, also argues against this conclusion. Moreover, although 2,6-DNT could not be tested, the post-ROUMRS concentrations did appear higher than the pre-ROUMRS concentrations (Figure 4-2).

Figure 4-2: Boxplots showing the distribution of the pre- and post-ROUMRS sediment data (<u>DMM stratum only</u>). The portions of the boxplots below the red line are censored by the maximum detection limit and should be ignored. The first panel indicates the number of samples (*n*); the results of the Wilcoxon significance test (α = 0.05) are shown with red text.

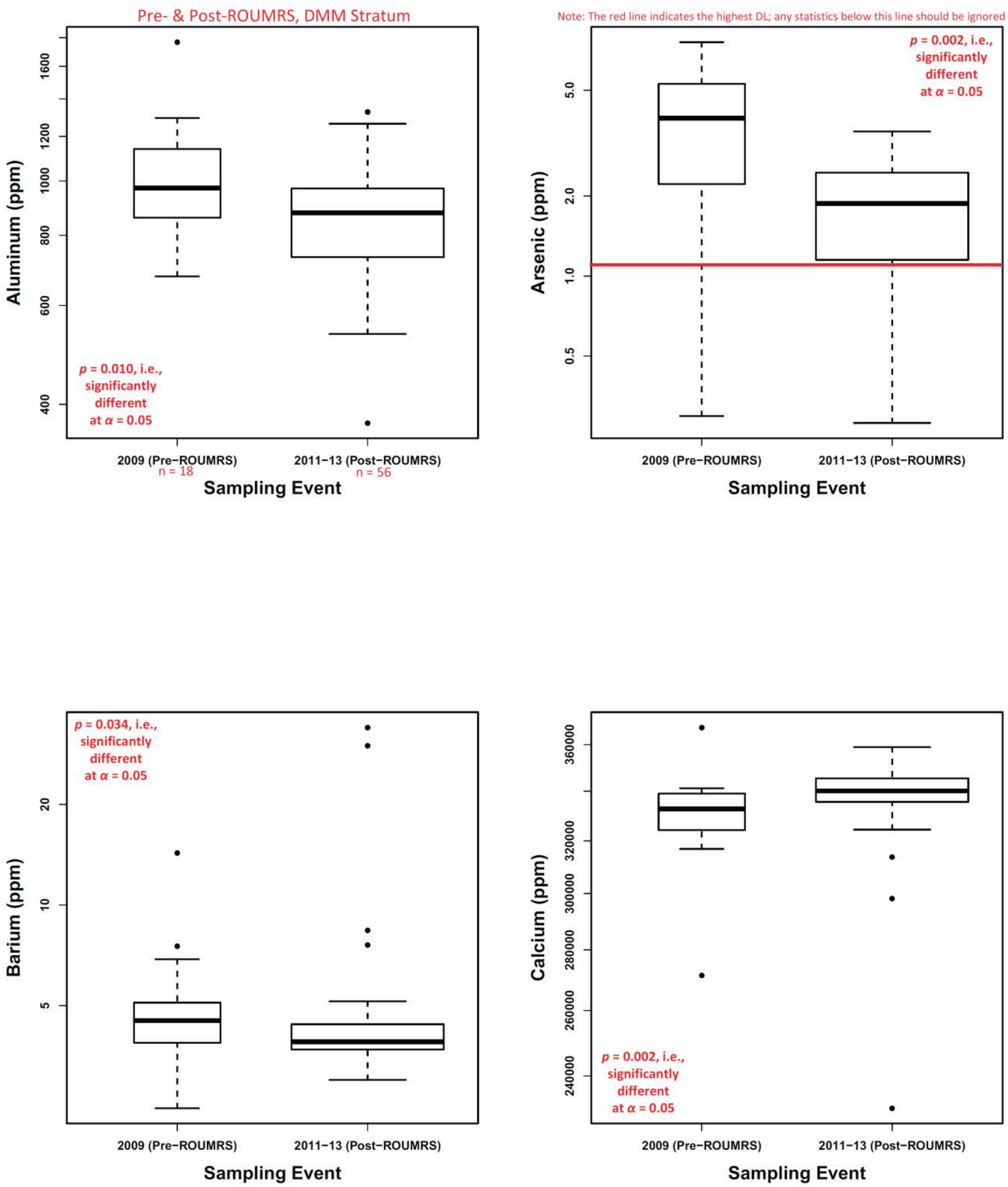


Figure 4-2 (continued): Boxplots showing the distribution of the pre- and post-ROUMRS sediment data (**DMM stratum only**). The portions of the boxplots below the red line are censored by the maximum detection limit and should be ignored.
The first panel indicates the number of samples (*n*);
the results of the Wilcoxon significance test ($\alpha = 0.05$) are shown with red text.

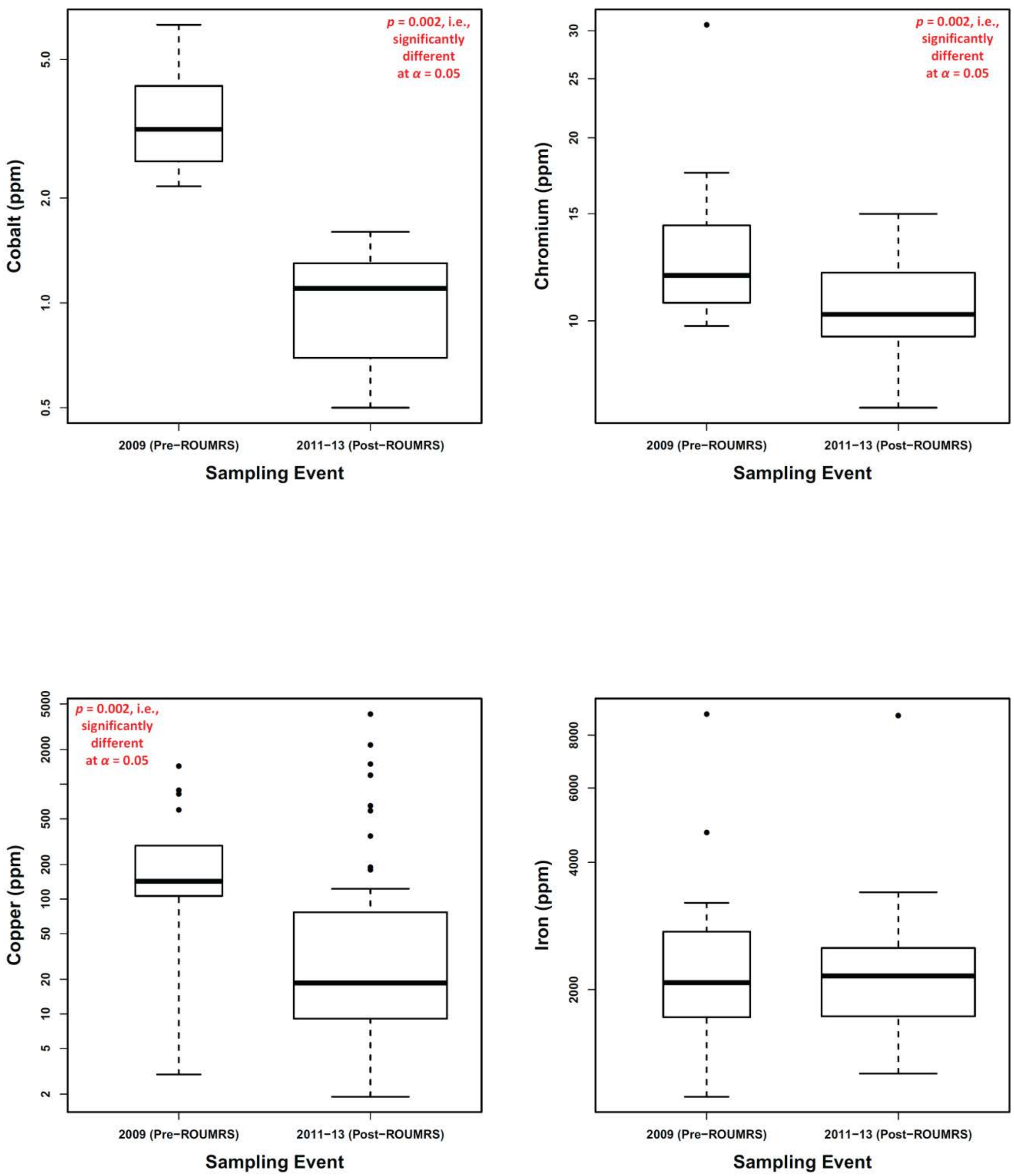


Figure 4-2 (continued): Boxplots showing the distribution of the pre- and post-ROUMRS sediment data (**<u>DMM stratum only</u>**). The portions of the boxplots below the red line are censored by the maximum detection limit and should be ignored.
The first panel indicates the number of samples (*n*);
the results of the Wilcoxon significance test ($\alpha = 0.05$) are shown with red text.

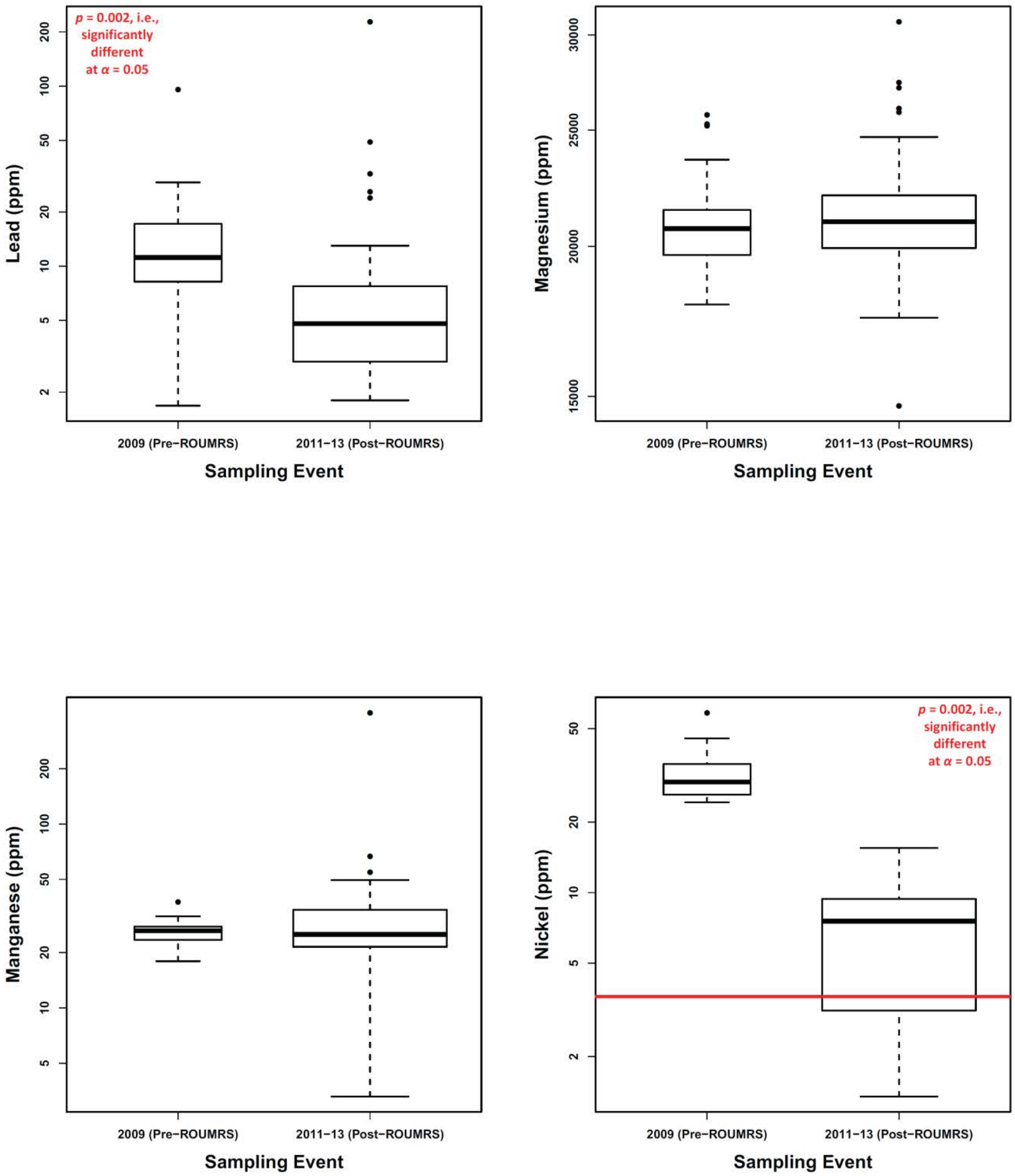


Figure 4-2 (continued): Boxplots showing the distribution of the pre- and post-ROUMRS sediment data (**DMM stratum only**). The portions of the boxplots below the red line are censored by the maximum detection limit and should be ignored.
The first panel indicates the number of samples (*n*);
the results of the Wilcoxon significance test (α = 0.05) are shown with red text.

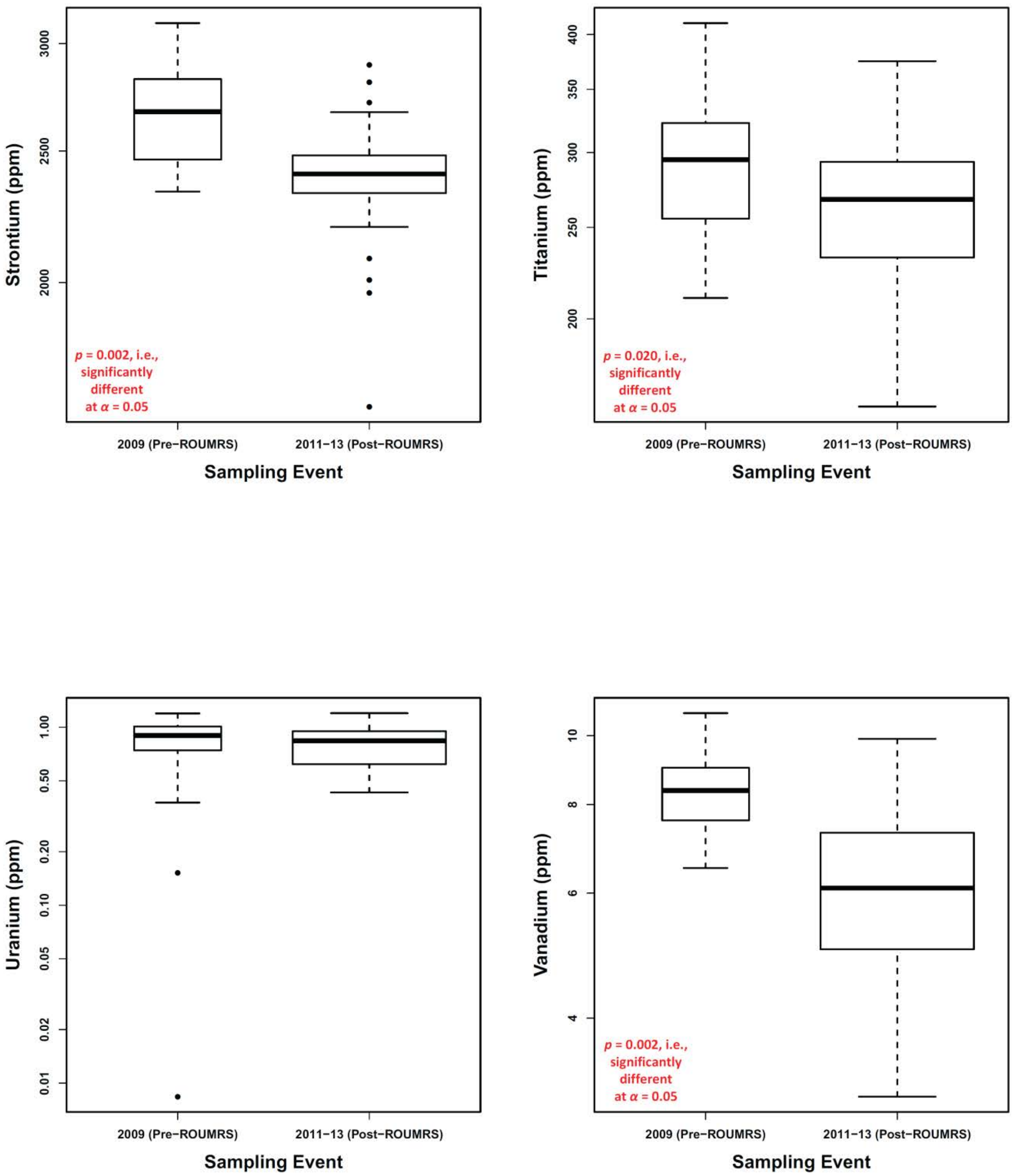
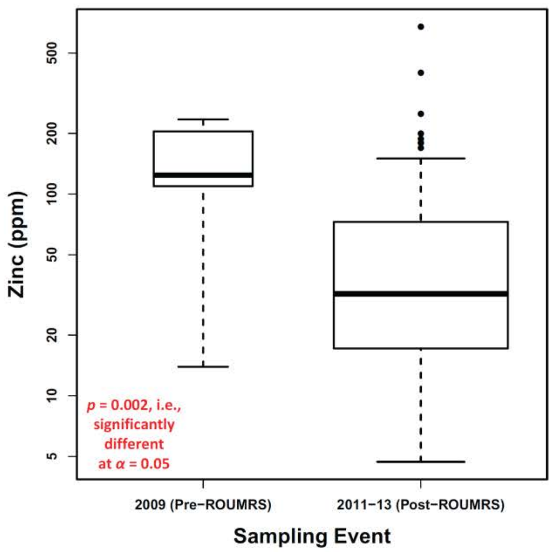
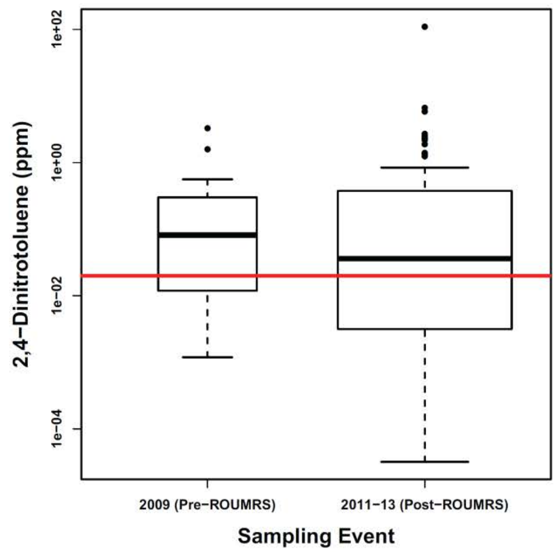
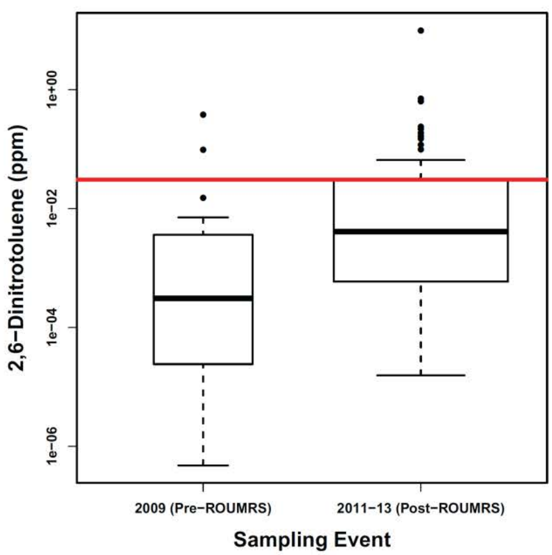


Figure 4-2 (continued): Boxplots showing the distribution of the pre- and post-ROUMRS sediment data (**DMM stratum only**). The portions of the boxplots below the red line are censored by the maximum detection limit and should be ignored.
The first panel indicates the number of samples (*n*);
the results of the Wilcoxon significance test ($\alpha = 0.05$) are shown with red text.







The pre- and post-ROUMRS boxplots for the CON stratum (Figure 4-3) did not support the conclusion that COPC and other DMM-associated analyte concentrations were reduced as a result of the ROUMRS demonstration. Given that the CON samples were obtained from a control area, we assumed that there would be no significant difference (pre- vs. post-ROUMRS) in any analytes from this stratum; however, this was not the case as shown in Figure 4-3. There were a number of analytes, including COPCs and other DMM-associated analytes that were significantly lower in the post-ROUMRS CON dataset. Like the data from DMM stratum, a number of non-DMM-associated analytes from the CON stratum also were significantly lower in the post-ROUMRS dataset leading us to conclude that, while there were a number of analytes with significantly lower concentrations in the post-ROUMRS dataset, it could not be determined why they were lower.

