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Mākua Marine Resources Supplemental Study Report

June 2015

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Abstract

This supplemental marine resources study is a follow-on assessment to the 2009 Marine Resources Study to further evaluate whether constituents potentially associated with military training at Mākua Military Reservation are present in samples of selected species of limu kohu (seaweed), he‘e (octopus), and loli (sea cucumber) found near Mākua Beach and relied on for subsistence by area residents. The selection of background sites and species to be sampled was conducted in accordance with the Settlement Agreement and in consultation with the community. The background sites and species were deemed suitable after the community had a chance to review and provide comments on the field sampling and analysis plan. This study includes an evaluation of the potential risks to human health based on the data and information collected during this study. Finally, this study has assessed the organic and inorganic fractions of arsenic present in limu kohu, he‘e, and loli.

A total of 144 samples were collected at Mākua and two background locations (Mokulē‘ia and Ka‘ena Point) during the dry and wet seasons. The samples were analyzed for the same 42 compounds analyzed in the original 2009 Marine Resources Study. The majority of the compounds were detected at similar levels in biota collected from near Mākua Beach compared to biota collected from the two background locations. These compounds are not unique to military training and are found at both Mākua and background locations; therefore, proposed military activities are anticipated to have little or no influence on contaminant levels within marine resources in the Mākua nearshore or muliwai areas.

A human health risk assessment conducted using some very conservative assumptions concluded that the total cumulative risks and hazards from consumption of a combination of all three biota types were within acceptable risk and hazard levels of concern for “average” consumers. In evaluation of individual species, there were no unacceptable levels of risk calculated for consumption of loli or he‘e at either the “average” or “high-end” consumption rate. The carcinogenic risk due to the consumption of limu kohu for both the “average” and “high-end” consumer exceeded regulatory levels of concern. In order to put this risk into further perspective, an individual would have to consume approximately two grams of limu

kohu collected only from Mākua Beach every day for 30 years in order to reach the regulatory level of concern. This level of consumption is highly unlikely, given that limu kohu at the study area is extremely scarce. This was corroborated during the sampling events and confirmed by a local fisherman at the public meeting. The risk from ingestion of limu kohu was driven primarily by two types of organochlorine pesticide: heptachlor and heptachlor epoxide. These two compounds were historically used in Hawai‘i in large quantities for commercial agriculture, commercial and domestic pest control, and lawn and garden services. Heptachlor and heptachlor epoxide may have been used in the region in the past, but their commercial use has been banned since 1988, they have not been used at Mākua Military Reservation in the interim, and they will not be used at Mākua Military Reservation in the future.

Compliance with the sustainable range program at Mākua Military Reservation and adherence to the long-term water quality monitoring program will minimize or prevent the introduction of trace amounts of heptachlor and heptachlor epoxide that may be present in soils at Mākua Military Reservation to marine resources at Mākua Beach. Because the source of heptachlor and heptachlor epoxide at Mākua Military Reservation has been eliminated and because implementation of best management practices will control the potential pathway for the introduction of residual heptachlor and heptachlor epoxide from Mākua Military Reservation to the marine resources at Mākua Beach, the proposed training activities are not anticipated to pose an increased risk to human health for area residents who rely on marine resources for subsistence.

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Contents

Abstract i

Figures and Tables v

Acronyms viii

Executive Summary xi

1 Introduction 1

1.1 Site description and history 1
1.2 Previous investigations 3
1.3 Objectives and scope of work 5

2 Field Sampling 7

2.1 Species of interest 7
2.2 Background locations and background samples 7
2.3 Other marine resources study sampling strategy 10
2.4 Field sampling methods 15
2.4.1 Sampling of Limu kohu 23
2.4.2 Sampling of He‘e 26
2.4.3 Sampling of Loli 28
2.5 Field sampling results 29
2.6 Sample preparation and handling 37
2.6.1 Limu kohu 40
2.6.2 He‘e 40
2.6.3 Loli 42