As stated previously, NMDS plots merely show patterns, they do not test hypotheses. Nevertheless, it was instructive to compare the pre- and post-ROUMRS NMDS plots (Figure 4-4). The data in the pre-ROUMRS NMDS plot (top panel) appear *tighter* than the data in the post-ROUMRS plot (bottom panel). The Kruskal's stress for each plot supports this observation. Given that a Kruskal's stress >0.20 means the pattern is essentially random, neither plot is necessarily random and the pattern seems to be stronger (less random) in the pre-ROUMRS data. Notice for example, that the DMM-associated analytes, particularly the elements are closer together in the pre-ROUMRS data and that only one of the DMM samples (DMM-10B) is on the left side of the NMDS plot whereas in the post-ROUMRS plot, the elements associated with DMM are spread out more, and more of the DMM samples are on the left side of the plot. These observations, however, are subjective but Kendall's τ can be used to see if this value has changed between the pre- and post-ROUMRS data.

The correlation matrix for the post-ROUMRS data was presented in Table 3-6 of this report; the correlation matrix using Kendall's τ for the pre-ROUMRS data is presented in Table 4-1, below. This table uses the same formatting to indicate significant (at α = 0.05) differences (bold font) and if the significant correlation is positive (green) or negative (red). Comparing Tables 3-6 and 4-1, however, is a tedious exercise; therefore, we plotted Kendall's τ for selected analytes, some associated with DMM (copper, lead, zinc, and 2,4-DNT) and others that are considered terrestrial in origin (aluminum, chromium, iron, and arsenic), as bar charts (Figure 4-5). The pre-ROUMRS data are light cyan; the post-ROUMRS data are yellow. The correlations, whether positive or negative, between pre-ROUMRS DMM-associated analytes seem to be somewhat greater.

Figure 4-3: Boxplots showing the distribution of the pre- and post-ROUMRS sediment data **(<u>CON stratum only</u>)**. The portions of the boxplots below the red line are censored by the maximum detection limit and should be ignored. The first panel indicates the number of samples (*n*); the results of the Wilcoxon significance test (α = 0.05) are shown with red text.

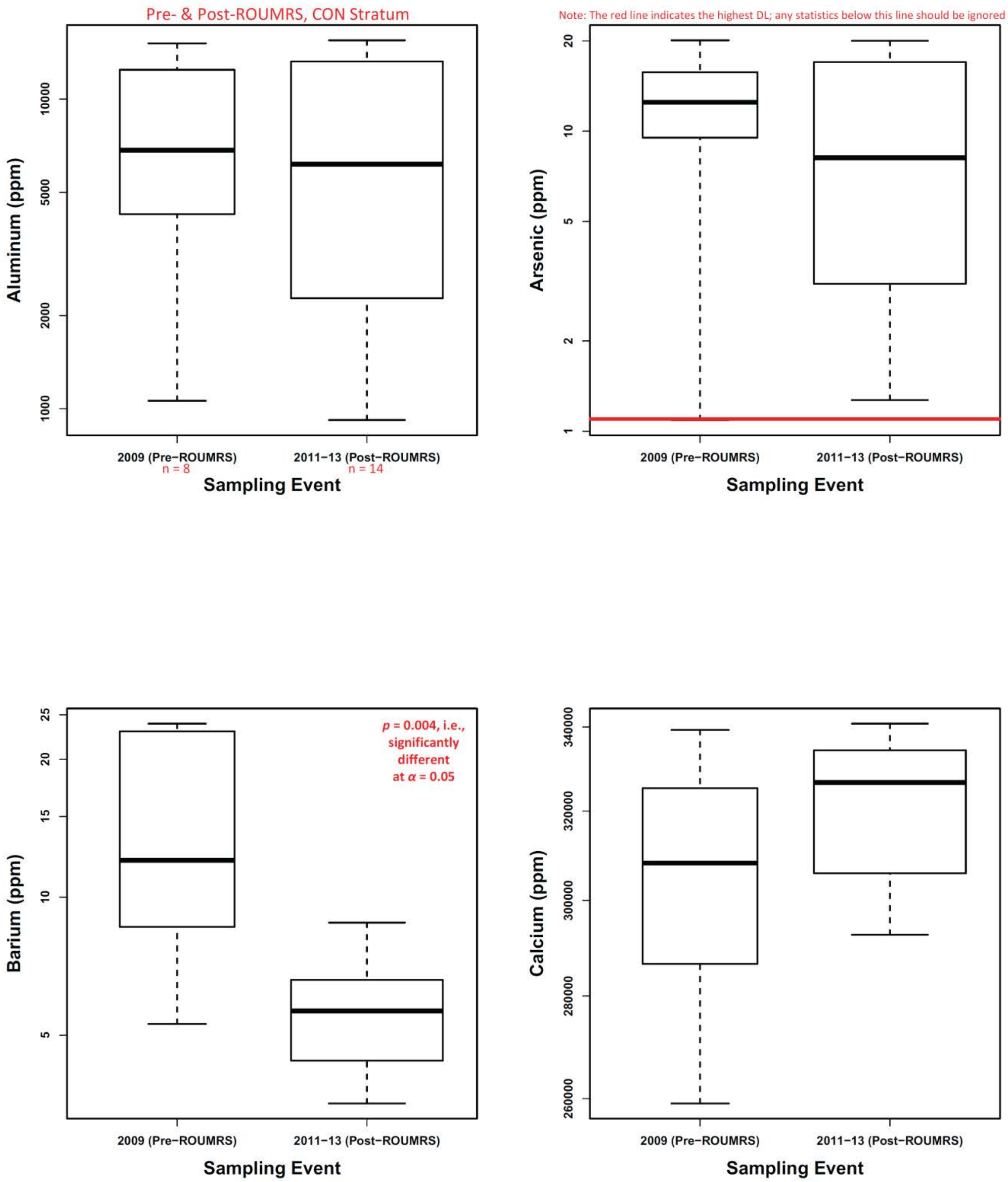


Figure 4-3 (continued): Boxplots showing the distribution of the pre- and post-ROUMRS sediment data (**<u>CON stratum only</u>**). The portions of the boxplots below the red line are censored by the maximum detection limit and should be ignored. The first panel indicates the number of samples (*n*); the results of the Wilcoxon significance test ($\alpha = 0.05$) are shown with red text.

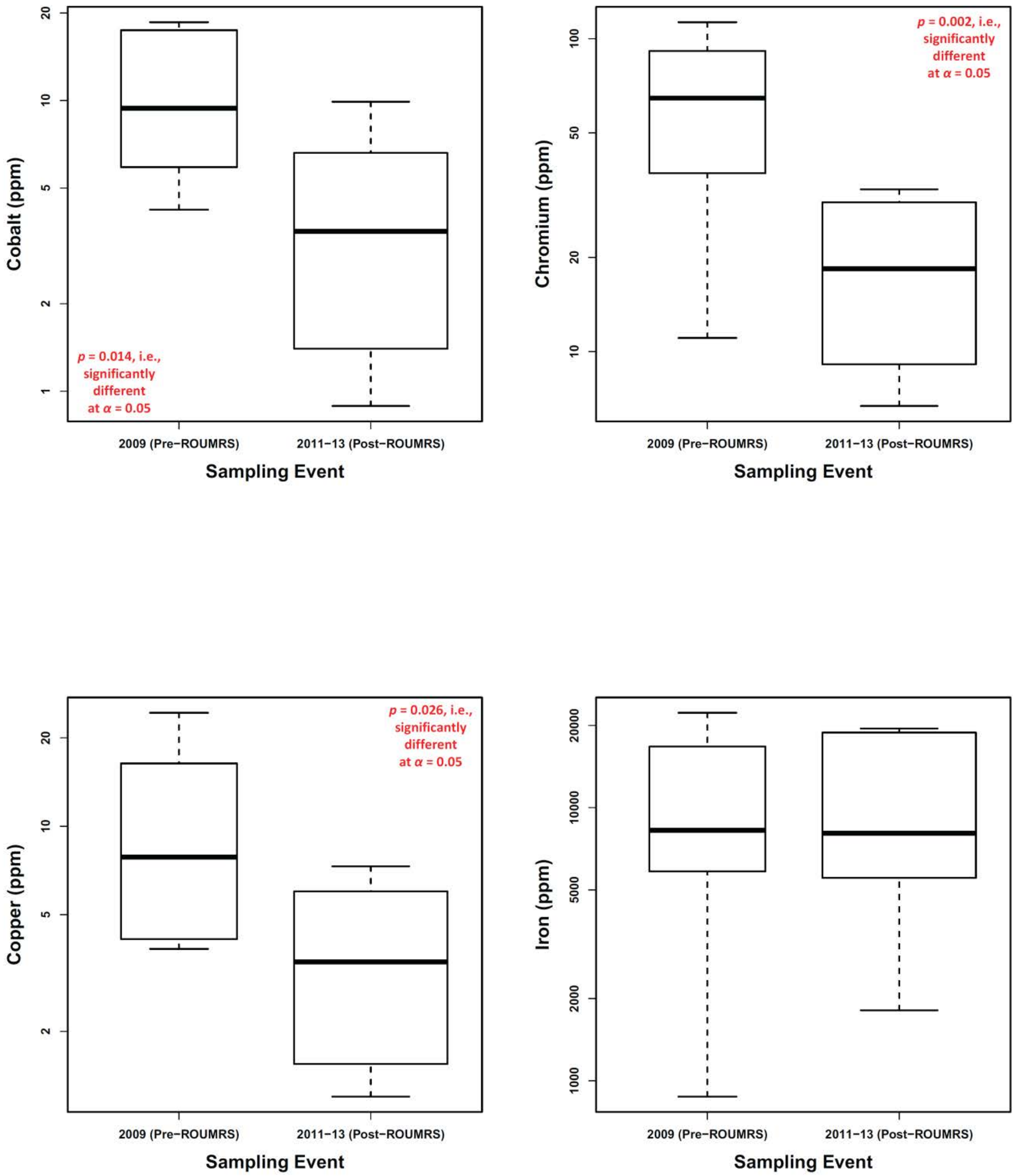


Figure 4-3 (continued): Boxplots showing the distribution of the pre- and post-ROUMRS sediment data (**<u>CON stratum only</u>**). The portions of the boxplots below the red line are censored by the maximum detection limit and should be ignored. The first panel indicates the number of samples (*n*); the results of the Wilcoxon significance test ($\alpha = 0.05$) are shown with red text.

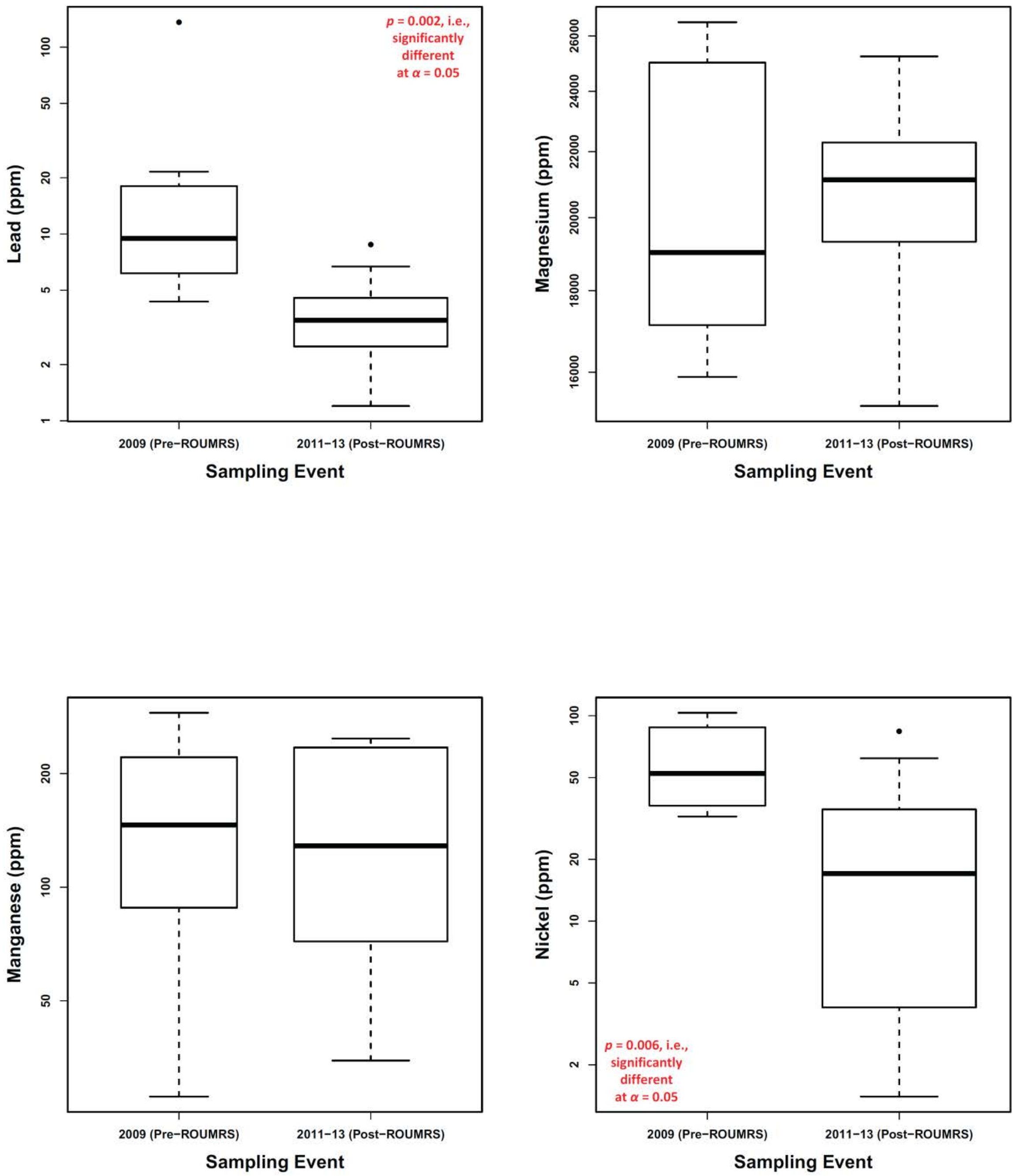


Figure 4-3 (continued): Boxplots showing the distribution of the pre- and post-ROUMRS sediment data (<u>**CON stratum only**</u>). The portions of the boxplots below the red line are censored by the maximum detection limit and should be ignored. The first panel indicates the number of samples (*n*); the results of the Wilcoxon significance test ($\alpha = 0.05$) are shown with red text.

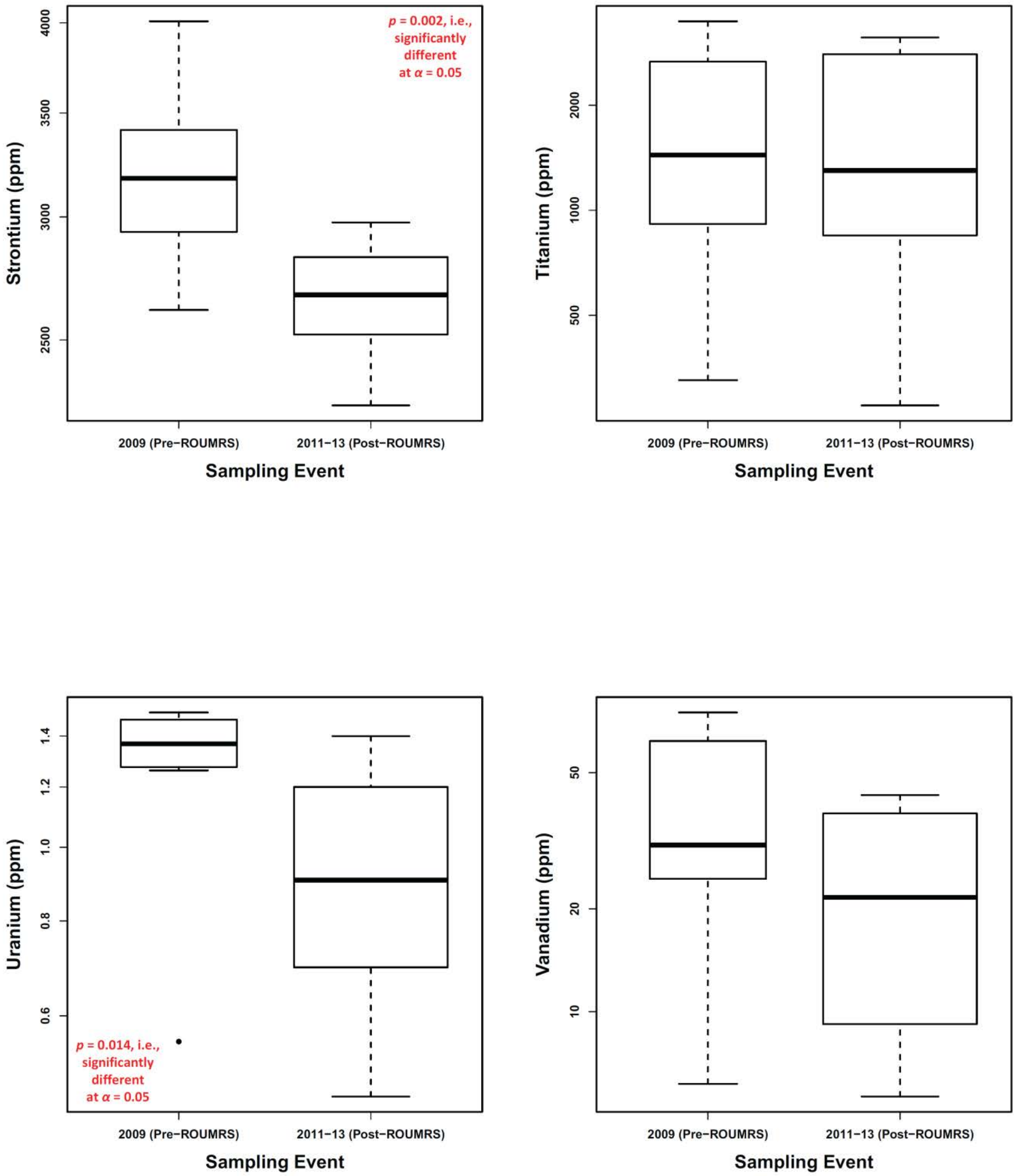


Figure 4-3 (continued): Boxplots showing the distribution of the pre- and post-ROUMRS sediment data (**CON stratum only**). The portions of the boxplots below the red line are censored by the maximum detection limit and should be ignored. The first panel indicates the number of samples (*n*); the results of the Wilcoxon significance test ($\alpha = 0.05$) are shown with red text.

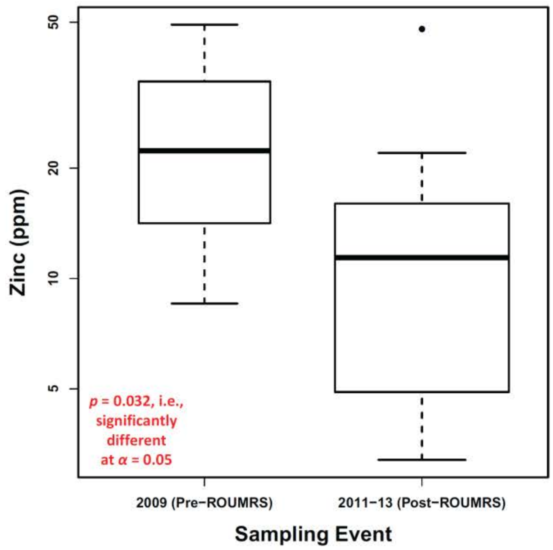


Figure 4-4: NMDS plots of pre-ROUMRS sediment analytes (red dots) and samples (top panel) and post-ROUMRS sediment analytes (red dots) and samples (bottom panel).