3 Analytical Chemistry 47

4 Analytical Chemistry Results 53

4.1 Mākua, Mokulē‘ia, and Ka‘ena Point 53
4.1.1 Volatile organic compounds (purgeable organics) 53
4.1.2 Semivolatile organic compounds 54
4.1.3 Organochlorine pesticides 56
4.1.4 Energetic compounds 58
4.1.5 Dioxins/dibenzofurans 60
4.1.6 Metals 62
4.1.7 Arsenic speciation 62
4.2 Comparison of Mākua results to background locations 67
4.2.1 Volatile organic compounds 68
4.2.2 Semivolatile organic compounds 68
4.2.3 Organochlorine pesticides 68
4.2.4 Energetic compounds 70

4.2.5 Dioxins/dibenzofurans *71*
4.2.6 Metals *72*
4.2.7 Arsenic speciation *75*
4.3 Data validation summary 79

5 Human Health Risk Assessment 80
5.1 Risk assessment results 82
5.1.1 2014 supplemental HHRA *82*
5.1.2 2009 HHRA *87*

6 Discussion and Conclusions 92
6.1 Discussion 92
6.1.1 Nature and extent of contamination *92*
6.1.2 Fate and transport *94*
6.1.3 Risk assessment *100*
6.2 Summary of HHRA from the 2009 study 101
6.3 Conclusions 102

References 111

Appendices (under separate cover)

Appendix A: Sample Collection Sheets

Appendix B: Limu Identification

Appendix C: Sample Collection List

Appendix D: Laboratory Reports

Appendix E: Data Validation Reports

Appendix F: Data Summary Table

Appendix G: Statistical Results

Appendix H: Analytical Data QA/QC Summary

Appendix I: Human Health Risk Assessment

Appendix J: Response to Comments

Figures and Tables

Figures

Figure 1. Location of the Mākua Military Reservation on the leeward side of O‘ahu. 1
Figure 2. Map of the Mākua Military Reservation showing the study area. 2
Figure 3. Limu Kohu. 8
Figure 4. He‘e. 8
Figure 5. Loli. 9
Figure 6. Background sampling locations in relation to Mākua Beach. 9
Figure 7. Scientists meeting with a local fisherman to review project sampling strategy. 11
Figure 8. View of the Mākua nearshore water facing northeast. 12
Figure 9. Local fisherman (project field team) on a fishing boat at Mākua nearshore water. 12
Figure 10. Orange buoy deployed within a Mākua sampling segment. 13
Figure 11. View of the Ka‘ena Point nearshore water facing south. 13
Figure 12. View of the Ka‘ena Point coastline facing north from the shore. 14
Figure 13. View of the Mokulē‘ia nearshore water facing south. 14
Figure 14. Mākua Study Area showing sampling transects. 16
Figure 15. Mokulē‘ia Study Area showing sampling transects. 17
Figure 16. Ka‘ena Point Study Area showing sampling transects. 18
Figure 17. Local fishermen snorkeling to search for samples at Mokulē‘ia during shoreline operations. 19
Figure 18. Local fishermen walking along Ka‘ena Point shoreline- in search of samples during shoreline operations. 20
Figure 19. Local fishermen searching for samples in a cove at Ka‘ena Point during shoreline operations. 20
Figure 20. Mobilizing from Wai‘anae Boat Harbor to the Mākua nearshore water on a fishing boat. 21
Figure 21. Local scuba diver with Hawaiian sling (3-prong spear) entering the water at Mākua. 21
Figure 22. View of reef shelf at Mākua during low tide facing southeast. 22
Figure 23. Documenting field information in a Sample Collection Sheet and recording sample locations on a GPS data logger. 23
Figure 24. Searching for limu kohu along a reef shelf at Mākua. 24
Figure 25. Collecting limu kohu with scissors from a Mākua reef shelf. 24
Figure 26. Short limu kohu growing on a shallow reef at Mokulē‘ia. 25
Figure 27. Double bagged limu kohu sample collected from Mākua. 25