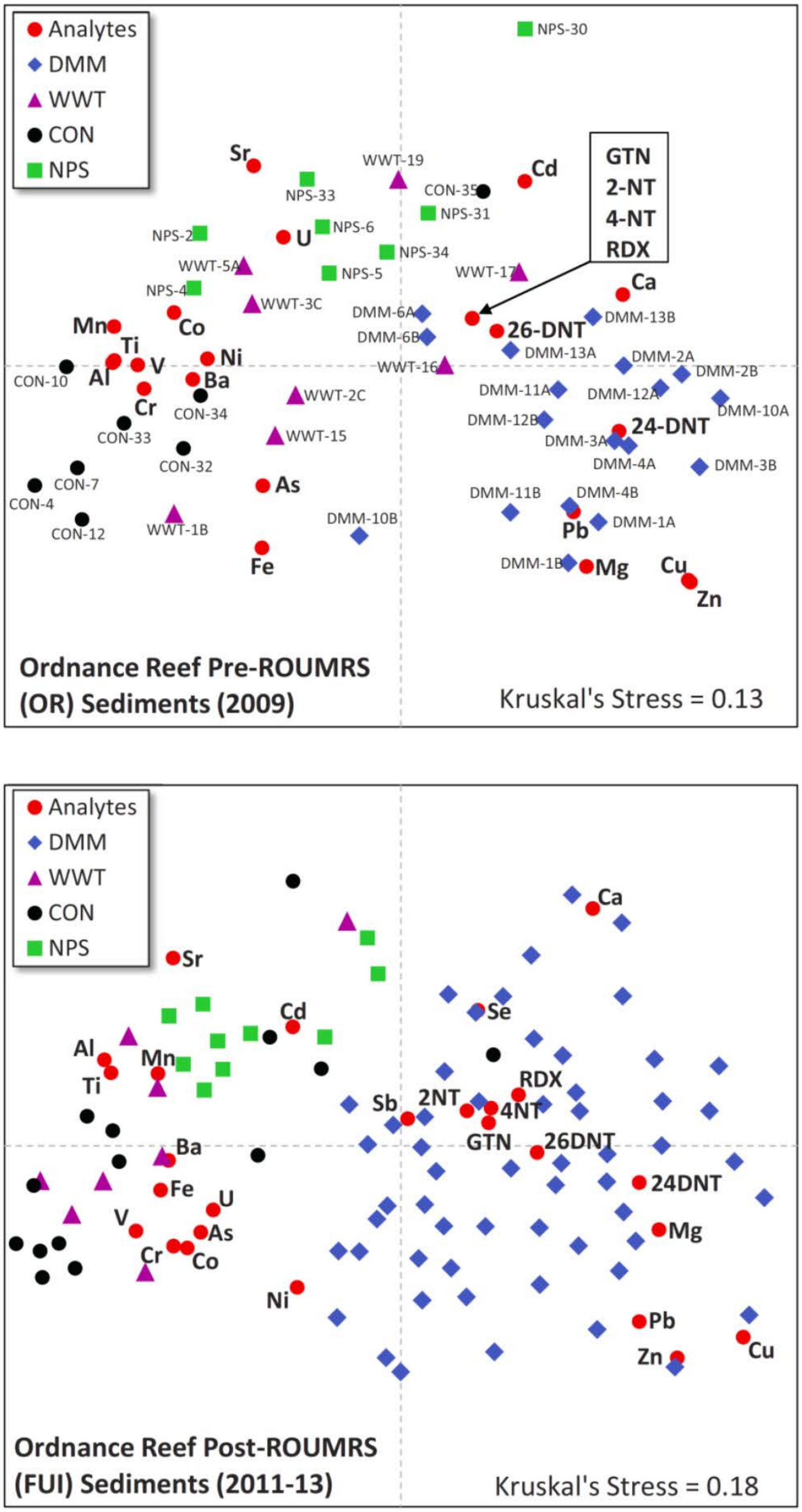
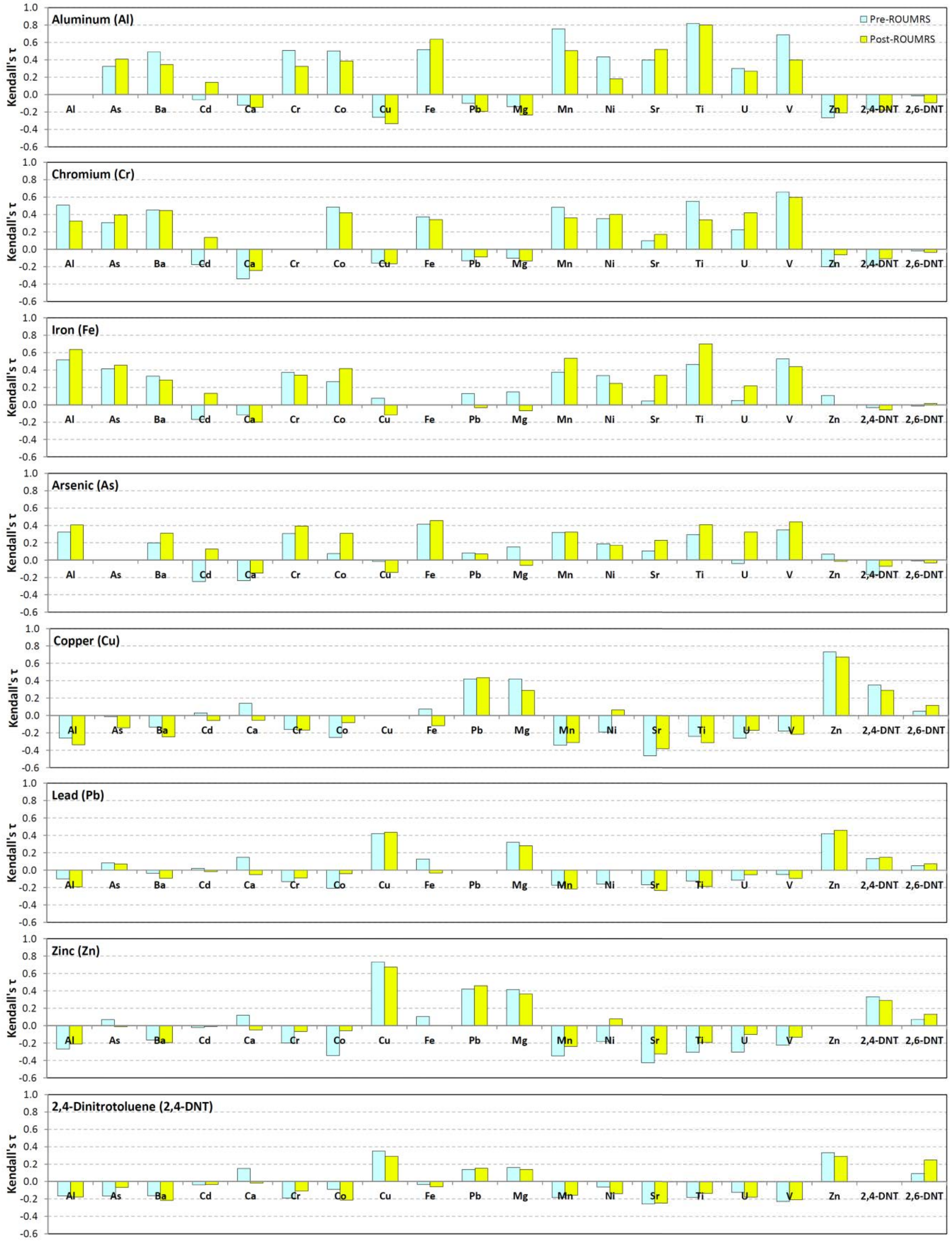


Table 4-1: Kendall's τ correlation matrix for sediment element and energetics data from the Ordnance Reef pre-ROUMRS (OR1-OR2) sampling during 2009. Significant correlations ($\alpha = 0.05$) are indicated with bold font; green indicates a positive correlation and red indicates a negative correlation.

Variable		Al	As	Ba	Cd	Ca	Cr	Co	Cu	Fe	Pb	Mg	Mn	Ni	Sr	Ti	U	V	Zn	2,4-DNT	2,6-DNT
Al	τ		0.323	0.489	-0.059	-0.122	0.507	0.502	-0.261	0.517	-0.100	-0.141	0.756	0.433	0.398	0.817	0.298	0.687	-0.267	-0.166	-0.013
	p		0.001	0.000	0.535	0.200	0.000	0.000	0.006	0.000	0.293	0.139	0.000	0.000	0.000	0.000	0.002	0.000	0.005	0.058	0.837
	n		53	53	53	53	53	53	53	53	53	53	53	53	53	53	53	53	53	42	42
As	τ	0.323		0.200	-0.247	-0.239	0.307	0.076	-0.012	0.414	0.085	0.152	0.320	0.188	0.107	0.294	-0.038	0.348	0.069	-0.167	-0.008
	p	0.001		0.036	0.009	0.012	0.001	0.425	0.902	0.000	0.374	0.111	0.001	0.048	0.263	0.002	0.696	0.000	0.471	0.056	0.902
	n	53		53	53	53	53	53	53	53	53	53	53	53	53	53	53	53	53	42	42
Ba	τ	0.489	0.200		-0.086	-0.090	0.451	0.374	-0.134	0.328	-0.036	-0.007	0.483	0.232	0.119	0.521	0.298	0.553	-0.165	-0.164	-0.041
	p	0.000	0.036		0.361	0.345	0.000	0.000	0.160	0.001	0.707	0.945	0.000	0.014	0.211	0.000	0.002	0.000	0.082	0.061	0.485
	n	53	53		53	53	53	53	53	53	53	53	53	53	53	53	53	53	53	42	42
Cd	τ	-0.059	-0.247	-0.086		0.239	-0.176	0.024	0.030	-0.169	0.021	0.044	-0.095	-0.182	0.017	-0.062	0.117	-0.065	-0.021	-0.039	0.066
	p	0.535	0.009	0.361		0.011	0.061	0.804	0.757	0.072	0.828	0.642	0.314	0.053	0.865	0.515	0.215	0.495	0.828	0.653	0.228
	n	53	53	53		53	53	53	53	53	53	53	53	53	53	53	53	53	53	42	42
Ca	τ	-0.122	-0.239	-0.090	0.239		-0.340	-0.170	0.141	-0.115	0.148	0.171	-0.203	-0.228	0.118	-0.186	-0.057	-0.189	0.120	0.150	0.078
	p	0.200	0.012	0.345	0.011		0.000	0.074	0.139	0.228	0.119	0.071	0.032	0.016	0.217	0.050	0.550	0.047	0.206	0.087	0.176
	n	53	53	53	53		53	53	53	53	53	53	53	53	53	53	53	53	53	42	42
Cr	τ	0.507	0.307	0.451	-0.176	-0.340		0.485	-0.160	0.372	-0.132	-0.103	0.483	0.351	0.096	0.550	0.224	0.657	-0.200	-0.189	-0.017
	p	0.000	0.001	0.000	0.061	0.000		0.000	0.093	0.000	0.165	0.279	0.000	0.000	0.315	0.000	0.018	0.000	0.035	0.030	0.774
	n	53	53	53	53	53		53	53	53	53	53	53	53	53	53	53	53	53	42	42
Co	τ	0.502	0.076	0.374	0.024	-0.170	0.485		-0.254	0.266	-0.206	-0.151	0.482	0.541	0.205	0.473	0.275	0.424	-0.344	-0.089	-0.029
	p	0.000	0.425	0.000	0.804	0.074	0.000		0.007	0.005	0.030	0.112	0.000	0.000	0.031	0.000	0.004	0.000	0.000	0.310	0.622
	n	53	53	53	53	53	53		53	53	53	53	53	53	53	53	53	53	53	42	42
Cu	τ	-0.261	-0.012	-0.134	0.030	0.141	-0.160	-0.254		0.074	0.421	0.421	-0.340	-0.190	-0.463	-0.238	-0.261	-0.177	0.733	0.352	0.050
	p	0.006	0.902	0.160	0.757	0.139	0.093	0.007		0.438	0.000	0.000	0.000	0.045	0.000	0.012	0.006	0.062	0.000	0.000	0.389
	n	53	53	53	53	53	53	53		53	53	53	53	53	53	53	53	53	53	42	42
Fe	τ	0.517	0.414	0.328	-0.169	-0.115	0.372	0.266	0.074		0.128	0.148	0.374	0.335	0.042	0.462	0.047	0.525	0.106	-0.034	-0.015
	p	0.000	0.000	0.001	0.072	0.228	0.000	0.005	0.438		0.179	0.119	0.000	0.000	0.662	0.000	0.623	0.000	0.266	0.708	0.805
	n	53	53	53	53	53	53	53	53		53	53	53	53	53	53	53	53	53	42	42
Pb	τ	-0.100	0.085	-0.036	0.021	0.148	-0.132	-0.206	0.421	0.128		0.321	-0.173	-0.160	-0.168	-0.123	-0.114	-0.048	0.421	0.136	0.052
	p	0.293	0.374	0.707	0.828	0.119	0.165	0.030	0.000	0.179		0.001	0.069	0.093	0.076	0.195	0.231	0.618	0.000	0.121	0.366
	n	53	53	53	53	53	53	53	53	53		53	53	53	53	53	53	53	53	42	42
Mg	τ	-0.141	0.152	-0.007	0.044	0.171	-0.103	-0.151	0.421	0.148	0.321		-0.170	-0.154	-0.369	-0.144	-0.114	-0.068	0.415	0.159	0.015
	p	0.139	0.111	0.945	0.642	0.071	0.279	0.112	0.000	0.119	0.001		0.074	0.106	0.000	0.131	0.231	0.476	0.000	0.069	0.805
	n	53	53	53	53	53	53	53	53	53	53		53	53	53	53	53	53	53	42	42
Mn	τ	0.756	0.320	0.483	-0.095	-0.203	0.483	0.482	-0.340	0.374	-0.173	-0.170		0.418	0.380	0.782	0.268	0.591	-0.348	-0.185	-0.034
	p	0.000	0.001	0.000	0.314	0.032	0.000	0.000	0.000	0.000	0.069	0.074		0.000	0.000	0.000	0.005	0.000	0.000	0.035	0.565
	n	53	53	53	53	53	53	53	53	53	53	53		53	53	53	53	53	53	42	42
Ni	τ	0.433	0.188	0.232	-0.182	-0.228	0.351	0.541	-0.190	0.335	-0.160	-0.154	0.418		0.147	0.380	-0.065	0.261	-0.181	-0.064	-0.041
	p	0.000	0.048	0.014	0.053	0.016	0.000	0.000	0.045	0.000	0.093	0.106	0.000		0.123	0.000	0.500	0.006	0.056	0.471	0.485
	n	53	53	53	53	53	53	53	53	53	53	53	53		53	53	53	53	53	42	42
Sr	τ	0.398	0.107	0.119	0.017	0.118	0.096	0.205	-0.463	0.042	-0.168	-0.369	0.380	0.147		0.354	0.288	0.177	-0.425	-0.259	0.003
	p	0.000	0.263	0.211	0.865	0.217	0.315	0.031	0.000	0.662	0.076	0.000	0.000	0.123		0.000	0.002	0.062	0.000	0.003	0.967
	n	53	53	53	53	53	53	53	53	53	53	53	53	53		53	53	53	53	42	42
Ti	τ	0.817	0.294	0.521	-0.062	-0.186	0.550	0.473	-0.238	0.462	-0.123	-0.144	0.782	0.380	0.354		0.343	0.646	-0.305	-0.180	-0.020
	p	0.000	0.002	0.000	0.515	0.050	0.000	0.000	0.012	0.000	0.195	0.131	0.000	0.000	0.000		0.000	0.000	0.001	0.040	0.743
	n	53	53	53	53	53	53	53	53	53	53	53	53	53	53		53	53	53	42	42
U	τ	0.298	-0.038	0.298	0.117	-0.057	0.224	0.275	-0.261	0.047	-0.114	-0.114	0.268	-0.065	0.288	0.343		0.272	-0.301	-0.122	0.024
	p	0.002	0.696	0.002	0.215	0.550	0.018	0.004	0.006	0.623	0.231	0.231	0.005	0.500	0.002	0.000		0.004	0.001	0.165	0.681
	n	53	53	53	53	53	53	53	53	53	53	53	53	53	53	53		53	53	42	42
V	τ	0.687	0.348	0.553	-0.065	-0.189	0.657	0.424	-0.177	0.525	-0.048	-0.068	0.591	0.261	0.177	0.646	0.272		-0.224	-0.226	-0.024
	p	0.000	0.000	0.000	0.495	0.047	0.000	0.000	0.062	0.000	0.618	0.476	0.000	0.006	0.062	0.000	0.004		0.019	0.010	0.681
	n	53	53	53	53	53	53	53	53	53	53	53	53	53	53	53	53		53	42	42
Zn	τ	-0.267	0.069	-0.165	-0.021	0.120	-0.200	-0.344	0.733	0.106	0.421	0.415	-0.348	-0.181	-0.425	-0.305	-0.301	-0.224		0.336	0.073
	p	0.005	0.471	0.082	0.828	0.206	0.035	0.000	0.000	0.266	0.000	0.000	0.000	0.056	0.000	0.001	0.001	0.019		0.000	0.203
	n	53	53	53	53	53	53	53	53	53	53	53	53	53	53	53	53	53		42	42
2,4-DNT	τ	-0.166	-0.167	-0.164	-0.039	0.150	-0.189	-0.089	0.352	-0.034	0.136	0.159	-0.185	-0.064	-0.259	-0.180	-0.122	-0.226	0.336		0.094
	p	0.058	0.056	0.061	0.653	0.087	0.030	0.310	0.000	0.708	0.121	0.069	0.035	0.471	0.003	0.040	0.165	0.010	0.000		0.035
	n	42	42	42	42	42	42	42	42	42	42	42	42	42	42	42	42	42	42		42
2,6-DNT	τ	-0.013	-0.008	-0.041	0.066	0.078	-0.017	-0.029	0.050	-0.015	0.052	0.015	-0.034	-0.041	0.003	-0.020	0.024	-0.024	0.073	0.094	
	p	0.837	0.902	0.485	0.228	0.176	0.774	0.622	0.389	0.805	0.366	0.805	0.565	0.485	0.967	0.743	0.681	0.681	0.203	0.035	
	n	42	42	42	42	42	42	42	42	42	42	42	42	42	42	42	42	42	42	42	

τ = Kendall's correlation coefficient; p = probability, if $p < \alpha = 0.05 \rightarrow$ correlation is significant; n = number of samples; 0.500 = significant positive correlation; -0.500 = significant negative correlation; $\tau \pm (0.15\text{-}0.20) = r$

Figure 4-5: Bar graphs comparing Kendall's tau (τ) correlation coefficients for pre ROUMRS (light cyan) and post-ROUMRS (yellow) terrestrial (Al, Cr, Fe, and As) and MC (Cu, Pb, Zn, and 2,4-DNT) analytes.



Interpretation of the meaning of the data, at this point, is purely conjecture without additional investigation. Given that the munitions were on the seafloor and, hence, in contact with the sediments for decades, it is possible that the chemicals that made up the casings, explosives, and propellants had reached pseudo-equilibrium with their environment. It is possible that in recovering some of the DMM, this equilibrium was disturbed and, as a result, the correlations are no longer as strong as they were in the pre-ROUMRS data. Again, this is a hypothesis that would require further testing to confirm. There could also be a number of other reasons why pre- and post-ROUMRS sediment data differ.

4.2 Biota

While we prepared censored boxplots that compared the pooled biota data (i.e., all organisms together) by sampling event (Figure 4-6) for the same reasons outlined for sediments (Section 4.1), we did not statistically test to see if there were differences. We have already established that there were differences between organism types; therefore, little information would be gained by statistically comparing all organisms together. These and subsequent boxplots are censored which means that, if a red line which represents the highest DL is present, all information below this line should be ignored. This information, in some instances, can be obtained from Table 3-2. Sometimes, however, there are too many NDs to create boxplots or estimate statistics. This was particularly true for the biota data and especially for the energetics data.

Probably the most useful information to be gleaned from Figure 4-6, is that, when pooled, much of the data were below the maximum DL. This was true for barium, cadmium, cobalt, lead, nickel, uranium, and vanadium; there were too many NDs to even create boxplots for the energetics in biota.

If we had attempted to analyze individual organism types by strata, there would have been too few data to provide meaningful results. We did, however, pool the pre- and post-ROUMRS data by organism and looked for patterns in the data by strata using NMDS. The NMDS plots for fish and crabs appeared random and this was borne out by Kruskal's stress >0.20. There did seem to be a slight pattern in the octopus data by sampling event. Whether this was caused by sampling during different life stages of the octopus or different environmental conditions during the sampling events is difficult to say.

Arguably the most interesting pattern was seen in the limu data particularly by strata. Given that limu are sessile seaweeds, some pattern by strata might be expected. As can be seen from the NMDS plot for limu by strata in Figure 4-7, the CON samples are separate from the DMM samples which are, in turn, near copper (Cu) and zinc (Zn).

We calculated summary statistics for limu by strata. These statistics are presented in Table 4-2. Like the FUI biota data, the summary statistics were calculated in various ways depending on the number of nondetects (NDs) in the data for each limu stratum. If there were no NDs, we used standard Minitab® descriptive statistics. If there were <50% NDs, we used Kaplan-Meier survival statistics. We used regression on order statistics (ROS) for NDs ≥50% and <80%, and for ≥80% NDs, we reported the %NDs and the maximum observed value.

Figure 4-6: Boxplots showing the distribution of the pre- and post-ROUMRS pooled biota data. The portions of the boxplots below the red line are censored by the maximum detection limit and should be ignored. The first panel indicates the number of samples (*n*).

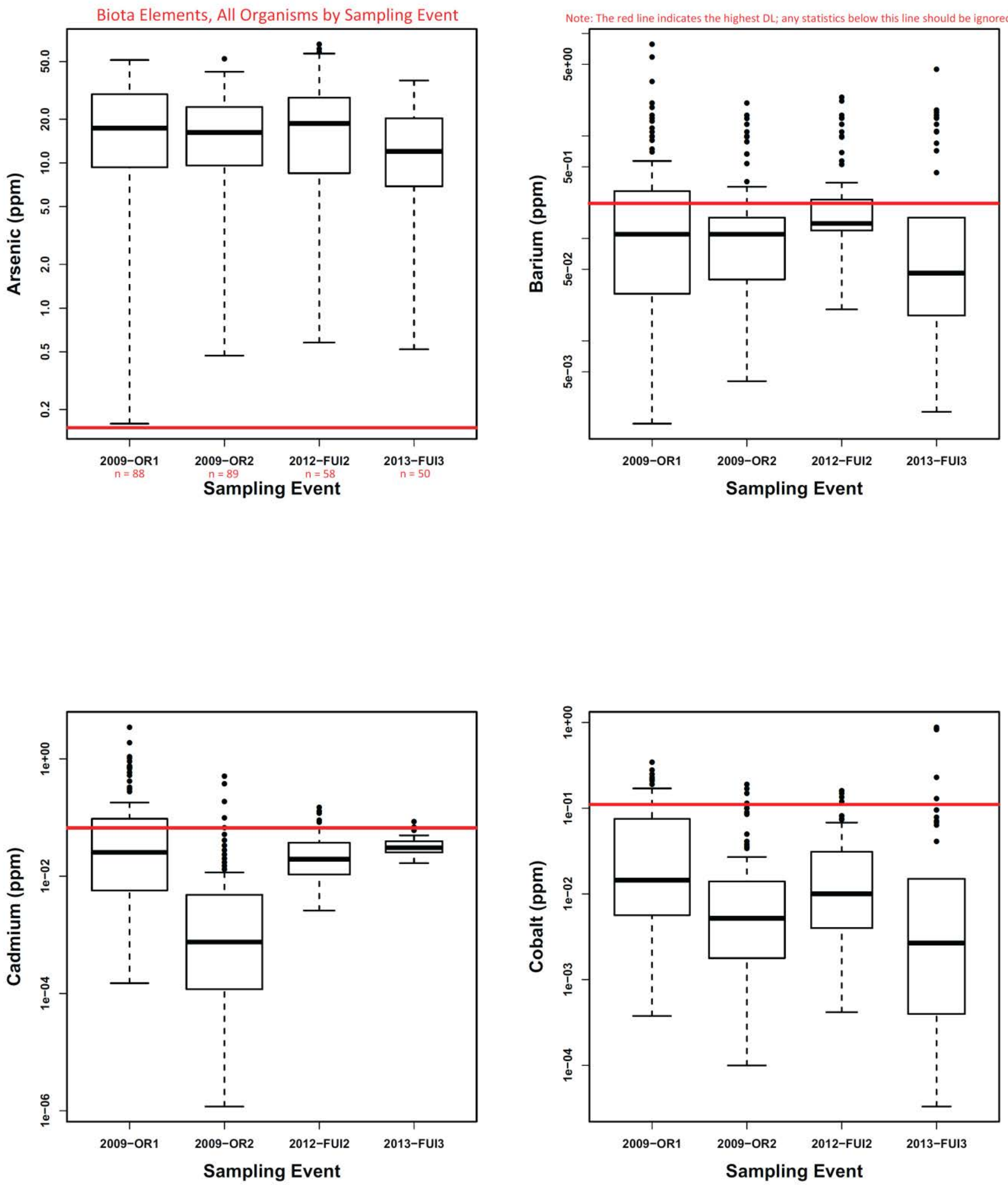


Figure 4-6 (continued): Boxplots showing the distribution of the pre- and post-ROUMRS pooled biota data. The portions of the boxplots below the red line are censored by the maximum detection limit and should be ignored. The first panel indicates the number of samples (*n*).

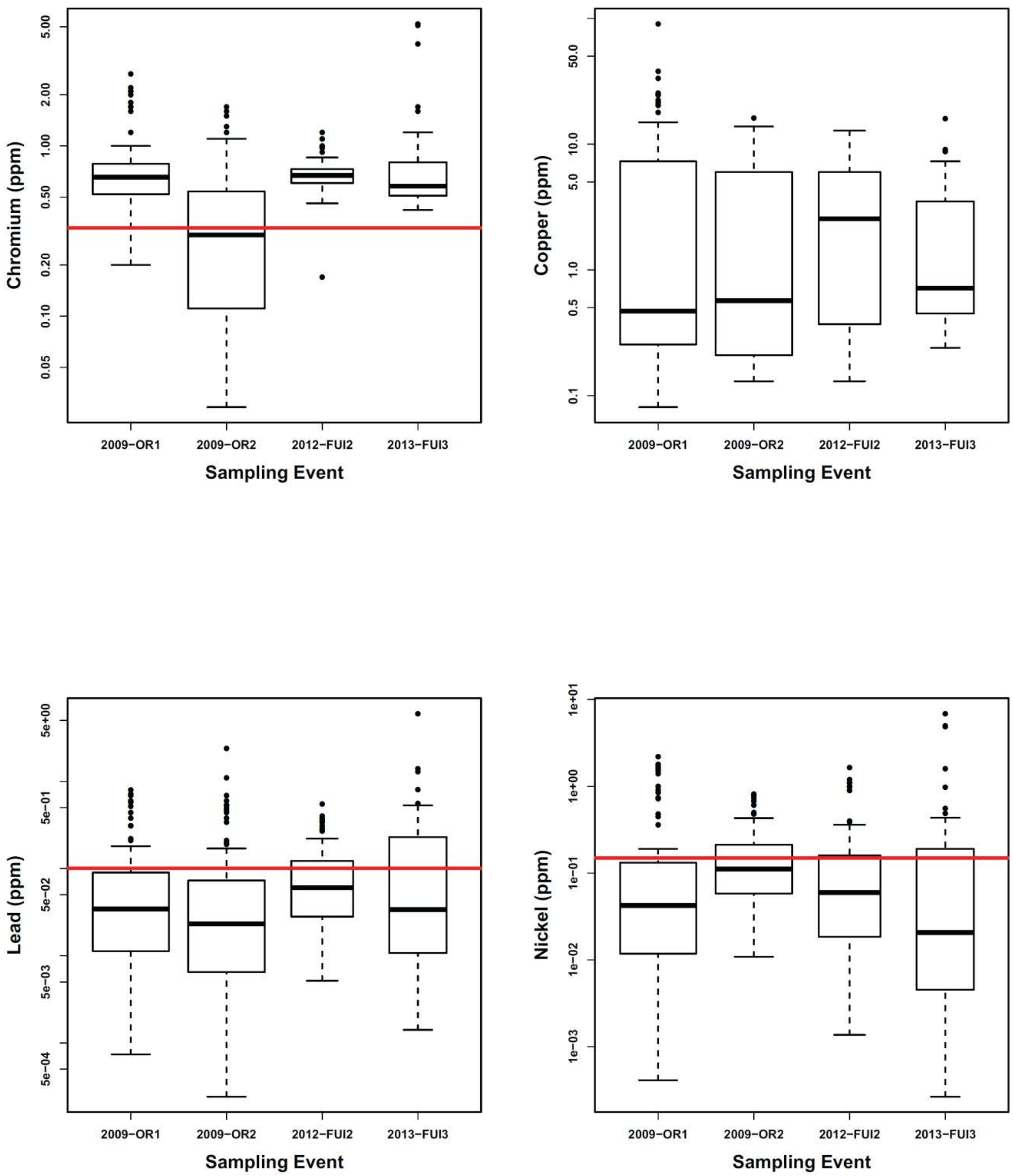


Figure 4-6 (continued): Boxplots showing the distribution of the pre- and post-ROUMRS pooled biota data. The portions of the boxplots below the red line are censored by the maximum detection limit and should be ignored. The first panel indicates the number of samples (*n*).

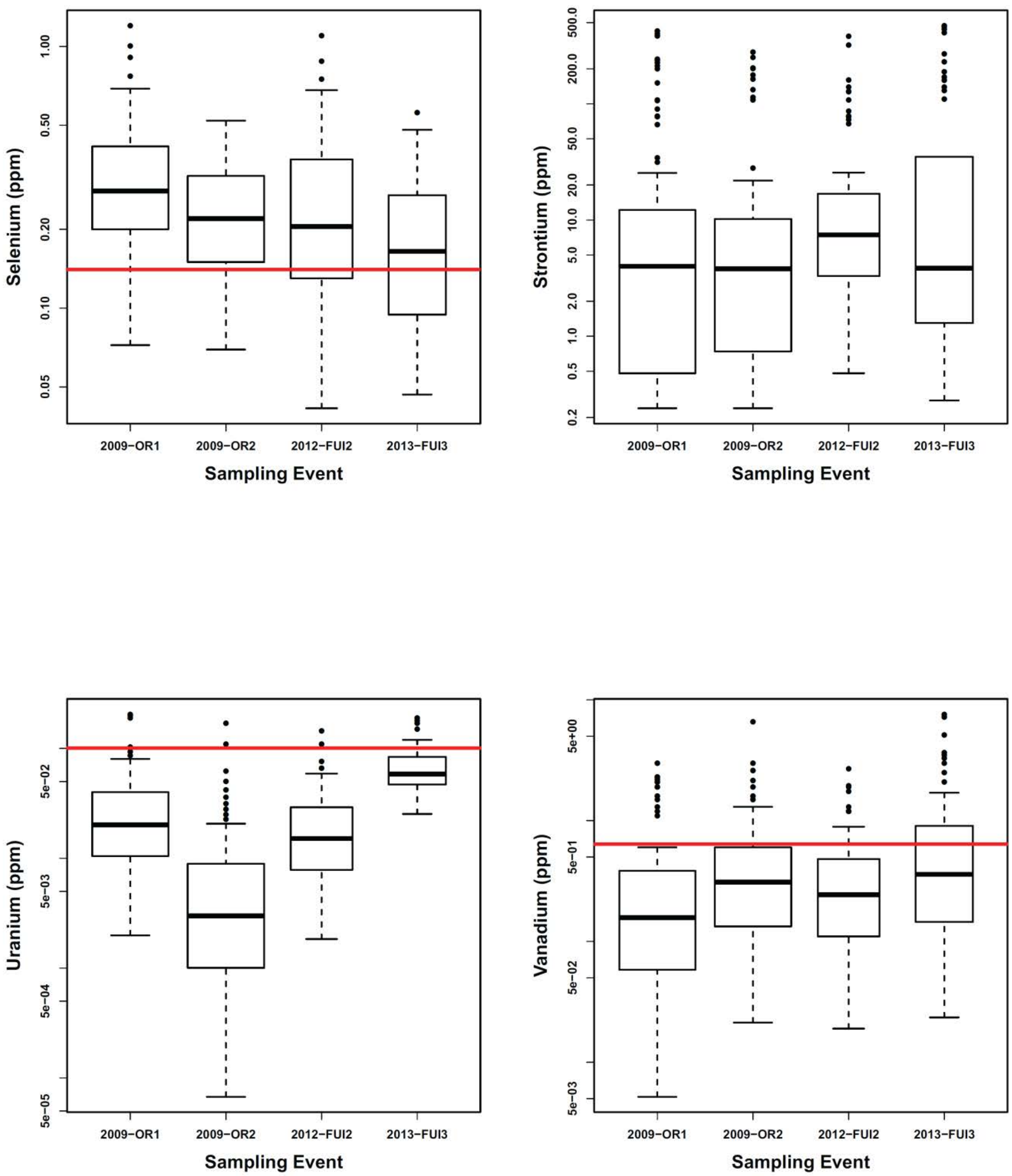


Figure 4-6 (continued): Boxplots showing the distribution of the pre- and post-ROUMRS pooled biota data. The portions of the boxplots below the red line are censored by the maximum detection limit and should be ignored. The first panel indicates the number of samples (*n*).

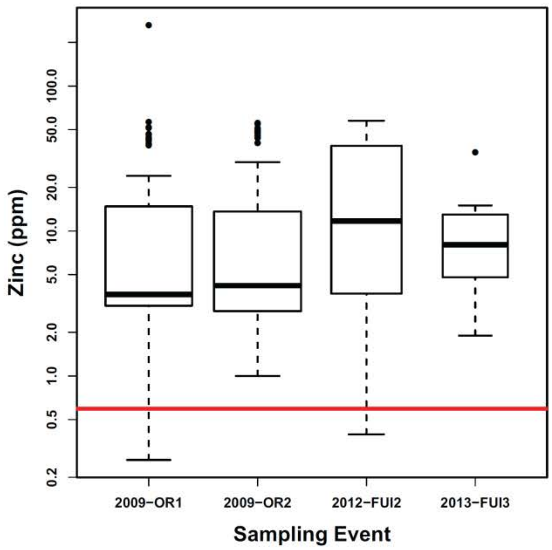
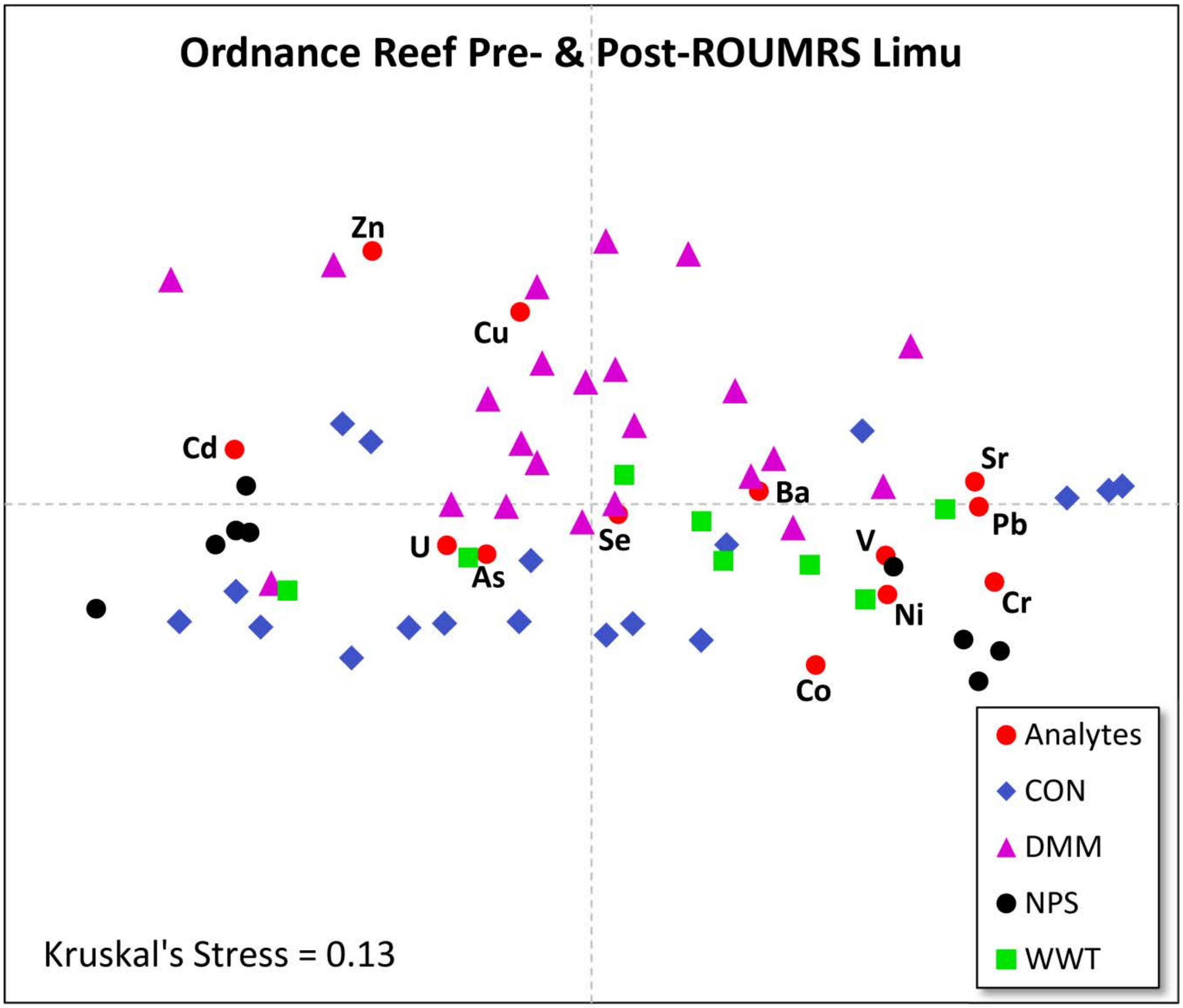


Figure 4-7: NMDS plot of pooled pre- and post-ROUMRS limu data; analytes are indicated with red dots and the different strata are represented by the other symbols indicated in the key.



It is apparent from these summary statistics in Table 4-2, that there were differences in limu by strata. Using the interval-censored data and the nonparametric R package *ictest* (Wilcoxon test), we compared selected analytes for the CON and DMM strata only (biota samples from the NPS and WWT were only obtained during the pre-ROUMRS phase of the Ordnance Reef investigation, i.e., UH OR Study). Copper (Cu), zinc (Zn), and strontium (Sr) were significantly higher (α = 0.05) in samples from the DMM stratum. Certainly copper and zinc are not surprising given that we have shown they are associated with the munitions. Only cobalt was significantly higher in the CON stratum compared with the DMM stratum.

Table 4-2: Statistical summary of Ordnance Reef pooled pre- and post-ROUMRS limu data by strata (all units are in mg/kg-wet weight)

Analyte	Strata	Mean	Std Error	Std Dev	Max	75th Pctl	Median	25th Pctl	Min	DL Range	n	# of NDs	%NDs	Method
Aluminum (Al)	DMM	149	13.1	26.3	182	176	145	126	123	3	23	0	0.0%	Std
	WWT	185	28.8	49.8	239	239	175	141	141	3	7	0	0.0%	Std
	NPS	57.3	47.7	107	248	130	10.0	8.10	7.00	3	9	0	0.0%	Std
	CON	49.3	4.98	8.62	58.3	58.3	48.6	41.1	41.1	3	18	0	0.0%	Std
Arsenic (As)	DMM	0.77	0.05	0.24	1.2	0.97	0.80	0.61	ND	0.15-0.21	23	1	4.3%	K-M
	WWT†	0.92	0.10	0.27	1.4	1.1	0.88	0.81	0.51	0.15	7	0	0.0%	Std
	NPS†	0.98	0.14	0.42	1.5	1.2	1.1	0.88	ND	0.15	9	1	11.1%	K-M
	CON	1.1	0.16	0.68	2.7	1.3	0.97	0.57	0.16	0.14-0.15	18	0	0.0%	Std
Barium (Ba)	DMM	1.28	0.178	0.853	4.50	1.50	1.10	0.880	0.430	0.088-0.120	23	0	0.0%	Std
	WWT†	1.06	0.148	0.393	1.50	1.49	1.10	0.670	0.450	0.090	7	0	0.0%	Std
	NPS†	2.23	0.953	2.86	7.85	4.65	0.540	0.270	0.210	0.090	9	0	0.0%	Std
	CON	1.11	0.146	0.620	2.40	1.60	0.990	0.530	0.260	0.086-0.092	18	0	0.0%	Std
Cadmium (Cd)	DMM	*	*	*	0.086	*	*	*	ND	0.05-0.07	23	22	95.7%	---
	WWT†	*	*	*	ND	*	*	*	ND	0.05	7	7	100.0%	---
	NPS†	*	*	*	ND	*	*	*	ND	0.05	9	9	100.0%	---
	CON	*	*	*	0.069	*	*	*	ND	0.05	18	15	83.3%	---
Chromium (Cr)	DMM	0.95	0.084	0.40	1.7	1.2	0.94	0.71	ND	0.10-0.14	23	1	4.3%	K-M
	WWT†	1.5	0.23	0.60	2.1	2.0	1.7	0.78	0.56	0.10	7	0	0.0%	Std
	NPS†	1.1	0.34	1.0	2.7	2.1	0.32	0.30	ND	0.10	9	1	11.1%	K-M
	CON	1.5	0.37	1.6	5.2	1.7	1.0	0.51	0.20	0.10	18	0	0.0%	Std
Cobalt (Co)	DMM	0.080	0.007	0.034	0.15	0.10	0.07	0.06	ND	0.010-0.014	23	1	4.3%	K-M
	WWT†	0.14	0.018	0.048	0.19	0.17	0.16	0.090	0.062	0.010	7	0	0.0%	Std
	NPS†	0.12	0.044	0.13	0.35	0.22	0.016	0.012	ND	0.010	9	1	11.1%	K-M
	CON	0.24	0.069	0.29	0.89	0.24	0.14	0.050	0.027	0.010	18	0	0.0%	Std
Copper (Cu)	DMM	3.1	1.2	5.8	25	1.8	1.2	0.7	0.30	0.01	23	0	0.0%	Std
	WWT†	0.70	0.13	0.34	1.3	0.92	0.71	0.45	0.23	0.01	7	0	0.0%	Std
	NPS†	0.37	0.089	0.27	0.78	0.63	0.20	0.15	0.081	0.01	9	0	0.0%	Std
	CON	0.50	0.083	0.35	1.4	0.58	0.41	0.26	0.16	0.01	18	0	0.0%	Std

Table 4-2: Statistical summary of Ordnance Reef pooled pre- and post-ROUMRS limu data by strata (all units are in mg/kg-wet weight)

Analyte	Strata	Mean	Std Error	Std Dev	Max	75th Pctl	Median	25th Pctl	Min	DL Range	n	# of NDs	%NDs	Method
Lead (Pb)	DMM	0.40	0.033	0.16	0.69	0.54	0.40	0.31	ND	0.059-0.082	23	1	4.3%	K-M
	WWT†	0.50	0.075	0.20	0.80	0.59	0.53	0.34	0.18	0.060	7	0	0.0%	Std
	NPS†	0.44	0.12	0.37	1.1	0.71	0.19	0.15	ND	0.060	9	1	11.1%	K-M
	CON	0.44	0.088	0.37	1.4	0.50	0.36	0.21	ND	0.057-0.061	17	1	5.9%	K-M
Mercury (Hg)	DMM	*	*	*	0.028	*	*	*	ND	0.020-0.046	10	9	90.0%	---
	WWT†	*	*	*	ND	*	*	*	ND	0.028-0.055	7	7	100.0%	---
	NPS†	*	*	*	ND	*	*	*	ND	0.025-0.061	9	9	100.0%	---
	CON	*	*	*	0.031	*	*	*	ND	0.025-0.045	8	7	87.5%	---
Nickel (Ni)	DMM	0.65	0.07	0.35	1.7	0.91	0.49	0.42	ND	0.10-0.14	23	1	4.3%	K-M
	WWT†	0.99	0.20	0.53	1.6	1.6	0.73	0.61	0.36	0.10	7	0	0.0%	Std
	NPS†	0.85	0.26	0.78	2.2	1.5	0.43	0.29	ND	0.10	9	1	11.1%	K-M
	CON	1.6	0.46	1.9	6.9	1.6	0.94	0.38	0.17	0.10	18	0	0.0%	Std
Selenium (Se)	DMM	0.10	0.008	0.040	0.20	0.13	0.094	0.074	0.048	0.10-0.14	23	15	65.2%	ROS
	WWT†	0.22	0.051	0.14	0.44	0.33	0.20	*	ND	0.10	7	3	42.9%	K-M
	NPS†	0.31	0.11	0.33	0.91	0.63	0.15	0.062	0.027	0.10	9	5	55.6%	ROS
	CON	0.090	0.020	0.087	0.33	0.12	0.059	0.030	ND	0.10	18	14	77.8%	ROS
Strontium (Sr)	DMM	183	22.1	106	460	230	161	108	7.20	0.10	23	0	0.0%	Std
	WWT†	190	25.2	66.7	252	243	226	133	77.8	0.10-0.14	7	0	0.0%	Std
	NPS†	162	64.0	192	425	393	10.7	8.80	7.70	0.10	9	0	0.0%	Std
	CON	138	35.0	148	470	157	97.0	21.5	10.9	0.10	18	0	0.0%	Std
Uranium (U)	DMM	0.080	0.006	0.030	0.15	0.10	0.071	0.058	0.037	0.10-0.14	23	18	78.3%	ROS
	WWT†	*	*	*	0.10	*	*	*	ND	0.10	7	6	85.7%	---
	NPS†	0.167	0.009	0.027	0.21	0.20	0.16	0.14	0.13	0.10	9	5	55.6%	ROS
	CON	*	*	*	0.19	*	*	*	ND	0.10	18	15	83.3%	---
Vanadium (V)	DMM	1.6	0.21	1.0	3.7	2.1	1.5	0.79	ND	0.29-0.41	23	1	4.3%	K-M
	WWT†	2.0	0.29	0.77	3.0	2.6	1.9	1.6	0.60	0.30	7	0	0.0%	Std
	NPS†	1.7	0.69	2.1	6.6	2.3	0.37	0.34	ND	0.30	9	2	22.2%	K-M
	CON	2.2	0.52	2.2	7.6	2.6	1.4	0.67	0.31	0.29-0.31	18	0	0.0%	Std

Table 4-2: Statistical summary of Ordnance Reef pooled pre- and post-ROUMRS limu data by strata (all units are in mg/kg-wet weight)

Analyte	Strata	Mean	Std Error	Std Dev	Max	75th Pctl	Median	25th Pctl	Min	DL Range	n	# of NDs	%NDs	Method
Zinc (Zn)	DMM	14	11	54	263	3.5	2.6	1.9	0.70	0.59-0.82	23	0	0.0%	Std
	WWT†	1.8	0.30	0.80	3.1	2.2	1.7	1.0	0.66	0.60	7	0	0.0%	Std
	NPS†	1.6	0.24	0.73	3.0	1.8	1.5	1.2	ND	0.60	9	1	11.1%	K-M
	CON	2.6	0.74	3.1	14	2.9	1.6	1.0	ND	0.57-0.60	18	3	16.7%	K-M

* Insufficient data to calculate statistic; ND = not detected (i.e., <DL); and NA = not analyzed; %NDs = the percent of nondetects; and a < means one replicate was ND and the other was the value.

† Pre-ROUMRS (2009) only sampling for this stratum.
Note: J-flagged data (i.e., data between DL and RL) were treated as quantitative data; if one of two replicate samples was ND, the mean result was counted as an ND because the indicator variable was coded as "less than"
Statistical Method: Std = *standard* Minitab summary statistics; K-M = Kaplan-Meier method (NDs <50 %); ROS = regression on order statistics (NDs ≥50 % and <80 %); and -- not calculated (NDs ≥80 %)

Like the sediment data, we ran the Wilcoxon test analog to compare pre- and post-ROUMRS biota data for each organism type. The results of these tests were indicated in notes added to all boxplots for which there was a significant difference. In the case of limu (Figure 4-8), the only analytes for which there was a significant difference were barium and vanadium, i.e., none of the DMM-associated analytes. Arguably, limu, being sessile, and in light of our NMDS (Figure 4-7) and Wilcoxon test findings, may be the best indicator of effects of the ROUMRS technology demonstration. If this is true, then there was no real difference between the pre- and post-ROUMRS data, hence, no effect. While not statistically significant, some median concentrations were marginally higher (copper and zinc) but others were marginally lower (lead).

It was apparent from Figure 4-9 that arsenic was significantly higher in post-ROUMRS crabs; however, it was already established that arsenic is not associated with DMM. Of those analytes associated with DMM (copper and zinc), there was no significant difference. For copper this is not surprising given that crab blood contains copper-based hemocyanin which could, presumably, overwhelm any copper released from DMM.

Copper, however, was significantly lower in post-ROUMRS samples of octopus (Figure 4-10) and yet octopus blood also contains copper-based hemocyanin. There was also significantly lower zinc in the post-ROUMRS octopus. It is difficult to say whether or not this was the result of the ROUMRS technology demonstration because there were a number of analytes that are not associated with DMM that were also significantly lower including cobalt and selenium, whereas, chromium was significantly higher in the post-ROUMRS samples.

Post-ROUMRS copper and zinc were significantly higher in fish but so were chromium, and strontium (Figure 4-11). Post-ROUMRS arsenic, lead, and vanadium were significantly lower. There were sufficient detects in the 2,4-DNT to prepare both a boxplot, albeit censored, and to conduct the Wilcoxon test which indicated that the difference between the pre- and post-ROUMRS 2,4-DNT concentrations was not significant at $\alpha = 0.05$ ($p = 0.132$), however, there was only a single detection in the post-ROUMRS dataset.

Finally, a NMDS plot was prepared for the pre-ROUMRS biota data so a comparison could be made with pre- and post-ROUMRS data (Figure 4-12). Like the sediments (Figure 4-4), the pre-ROUMRS plot appears *tighter* but Kruskal's stress (0.15) was marginally higher than the post-ROUMRS Kruskal's stress (0.13). This may be due to the fact that in the pre-ROUMRS data (Figure 4-12, top panel), the octopus data (green squares) and crab data (blue diamonds) are mixed (i.e., they cluster together but do not form two distinct clusters) whereas, in the post-ROUMRS data (bottom panel), the crab data (blue diamonds) and octopus data (green squares) form two distinct and separate clusters in the NMDS plot. They both clustered, however, near copper probably as a result of both organisms containing copper-based hemocyanin in their blood. While the change in the clustering of crab and octopus may explain the difference in Kruskal's stress, we do not know why the clustering changed and any explanation would be conjecture.

Figure 4-8: Boxplots showing the distribution of the pre- and post-ROUMRS limu data. The portions of the boxplots below the red line are censored by the maximum detection limit and should be ignored. The first panel indicates the number of samples (*n*); the results of the Wilcoxon significance test ($\alpha = 0.05$) are shown with red text.

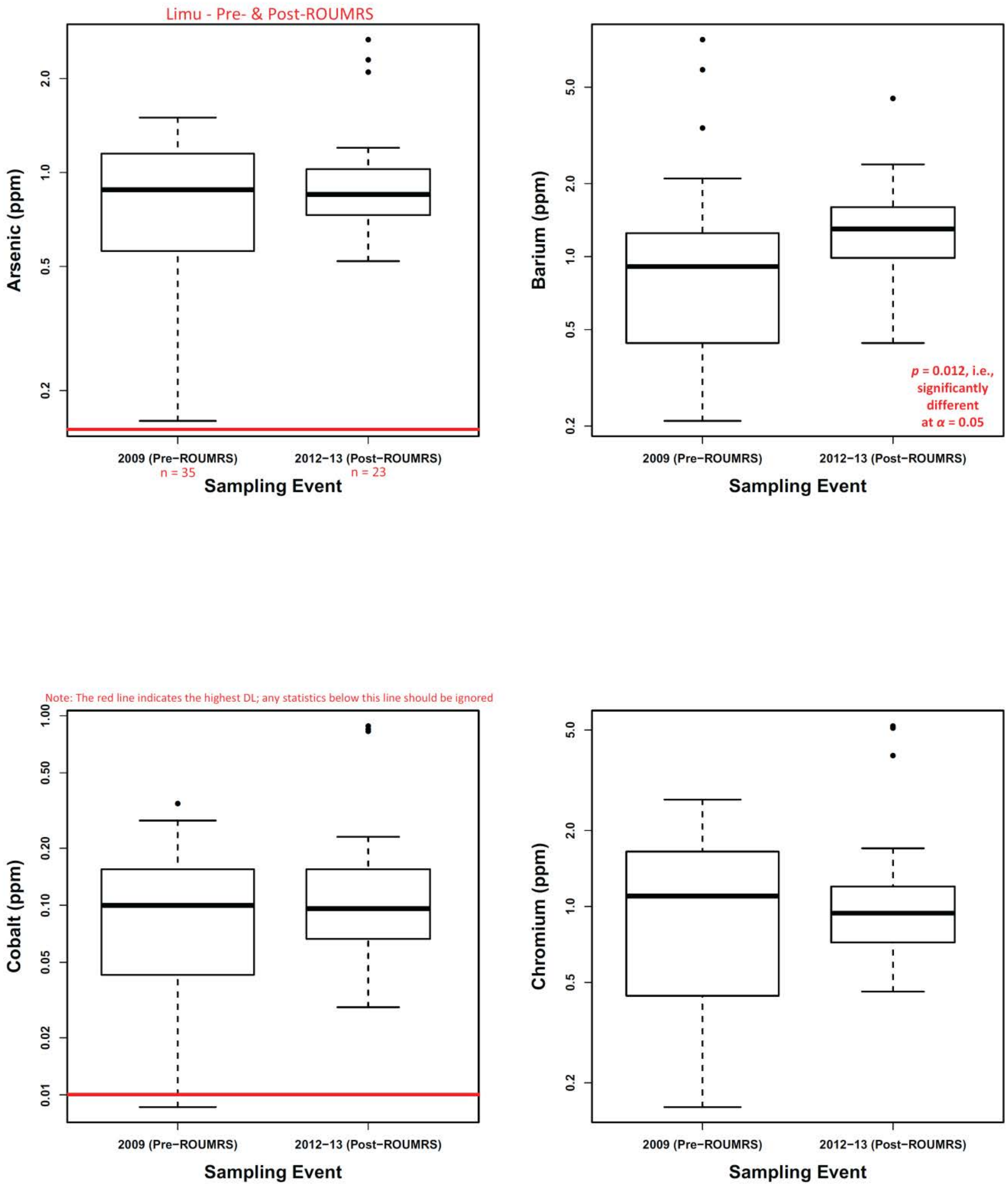


Figure 4-8 (continued): Boxplots showing the distribution of the pre- and post-ROUMRS **limu** data. The portions of the boxplots below the red line are censored by the maximum detection limit and should be ignored. The first panel indicates the number of samples (n); the results of the Wilcoxon significance test ($\alpha = 0.05$) are shown with red text.

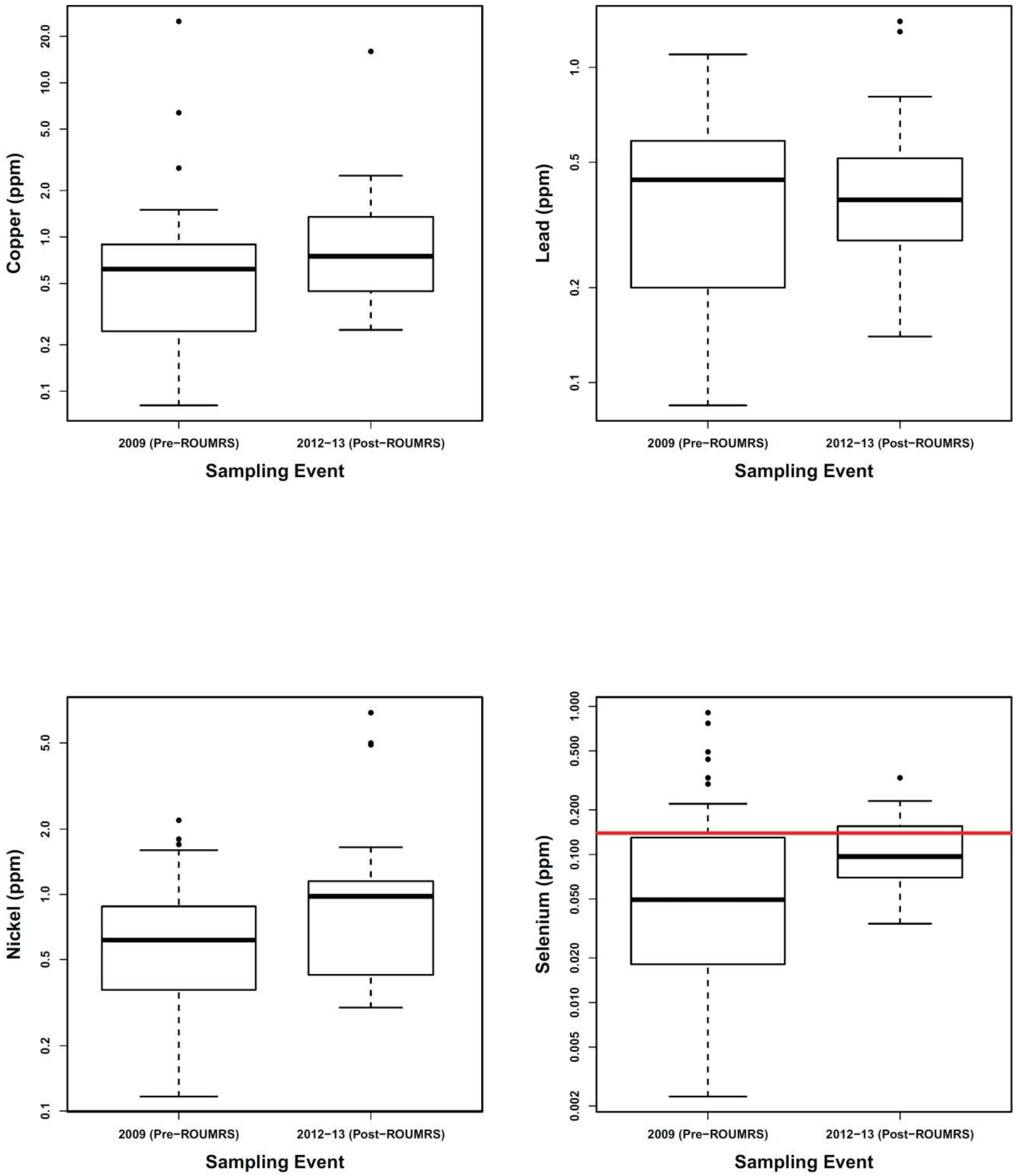


Figure 4-8 (continued): Boxplots showing the distribution of the pre- and post-ROUMRS **limu** data. The portions of the boxplots below the red line are censored by the maximum detection limit and should be ignored. The first panel indicates the number of samples (*n*); the results of the Wilcoxon significance test (α = 0.05) are shown with red text.

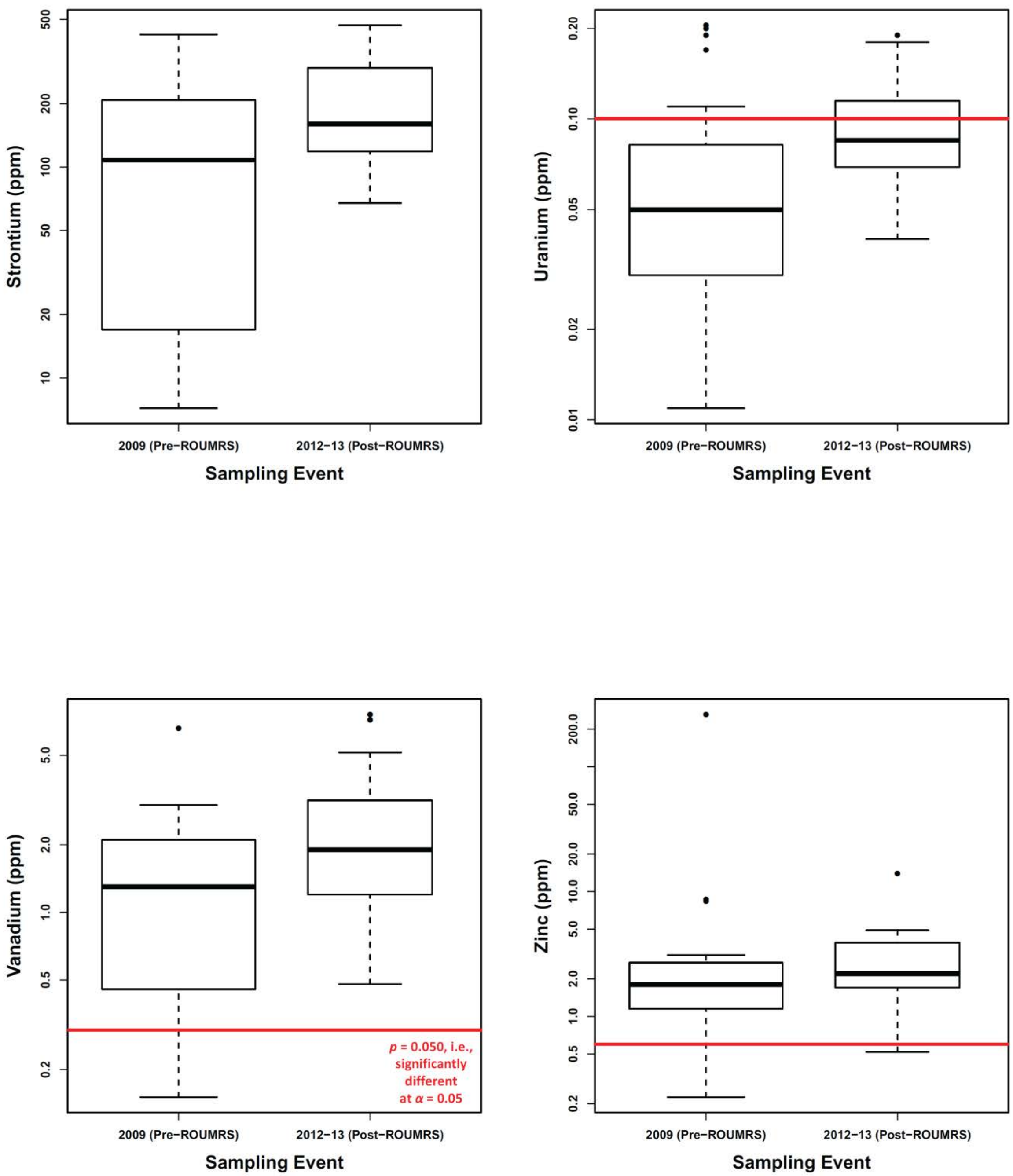


Figure 4-9: Boxplots showing the distribution of the pre- and post-ROUMRS crab data. The portions of the boxplots below the red line are censored by the maximum detection limit and should be ignored. The first panel indicates the number of samples (*n*); the results of the Wilcoxon significance test ($\alpha = 0.05$) are shown with red text.

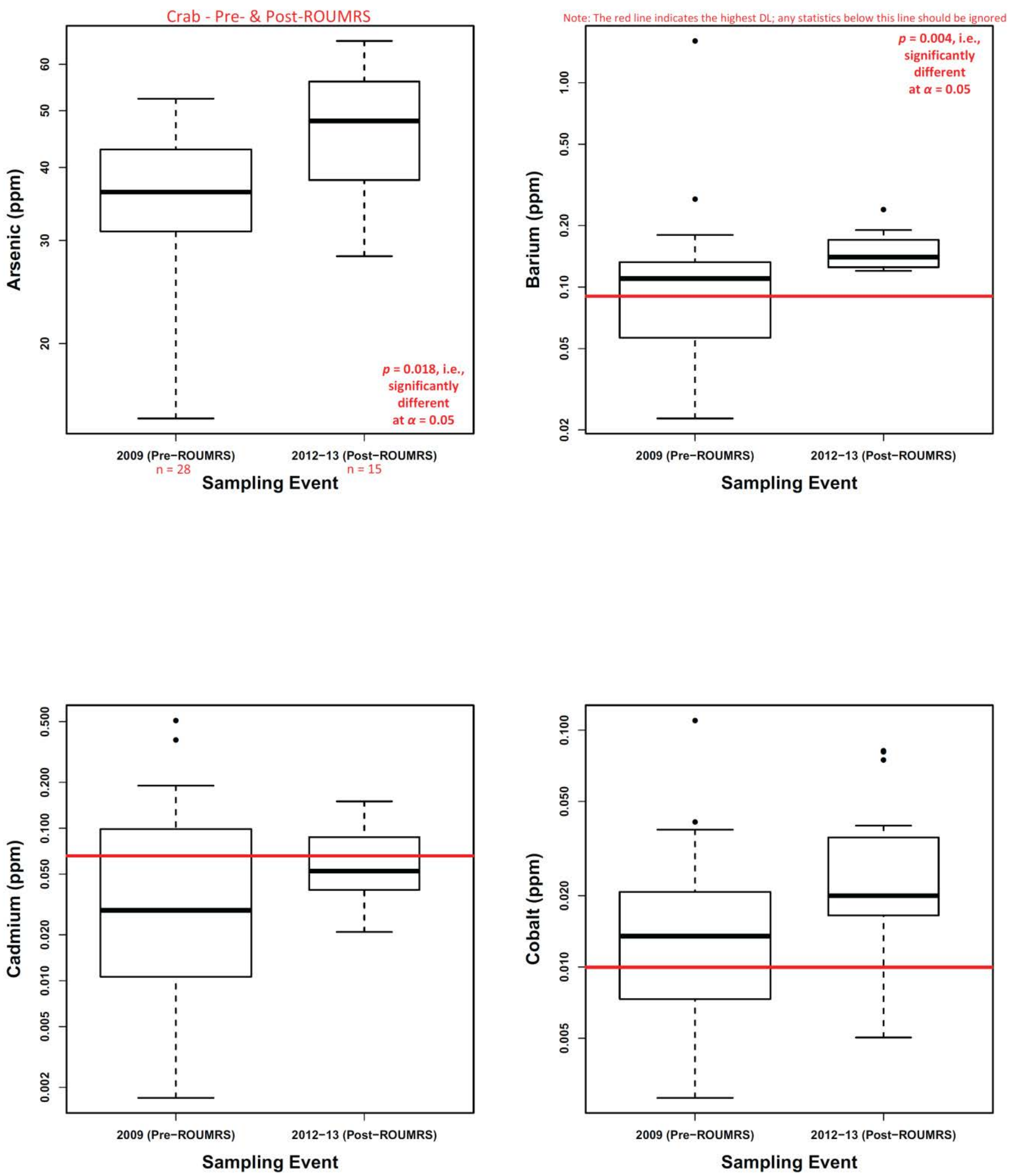


Figure 4-9 (continued): Boxplots showing the distribution of the pre- and post-ROUMRS **crab** data. The portions of the boxplots below the red line are censored by the maximum detection limit and should be ignored. The first panel indicates the number of samples (*n*); the results of the Wilcoxon significance test (α = 0.05) are shown with red text.

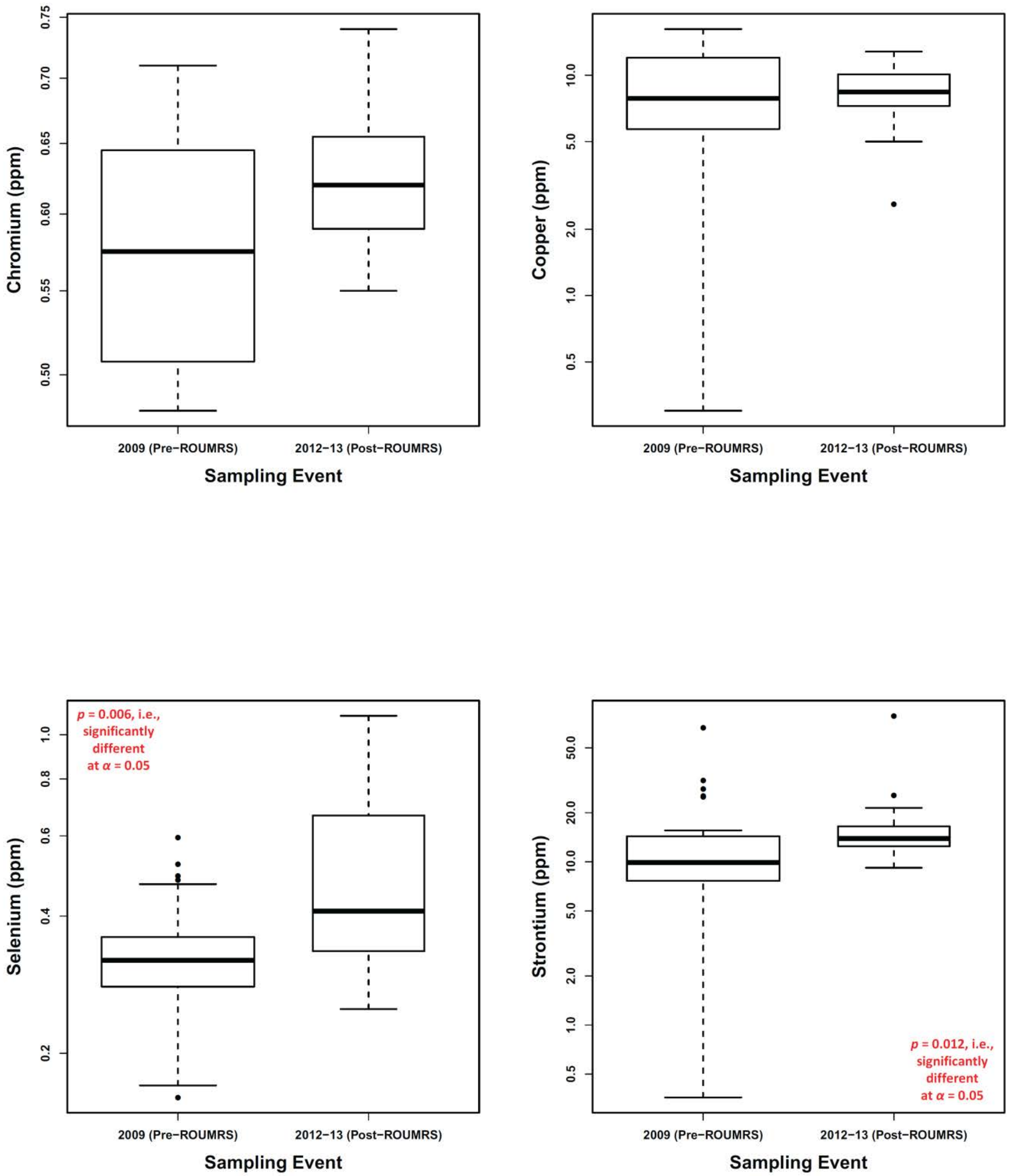


Figure 4-9 (continued): Boxplots showing the distribution of the pre- and post-ROUMRS **crab** data. The portions of the boxplots below the red line are censored by the maximum detection limit and should be ignored. The first panel indicates the number of samples (*n*); the results of the Wilcoxon significance test ($\alpha = 0.05$) are shown with red text.

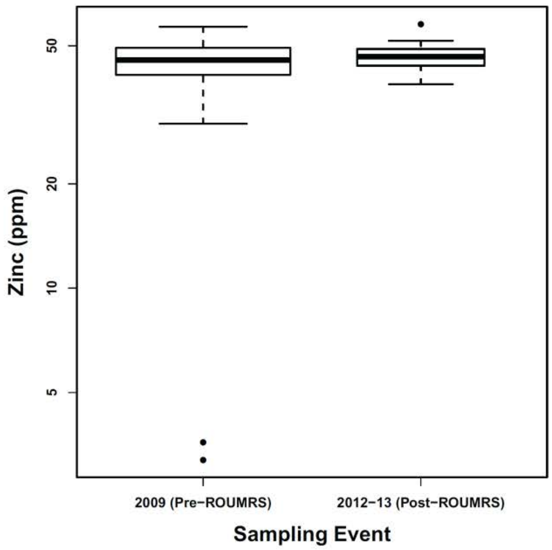


Figure 4-10: Boxplots showing the distribution of the pre- and post-ROUMRS octopus data. The portions of the boxplots below the red line are censored by the maximum detection limit and should be ignored. The first panel indicates the number of samples (*n*); the results of the Wilcoxon significance test ($\alpha = 0.05$) are shown with red text.

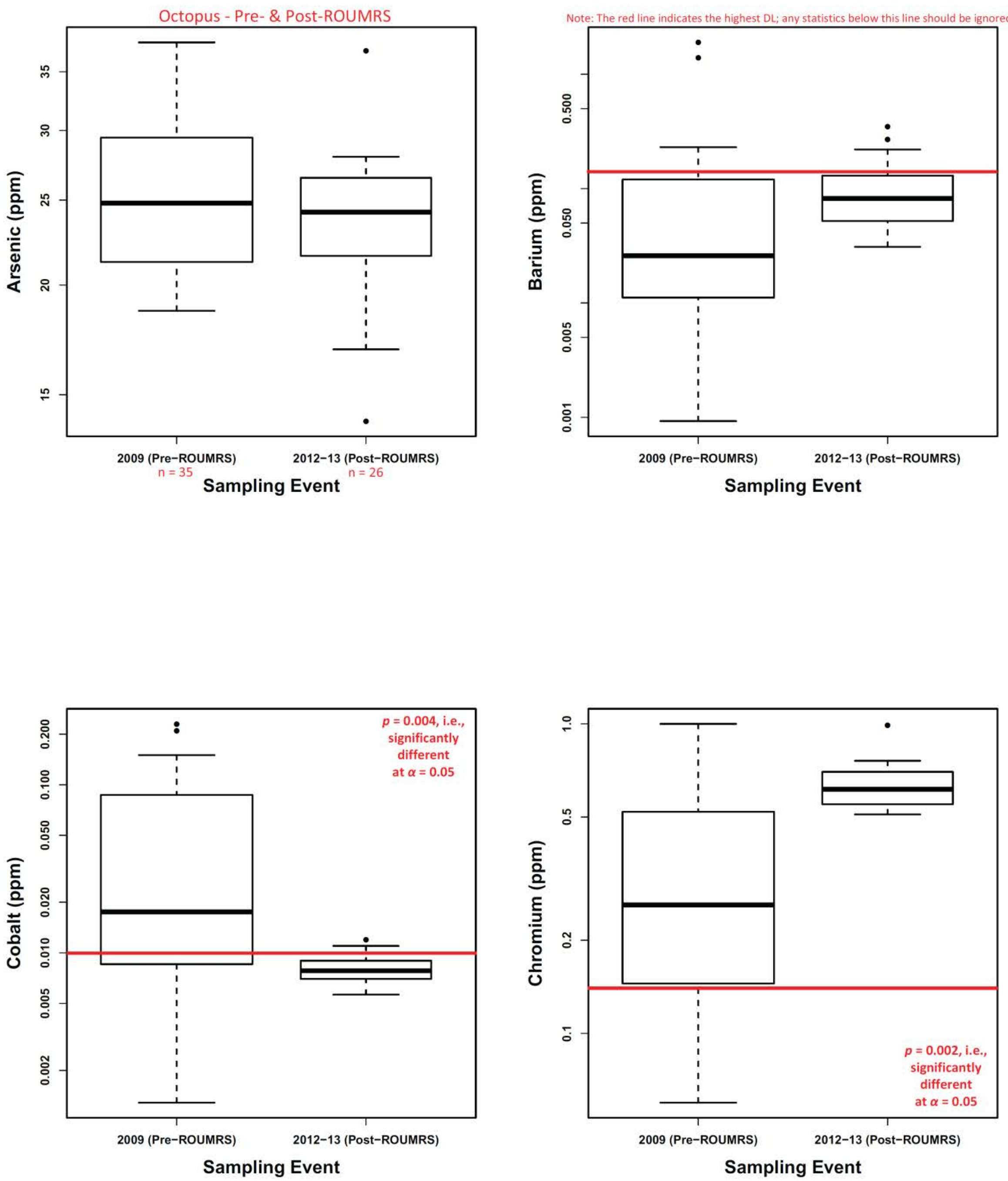


Figure 4-10 (continued): Boxplots showing the distribution of the pre- and post-ROUMRS **octopus** data. The portions of the boxplots below the red line are censored by the maximum detection limit and should be ignored. The first panel indicates the number of samples (*n*); the results of the Wilcoxon significance test ($\alpha = 0.05$) are shown with red text.

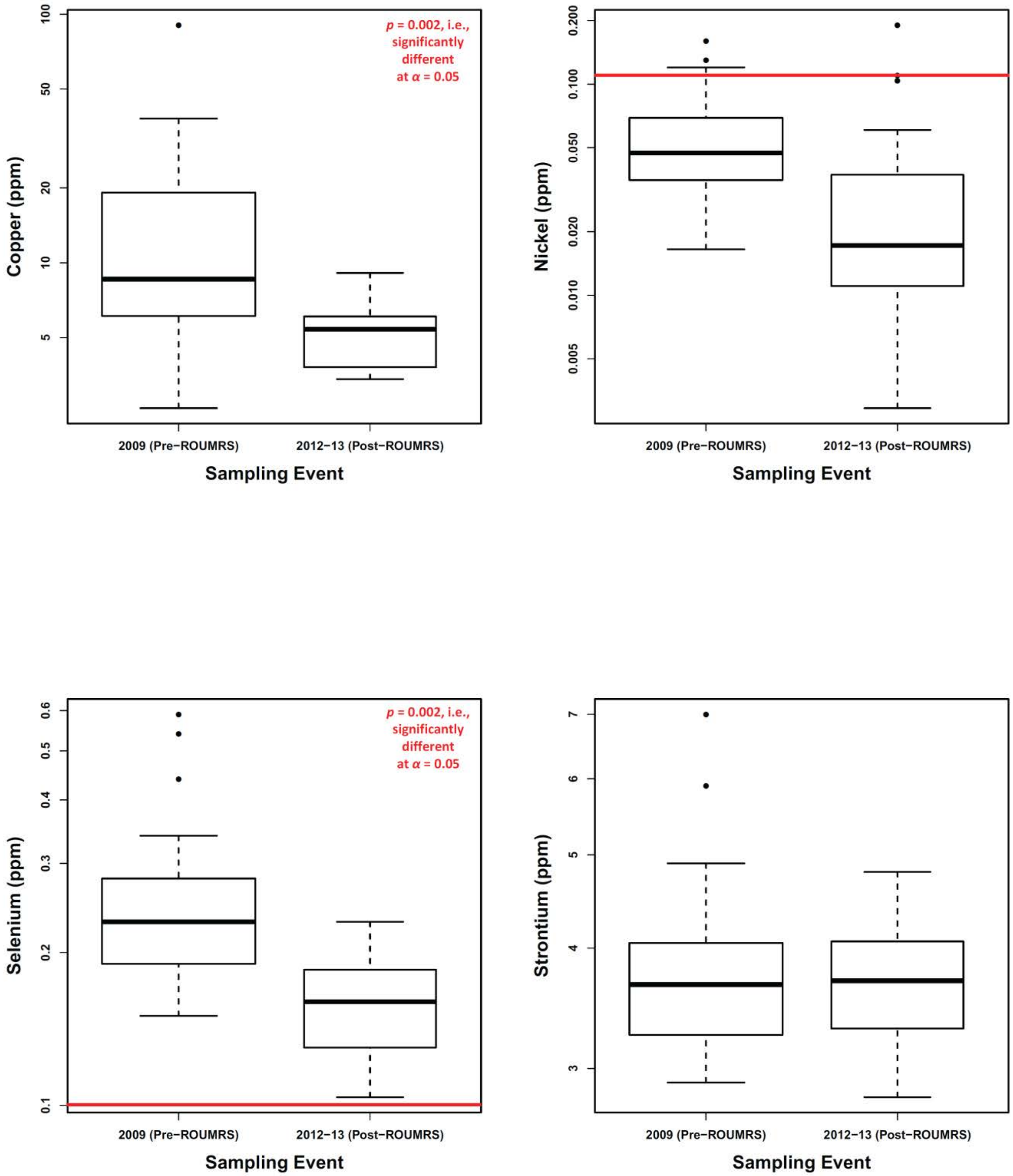


Figure 4-10 (continued): Boxplots showing the distribution of the pre- and post-ROUMRS **octopus** data. The portions of the boxplots below the red line are censored by the maximum detection limit and should be ignored. The first panel indicates the number of samples (*n*); the results of the Wilcoxon significance test ($\alpha = 0.05$) are shown with red text.

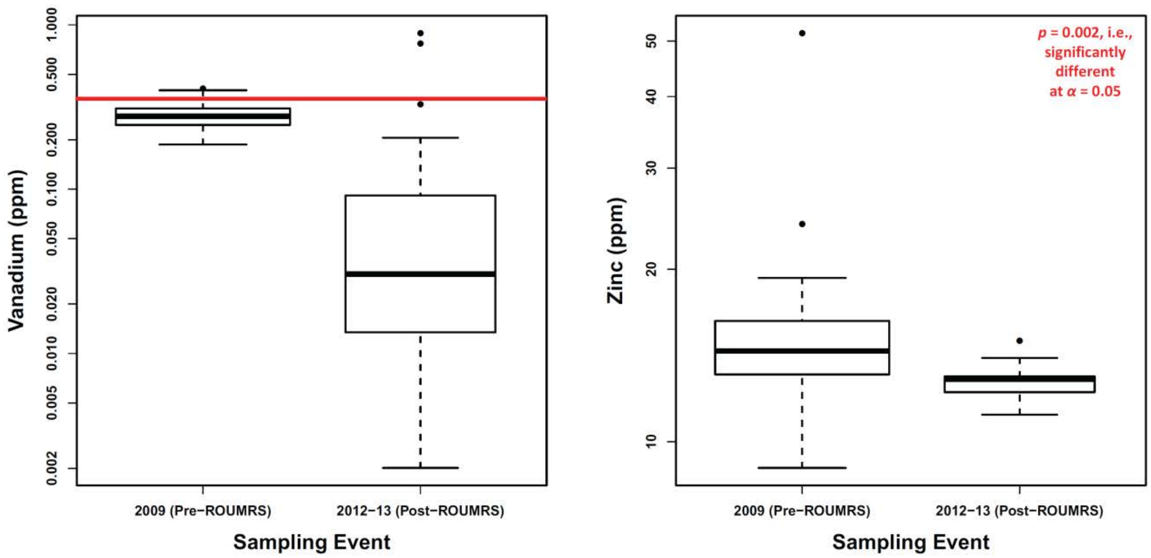


Figure 4-11: Boxplots showing the distribution of the pre- and post-ROUMRS fish data. The portions of the boxplots below the red line are censored by the maximum detection limit and should be ignored. The first panel indicates the number of samples (*n*); the results of the Wilcoxon significance test ($\alpha = 0.05$) are shown with red text.

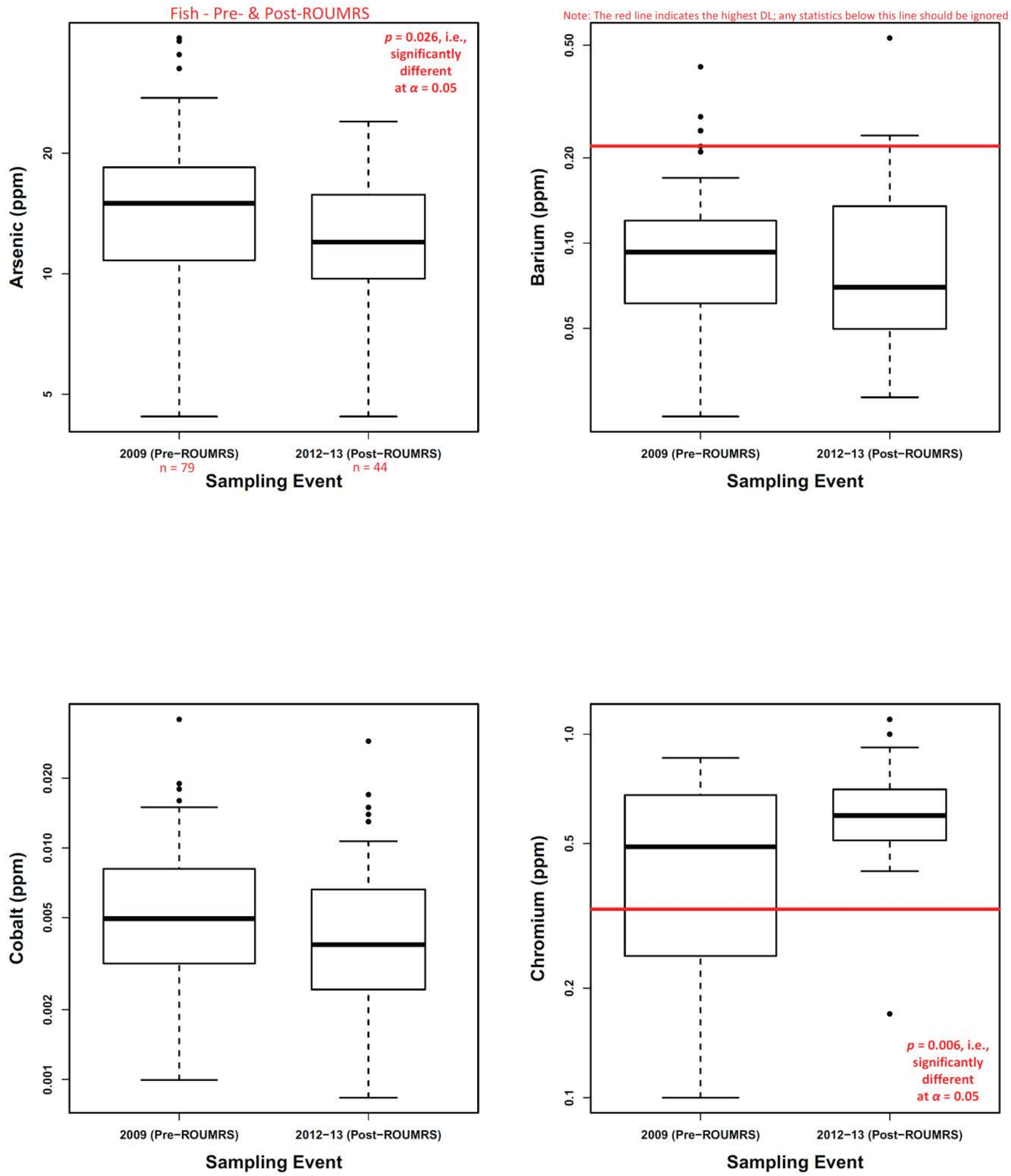


Figure 4-11 (continued): Boxplots showing the distribution of the pre- and post-ROUMRS **fish** data. The portions of the boxplots below the red line are censored by the maximum detection limit and should be ignored. The first panel indicates the number of samples (*n*); the results of the Wilcoxon significance test ($\alpha = 0.05$) are shown with red text.

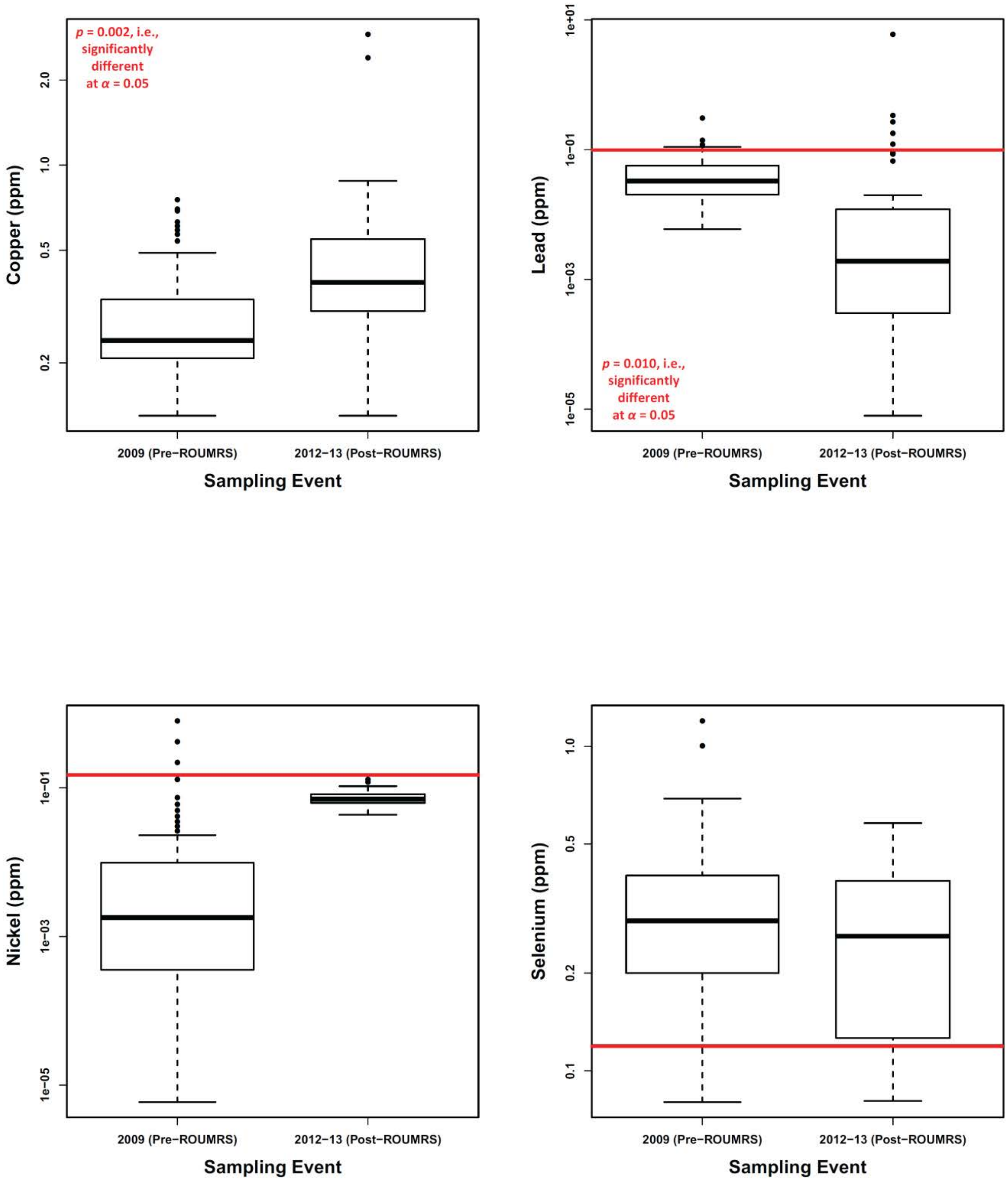


Figure 4-11 (continued): Boxplots showing the distribution of the pre- and post-ROUMRS **fish** data. The portions of the boxplots below the red line are censored by the maximum detection limit and should be ignored. The first panel indicates the number of samples (*n*); the results of the Wilcoxon significance test ($\alpha = 0.05$) are shown with red text.

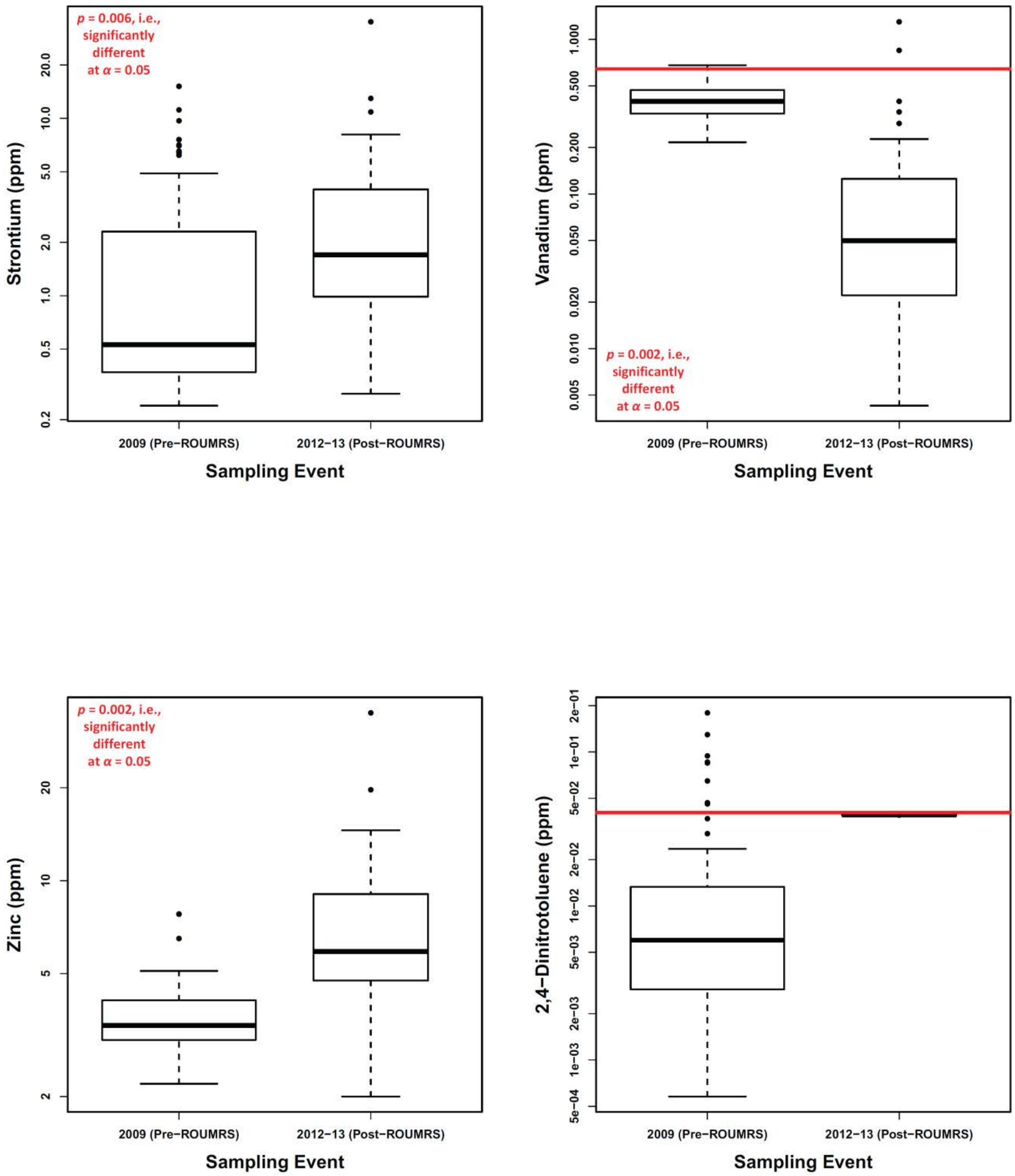
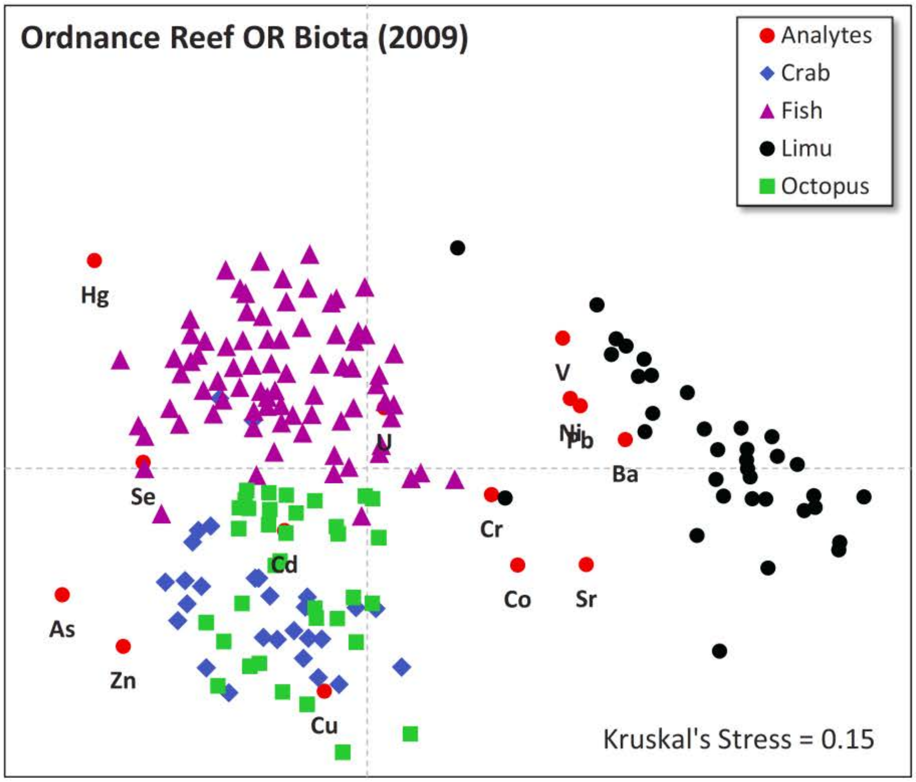
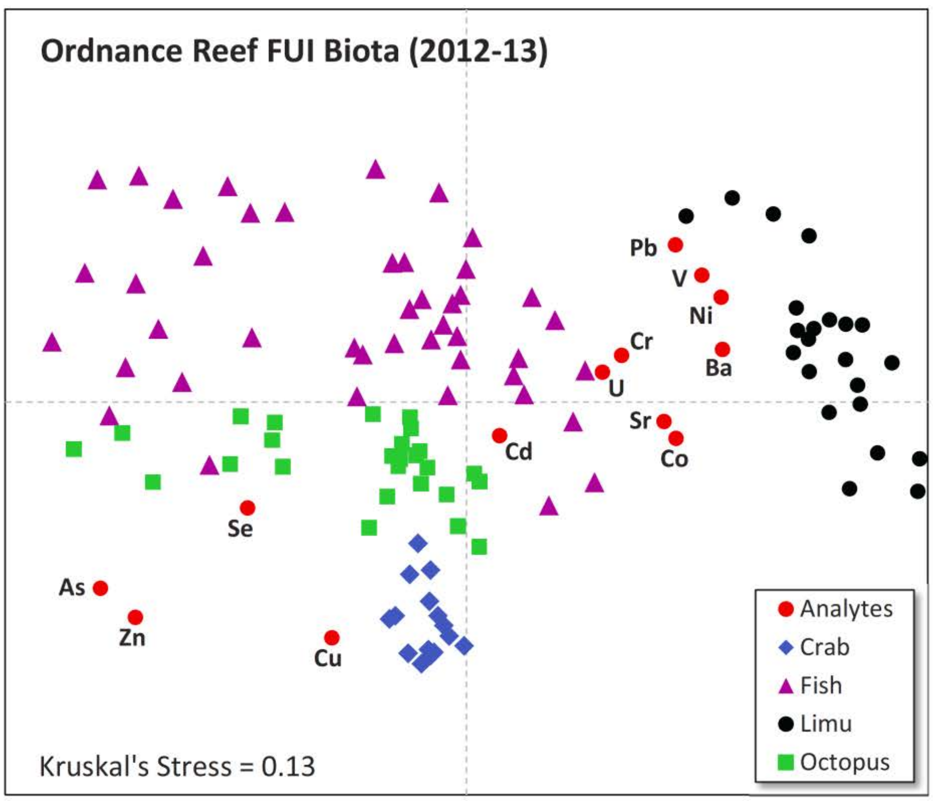


Figure 4-12: NMDS plots of pre-ROUMRS (top panel) biota analytes (red dots) and samples and post-ROUMRS (bottom panel) biota analytes (red dots) and samples.





We created correlation matrices using the nonparametric Kendall's tau (τ) and the pooled pre- and post-ROUMRS biota data by organism type. There were some significant (α = 0.05) positive and negative correlations as shown in Tables 4-3 through 4-6. Because of the high number of nondetects in the biota energetics data, correlations were limited to elements and, in some cases, a limited number of elements, with the totals ranging from nine elements for crab to 13 elements for limu.

Probably the most notable observation regarding the Kendall's τ correlation coefficients for limu (Table 4-3) is that 83% of all correlations were significant (α = 0.05), they were all positive, and nearly 50% of the correlations had a Kendall's τ >0.3. Any *significant* correlations with a high number of NDs (>80%, e.g., cadmium) should, however, be considered suspect. The highest correlation coefficient was 0.758 for chromium and cobalt.

Unlike limu, the crab data had far fewer significant correlations and there was one significant negative correlation between cadmium and chromium (Figure 4-4); there also were fewer cadmium NDs than with the limu. The single strongest positive correlation was between copper (Cu) and zinc (Zn) with a Kendall's τ = 0.436. As discussed previously, to equate Kendall's τ to Pearson's r, add 0.2 to positive correlations and subtract 0.2 from negative correlations. Therefore, in this case, the Kendall's τ between copper and zinc would be equivalent to a Pearson's r of about 0.6, and for cadmium and chromium, a Kendall's τ of -0.206 would be equivalent to a Pearson's r of -0.4. The strong positive correlation between copper and zinc in crabs is not altogether surprising given that the blood of crabs contains copper-based hemocyanin. As stated previously, according to White and Rainbow (1985), "… metabolically functional copper and zinc often make up significant proportions of the total content of these metals in molluscs [e.g., octopus] and crustaceans [e.g., Kona crab] from non-polluted environments, especially the open ocean." For example, crabs (as well as many other organisms) contain the copper- and zinc-based enzyme Cu/Zn-SOD, in addition to other copper- or zinc-based enzymes.

The correlation between copper and zinc was only slightly lower (Kendall's τ = 0.407) in the octopus (Table 4-5), another organism with copper-based hemocyanin and copper- and/or zinc-based enzymes. In addition to copper, zinc had coefficients >0.4 for cobalt and selenium. The strongest, significant negative correlation for octopus was between vanadium and chromium (Kendall's τ = -0.209).

The strongest, significant positive correlation in fish (Table 4-6) was also copper and zinc (Kendall's τ = 0.400). Although fish do not have copper-based hemocyanin in their blood, they do have the enzyme Cu/Zn-SOD which could explain, at least in part, this strong correlation between the two elements. The strongest, significant negative correlation in fish was between vanadium and chromium with a Kendall's τ = -0.245.

Table 4-3: Kendall's τ correlation matrix for pooled pre- and post-ROUMRS **limu** data from Ordnance Reef. Significant correlations (α = 0.05) are indicated with bold font; green indicates a positive correlation and red indicates a negative correlation.

Variable		As	Ba	Cd	Cr	Co	Cu	Pb	Ni	Se	Sr	U	V	Zn
As	τ		0.223	0.107	0.312	0.352	0.033	0.405	0.355	0.175	0.261	0.148	0.279	0.199
	p		0.013	0.062	0.001	0.000	0.717	0.000	0.000	0.021	0.004	0.027	0.002	0.027
	n		58	58	58	58	58	58	58	58	58	58	58	58
Ba	τ	0.223		0.100	0.442	0.366	0.291	0.480	0.391	0.304	0.494	0.287	0.450	0.198
	p	0.013		0.081	0.000	0.000	0.001	0.000	0.000	0.000	0.000	0.000	0.000	0.028
	n	58		58	58	58	58	58	58	58	58	58	58	58
Cd	τ	0.107	0.100		0.103	0.094	0.083	0.109	0.091	0.091	0.120	0.112	0.123	0.109
	p	0.062	0.081		0.072	0.103	0.147	0.057	0.115	0.057	0.037	0.007	0.032	0.057
	n	58	58		58	58	58	58	58	58	58	58	58	58
Cr	τ	0.312	0.442	0.103		0.758	0.334	0.698	0.676	0.399	0.636	0.238	0.615	0.193
	p	0.001	0.000	0.072		0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.033
	n	58	58	58		58	58	58	58	58	58	58	58	58
Co	τ	0.352	0.366	0.094	0.758		0.209	0.562	0.749	0.316	0.581	0.262	0.611	0.087
	p	0.000	0.000	0.103	0.000		0.021	0.000	0.000	0.000	0.000	0.000	0.000	0.337
	n	58	58	58	58		58	58	58	58	58	58	58	58
Cu	τ	0.033	0.291	0.083	0.334	0.209		0.394	0.321	0.188	0.459	0.143	0.273	0.439
	p	0.717	0.001	0.147	0.000	0.021		0.000	0.000	0.014	0.000	0.032	0.002	0.000
	n	58	58	58	58	58		58	58	58	58	58	58	58
Pb	τ	0.405	0.480	0.109	0.698	0.562	0.394		0.517	0.400	0.656	0.279	0.540	0.335
	p	0.000	0.000	0.057	0.000	0.000	0.000		0.000	0.000	0.000	0.000	0.000	0.000
	n	58	58	58	58	58	58		58	58	58	58	58	58
Ni	τ	0.355	0.391	0.091	0.676	0.749	0.321	0.517		0.263	0.546	0.255	0.469	0.088
	p	0.000	0.000	0.115	0.000	0.000	0.000	0.000		0.001	0.000	0.000	0.000	0.333
	n	58	58	58	58	58	58	58		58	58	58	58	58
Se	τ	0.175	0.304	0.091	0.399	0.316	0.188	0.400	0.263		0.379	0.226	0.339	0.153
	p	0.021	0.000	0.057	0.000	0.000	0.014	0.000	0.001		0.000	0.000	0.000	0.044
	n	58	58	58	58	58	58	58	58		58	58	58	58
Sr	τ	0.261	0.494	0.120	0.636	0.581	0.459	0.656	0.546	0.379		0.366	0.575	0.260
	p	0.004	0.000	0.037	0.000	0.000	0.000	0.000	0.000	0.000		0.000	0.000	0.004
	n	58	58	58	58	58	58	58	58	58		58	58	58
U	τ	0.148	0.287	0.112	0.238	0.262	0.143	0.279	0.255	0.226	0.366		0.236	0.091
	p	0.027	0.000	0.007	0.000	0.000	0.032	0.000	0.000	0.000	0.000		0.000	0.176
	n	58	58	58	58	58	58	58	58	58	58		58	58
V	τ	0.279	0.450	0.123	0.615	0.611	0.273	0.540	0.469	0.339	0.575	0.236		0.239
	p	0.002	0.000	0.032	0.000	0.000	0.002	0.000	0.000	0.000	0.000	0.000		0.008
	n	58	58	58	58	58	58	58	58	58	58	58		58
Zn	τ	0.199	0.198	0.109	0.193	0.087	0.439	0.335	0.088	0.153	0.260	0.091	0.239	
	p	0.027	0.028	0.057	0.033	0.337	0.000	0.000	0.333	0.044	0.004	0.176	0.008	
	n	58	58	58	58	58	58	58	58	58	58	58	58	

τ = Kendall's correlation coefficient; p = probability, if $p < \alpha = 0.05 \rightarrow$ correlation is significant; n = number of samples; **0.500** = significant positive correlation; **-0.500** = significant negative correlation

Table 4-4: Kendall's τ correlation matrix for pooled pre- and post-ROUMRS **crab** data from Ordnance Reef. Significant correlations (α = 0.05) are indicated with bold font; green indicates a positive correlation and red indicates a negative correlation.

Variable		As	Ba	Cd	Cr	Co	Cu	Se	Sr	Zn
As	*τ*		0.042	0.114	0.022	**0.289**	**0.239**	**0.227**	0.206	**0.247**
	p		0.696	0.214	0.842	**0.006**	**0.024**	**0.032**	0.053	**0.020**
	n		43	43	43	43	43	43	43	43
Ba	*τ*	0.042		-0.030	**0.251**	0.186	**0.212**	0.075	**0.350**	0.192
	p	0.696		0.749	**0.017**	0.075	**0.045**	0.478	**0.001**	0.069
	n	43		43	43	43	43	43	43	43
Cd	*τ*	0.114	-0.030		**-0.206**	**0.396**	0.127	0.053	0.033	0.061
	p	0.214	0.749		**0.024**	**0.000**	0.165	0.566	0.724	0.511
	n	43	43		43	43	43	43	43	43
Cr	*τ*	0.022	**0.251**	**-0.206**		-0.040	0.112	0.071	0.059	0.206
	p	0.842	**0.017**	**0.024**		0.711	0.294	0.508	0.585	0.052
	n	43	43	43		43	43	43	43	43
Co	*τ*	**0.289**	0.186	**0.396**	-0.040		**0.229**	**0.289**	0.165	0.204
	p	**0.006**	0.075	**0.000**	0.711		**0.030**	**0.006**	0.119	0.054
	n	43	43	43	43		43	43	43	43
Cu	*τ*	**0.239**	**0.212**	0.127	0.112	**0.229**		0.117	0.099	**0.436**
	p	**0.024**	**0.045**	0.165	0.294	**0.030**		0.271	0.357	**0.000**
	n	43	43	43	43	43		43	43	43
Se	*τ*	**0.227**	0.075	0.053	0.071	**0.289**	0.117		0.101	0.127
	p	**0.032**	0.478	0.566	0.508	**0.006**	0.271		0.345	0.232
	n	43	43	43	43	43	43		43	43
Sr	*τ*	0.206	**0.350**	0.033	0.059	0.165	0.099	0.101		0.142
	p	0.053	**0.001**	0.724	0.585	0.119	0.357	0.345		0.184
	n	43	43	43	43	43	43	43		43
Zn	*τ*	**0.247**	0.192	0.061	0.206	0.204	**0.436**	0.127	0.142	
	p	**0.020**	0.069	0.511	0.052	0.054	**0.000**	0.232	0.184	
	n	43	43	43	43	43	43	43	43	

τ = Kendall's correlation coefficient; ***p*** = probability, if ***p*** < ***α*** = 0.05 → correlation is significant; ***n*** = number of samples; **0.500** = significant positive correlation; **-0.500** = significant negative correlation

Table 4-5: Kendall's τ correlation matrix for pooled pre- and post-ROUMRS **octopus** data from Ordnance Reef. Significant correlations ($\alpha = 0.05$) are indicated with bold font; green indicates a positive correlation and red indicates a negative correlation.

Variable		As	Ba	Cd	Cr	Co	Cu	Pb	Se	Sr	V	Zn
As	τ		-0.015	**0.252**	0.069	**0.250**	**0.254**	-0.039	0.093	**0.233**	**-0.173**	**0.279**
	p		0.865	**0.001**	0.433	**0.002**	**0.004**	0.557	0.291	**0.008**	**0.015**	**0.002**
	n		61	61	61	61	61	61	61	61	61	61
Ba	τ	-0.015		0.042	0.143	0.026	0.019	0.002	-0.022	-0.073	-0.040	-0.013
	p	0.865		0.552	0.078	0.736	0.818	0.978	0.791	0.368	0.540	0.882
	n	61		61	61	61	61	61	61	61	61	61
Cd	τ	**0.252**	0.042		0.015	**0.462**	**0.420**	0.076	**0.299**	**0.221**	-0.089	**0.390**
	p	**0.001**	0.552		0.851	**0.000**	**0.000**	0.186	**0.000**	**0.003**	0.150	**0.000**
	n	61	61		61	61	61	61	61	61	61	61
Cr	τ	0.069	0.143	0.015		0.030	-0.048	-0.101	**-0.193**	0.133	**-0.209**	-0.063
	p	0.433	0.078	0.851		0.721	0.592	0.130	**0.027**	0.129	**0.003**	0.477
	n	61	61	61		61	61	61	61	61	61	61
Co	τ	**0.250**	0.026	**0.462**	0.030		**0.478**	0.091	**0.263**	**0.304**	-0.110	**0.434**
	p	**0.002**	0.736	**0.000**	0.721		**0.000**	0.142	**0.001**	**0.000**	0.096	**0.000**
	n	61	61	61	61		61	61	61	61	61	61
Cu	τ	**0.254**	0.019	**0.420**	-0.048	**0.478**		0.084	**0.347**	**0.286**	-0.078	**0.407**
	p	**0.004**	0.818	**0.000**	0.592	**0.000**		0.206	**0.000**	**0.001**	0.274	**0.000**
	n	61	61	61	61	61		61	61	61	61	61
Pb	τ	-0.039	0.002	0.076	-0.101	0.091	0.084		0.100	0.095	0.053	0.048
	p	0.557	0.978	0.186	0.130	0.142	0.206		0.131	0.154	0.326	0.471
	n	61	61	61	61	61	61		61	61	61	61
Se	τ	0.093	-0.022	**0.299**	**-0.193**	**0.263**	**0.347**	0.100		0.012	-0.009	**0.411**
	p	0.291	0.791	**0.000**	**0.027**	**0.001**	**0.000**	0.131		0.896	0.908	**0.000**
	n	61	61	61	61	61	61	61		61	61	61
Sr	τ	**0.233**	-0.073	**0.221**	0.133	**0.304**	**0.286**	0.095	0.012		-0.128	**0.213**
	p	**0.008**	0.368	**0.003**	0.129	**0.000**	**0.001**	0.154	0.896		0.070	**0.015**
	n	61	61	61	61	61	61	61	61		61	61
V	τ	**-0.173**	-0.040	-0.089	**-0.209**	-0.110	-0.078	0.053	-0.009	-0.128		-0.079
	p	**0.015**	0.540	0.150	**0.003**	0.096	0.274	0.326	0.908	0.070		0.270
	n	61	61	61	61	61	61	61	61	61		61
Zn	τ	**0.279**	-0.013	**0.390**	-0.063	**0.434**	**0.407**	0.048	**0.411**	**0.213**	-0.079	
	p	**0.002**	0.882	**0.000**	0.477	**0.000**	**0.000**	0.471	**0.000**	**0.015**	0.270	
	n	61	61	61	61	61	61	61	61	61	61	

τ = Kendall's correlation coefficient; p = probability, if $p < \alpha = 0.05$ → correlation is significant; n = number of samples; **0.500** = significant positive correlation; **-0.500** = significant negative correlation

Table 4-6: Kendall's τ correlation matrix for pooled pre- and post-ROUMRS **fish** data from Ordnance Reef. Significant correlations (α = 0.05) are indicated with bold font; green indicates a positive correlation and red indicates a negative correlation.

Variable		As	Ba	Cr	Co	Cu	Pb	Ni	Se	Sr	V	Zn
As	τ		-0.019	0.043	**0.161**	**-0.132**	0.083	0.034	**0.176**	-0.013	-0.006	-0.049
	p		0.752	0.477	**0.001**	**0.030**	0.123	0.411	**0.004**	0.834	0.905	0.423
	n		123	123	123	123	123	123	123	123	123	123
Ba	τ	-0.019		**0.153**	0.052	0.110	**0.151**	0.009	0.051	**0.215**	-0.028	0.085
	p	0.752		**0.010**	0.284	0.065	**0.001**	0.833	0.396	**0.000**	0.576	0.154
	n	123		123	123	123	123	123	123	123	123	123
Cr	τ	0.043	**0.153**		**0.115**	**0.220**	**0.153**	0.010	0.058	0.046	**-0.245**	**0.153**
	p	0.477	**0.010**		**0.019**	**0.000**	**0.004**	0.800	0.343	0.454	**0.000**	**0.012**
	n	123	123		123	123	123	123	123	123	123	123
Co	τ	**0.161**	0.052	**0.115**		0.054	**0.094**	0.046	**0.168**	0.043	-0.073	0.066
	p	**0.001**	0.284	**0.019**		0.275	**0.031**	0.162	**0.001**	0.388	0.082	0.180
	n	123	123	123		123	123	123	123	123	123	123
Cu	τ	**-0.132**	0.110	**0.220**	0.054		0.046	0.020	-0.021	0.101	-0.077	**0.400**
	p	**0.030**	0.065	**0.000**	0.275		0.391	0.630	0.726	0.098	0.132	**0.000**
	n	123	123	123	123		123	123	123	123	123	123
Pb	τ	0.083	**0.151**	**0.153**	**0.094**	0.046		0.002	**0.158**	**0.098**	-0.051	0.045
	p	0.123	**0.001**	**0.004**	**0.031**	0.391		0.940	**0.000**	**0.029**	0.143	0.317
	n	123	123	123	123	123		123	123	123	123	123
Ni	τ	0.034	0.009	0.010	0.046	0.020	0.002		0.054	0.003	-0.005	-0.020
	p	0.411	0.833	0.800	0.162	0.630	0.940		0.183	0.935	0.889	0.623
	n	123	123	123	123	123	123		123	123	123	123
Se	τ	**0.176**	0.051	0.058	**0.168**	-0.021	**0.158**	0.054		0.058	-0.072	0.027
	p	**0.004**	0.396	0.343	**0.001**	0.726	**0.000**	0.183		0.342	0.163	0.657
	n	123	123	123	123	123	123	123		123	123	123
Sr	τ	-0.013	**0.215**	0.046	0.043	0.101	**0.098**	0.003	0.058		**-0.112**	**0.303**
	p	0.834	**0.000**	0.454	0.388	0.098	**0.029**	0.935	0.342		**0.029**	**0.000**
	n	123	123	123	123	123	123	123	123		123	123
V	τ	-0.006	-0.028	**-0.245**	-0.073	-0.077	-0.051	-0.005	-0.072	**-0.112**		**-0.127**
	p	0.905	0.576	**0.000**	0.082	0.132	0.143	0.889	0.163	**0.029**		**0.014**
	n	123	123	123	123	123	123	123	123	123		123
Zn	τ	-0.049	0.085	**0.153**	0.066	**0.400**	0.045	-0.020	0.027	**0.303**	**-0.127**	
	p	0.423	0.154	**0.012**	0.180	**0.000**	0.317	0.623	0.657	**0.000**	**0.014**	
	n	123	123	123	123	123	123	123	123	123	123	

τ = Kendall's correlation coefficient; ***p*** = probability, if ***p*** < ***α*** = 0.05 → correlation is significant; ***n*** = number of samples; **0.500** = significant positive correlation; **-0.500** = significant negative correlation

Section 5 *Conclusions*

Under contract to NDCEE (operated by CTC), the UH Department of Oceanography and its subcontractor Environet conducted a nearly 3-year Follow-Up Investigation to evaluate whether the recovery of sea disposed military munitions from Ordnance Reef (HI-06) during the Army's ROUMRS technology demonstration had any impact on the concentrations of MC present in the environment. This was accomplished by comparing post-demonstration sampling results to those collected during UH's earlier investigation in 2009. To this end, sediments were sampled during and within a week following the summer 2011 ROUMRS demonstration (FUI1 – August 2011). These sediments were collected from four strata: DMM – an area where DMM were recovered during the ROUMRS demonstration, CON – a control area located away from the influence of the ROUMRS demonstration and away from other influences, NPS – an area influenced by nonpoint source pollution, and WWT – an area believed to be influenced by the discharge from the Wai'anae WWTP. We revisited Ordnance Reef (HI-06) during July 2012 (FUI2) and again sampled sediments from the four strata, as well as biota from the four strata. Finally, nearly 2 years after the ROUMRS demonstration, in June 2013 (FUI3), we once again sampled sediments and biota but this time limiting our sampling to the DMM and CON strata.

We collected sediment samples (consisting of clay, silt, and sand but no gravel); these samples were analyzed for major and minor elements in the laboratories of Eric De Carlo (UH Department of Oceanography); trace elements and energetics in these sediments were analyzed by a NELAP laboratory, TestAmerica West Sacramento. In addition to the sediments, we collected biota samples consisting of limu (seaweed), crabs, octopus, and fish. TestAmerica analyzed the biota for trace elements and energetics. In addition, subsamples were prepared by TestAmerica and shipped to Brooks Rand Laboratories to determine arsenic speciation (i.e., total, inorganic, and organic species).

This report presents the findings of this Follow-Up (post-ROUMRS) Investigation and compares the sediment and biota data with those of the 2009 UH OR (post-ROUMRS) Study. The data, some of which were multiply left-censored (i.e., less than multiple DLs), presented some challenges for statistical analysis. A common approach when dealing with NDs is to use some form of substitution (e.g., ½DL). This approach, however, can introduce what Helsel (2012) refers to as "invasive data" which can alter data patterns and lead to erroneous conclusions. With this in mind, we used statistical techniques that did not require substitution in order to calculate statistics.

A multivariate, nonparametric ordination technique (NMDS) was used to look for patterns in the data from the sediment and biota samples. The particular NMDS technique used does not rely on substitution but instead works with data that include what are called interval-censored data. When the result was above the RL (reporting level or quantitation limit), the value reported was used; for estimated ("J-flagged") data, the interval was between the DL and the RL; and for data below the DL, the interval was between 0 and the DL. Notice, in the latter two cases, we are reporting what is known, i.e., the values lie somewhere within the intervals but we are not forced to pick a single, arbitrary value such as ½DL.

Arguably the most important information to come out of NMDS was that certain elements (copper, zinc, lead, and magnesium) and, of course, the energetics were associated with the DMM. The copper and zinc were most likely associated with brass shell casings, lead with SAA slugs, and magnesium possibly with tracer rounds. The association of these elements and energetics with DMM was readily apparent in the NMDS plots, particularly after the samples were overlaid on the analytes in the plots. It was apparent that the DMM samples clustered with these analytes. This relationship held for both the pre- and post-ROUMRS sediment data. We tested the strength of the relationship between the analytes using another nonparametric statistical method, Kendall's τ correlation analysis again modified to accommodate multiply left-censored data. The Kendall's τ correlation coefficients between these elements were significant at $\alpha = 0.05$ and generally ranged from 0.3 to nearly 0.6 (roughly equivalent to a Pearson's r from 0.5 to 0.8).

NMDS and the correlation analysis also confirmed that arsenic was not associated with the munitions. In fact, the results of NMDS and the correlation analysis strongly suggested that the arsenic found in the sediments was associated with terrestrial runoff given that arsenic had a tendency to cluster with many of the petrogenic elements found in Hawaiian basalts (aluminum, chromium, iron, manganese, and vanadium) with Kendall's τ correlation coefficients >0.3 (roughly equivalent to a Pearson's $r = 0.5$).

As was quantified in Table 3-1, the terrestrial elements (aluminum, arsenic, chromium, iron, and vanadium) were generally higher in the samples from the CON stratum, regardless of whether they were collected pre- or post-ROUMRS. Likewise, the elements copper and zinc were highest in samples from the DMM stratum. Not surprisingly, with rare exception, energetics were found primarily in samples from the DMM stratum.

We pooled the sediment data into pre- and post-ROUMRS datasets and examined the distribution of selected analytes using censored boxplots for the DMM and CON strata. Using the interval-censored data previously described, we performed an analog to the generalized Wilcoxon test to see if there were significant differences at significance level $\alpha = 0.05$ between the pre- and post-ROUMRS data from the DMM stratum. We did find DMM associated analyte concentrations to be significantly lower in the post-ROUMRS data; however, we also found that the concentrations of analytes not associated with DMM also were significantly lower. Perhaps even more telling was the fact that many of the analytes in post-ROUMRS samples from the CON stratum also were significantly lower. Therefore, while we can say that post-ROUMRS analyte concentrations were significantly lower, we cannot necessarily attribute this to the ROUMRS technology demonstration.

The results of the biota sampling were, if anything, less clear. First, NMDS plots of the pre- and post-ROUMRS biota data showed that the data clustered by organism and, with the exception of the pooled pre- and post-ROUMRS limu data, not by stratum. Moreover, unlike the sediment data, there was no clear relationship between the analytes except for a consistent positive correlation between copper and zinc (Kendall's $\tau \geq 0.4$). We attributed this correlation to the existence of copper- and/or zinc-based enzymes in the organisms. Given the number of factors that control the chemistry of an organism (feeding habits, metabolism, maturity, etc.), this is not altogether surprising. Second, one additional pattern seen in the NMDS plot (Figure 4-12) lends credence to our approach and that was the fact that the crab data and octopus data both clustered near each other either as one mixed cluster (pre-ROUMRS) or two clusters near each other (post-ROUMRS) in the NMDS plot (Figure 4-12) and near copper in both cases. We attributed this to the fact that both organisms have copper-based hemocyanin in their blood.

Generally, differences in pre- and post-ROUMRS analyte concentrations in limu were not significant, particularly those analytes associated with DMM such as copper, lead, and zinc. Likewise, these elements were not significantly different in crabs but possibly any effect of copper would have been masked by the hemocyanin. Copper and zinc were significantly lower in post-ROUMRS octopus as was cobalt; chromium was significantly higher. Copper and zinc were significantly higher in post-ROUMRS fish but lead was significantly lower. Also, post-ROUMRS arsenic was lower but chromium was higher. So once again, while there were significant differences, the analytes were not consistently lower or higher in post-ROUMRS biota.

In summary, we did see significant differences between pre- and post-ROUMRS sediment and biota data. Nonetheless, it is difficult to say that these differences resulted from the ROUMRS technology demonstration and, in fact, the data suggest that there were other, unknown factors that may have contributed to these differences. While the sediment data did not explain the differences, it was apparent that sediment data are at least more consistent than biota data. On the other hand, the biota data need to be collected in order to determine what MC load might be ingested by humans. Other, more mobile organisms such as fish, while part of the local diet, may be less satisfactory as highly localized biomonitoring organisms.

Section 6
References

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Appendix A
Summary of Military Munitions

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Appendix D
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Appendix E
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Appendix G
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Appendix H
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Appendix I
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