Figure 28. Local scuba diver with a he‘e caught using a Hawaiian sling at Mokulē‘ia. 26
Figure 29. Local fisherman removing he‘e from a Hawaiian sling caught at Mokulē‘ia during shoreline operations. 27
Figure 30. Double bagged he‘e sample caught at Mokulē‘ia during shoreline operations. 27
Figure 31. Local scuba diver with a loli collected at Mākua. 28
Figure 32. Double bagged loli sample collected at Mokulē‘ia during shoreline operations. 29
Figure 33. 2013 Sample locations at Mākua. 30
Figure 34. 2013 Sample locations at Mokulē‘ia. 31
Figure 35. 2013 Sample locations at Ka‘ena Point. 32
Figure 36. 2014 Sample locations at Mākua. 33
Figure 37. 2014 Sample locations at Mokulē‘ia. 34
Figure 38. 2014 Sample locations at Ka‘ena Point. 35
Figure 39. Michael Kumukauoha Lee (third from left) instructing scientist how to process the loli sample. 38
Figure 40. Limu kohu to be rinsed with ultra pure water in the Class 100 laminar flow hood. 41
Figure 41. Processed limu kohu sample which is double bagged and labeled with a unique laboratory identification number. 41
Figure 42. He‘e to be processed in the Class 100 laminar flow hood. 42
Figure 43. Removing the he‘e beak and ink sac using a ceramic knife in the Class 100 laminar flow hood. 43
Figure 44. Scale used to weigh samples after they have been processed in the Class 100 laminar flow hood. 43
Figure 45. Loli prior to sample processing in the Class 100 laminar flow hood at the University of Hawai‘i laboratory. 44
Figure 46. Scraping off the skin of a loli using a ceramic knife in the Class 100 laminar flow hood. 45
Figure 47. Cutting loli lengthwise using a ceramic knife in the Class 100 laminar flow hood. 45
Figure 48. Removing the loli’s internal lining and organs using a disposable plastic spoon in the Class 100 laminar flow hood. 46

Tables

Table 1. Classes of compounds determined by each contract laboratory for this study. 48
Table 2. Estimated analytical reporting limits by method and contract laboratory. 49
Table 3. Summary of analytical results for volatile organic compounds. 54
Table 4. Summary of analytical results for semivolatile organic compounds. 55
Table 5. Summary of analytical results for organochlorine pesticides. 57

Table 6. Summary of analytical results for energetic compounds. 59
Table 7. Summary of analytical results for dioxins/dibenzofurans..... 61
Table 8. Summary of analytical results for metals. 63
Table 9. Summary of analytical results for arsenic speciation. 65
Table 10. Summary of risks and hazards, average consumer. 84
Table 11. Summary of risks and hazards, high-end consumer..... 85
Table 12. Summary of lead hazards..... 87
Table 13. Summary of the incremental carcinogenic risk for Mākua. 89
Table 14. Summary of the noncarcinogenic hazard for Mākua..... 90
Table 15. Summary of potential chemical sources and migration pathways.....103

Acronyms

25th ID (L)	25th Infantry Division (Light)
°C	Degrees Celsius
°F	Degrees Fahrenheit
%	Percent
%R	Percent Recovery
µg/dL	micrograms per deciliter
µg/kg	micrograms per kilogram
ARDL	Applied Research and Development Laboratory
ATSDR	Agency for Toxic Substances and Disease Registry
BHC	Benzene hexachloride
BTV	Background threshold value
CALFEX	Combined Arms Live-Fire Exercises
CDD	chlorinated dioxins
CDF	chlorinated dibenzofurans
COC	Chain-of-Custody
COPC	Chemicals of Potential Concern
CSM	Conceptual Site Model
CTE	Central Tendency
DNT	Dinitrotoluene
DoD	United States Department of Defense
EIS	Environmental Impact Statement
EPC	Exposure Point Concentrations
ERDC	US Army Engineer Research and Development Center
ERDC-ECB	ERDC Environmental Chemistry Branch
ft	Foot/Feet
g	Gram(s)

GPS	Global Positioning System
HDOH	State of Hawai‘i Department of Health
HEPA	high efficiency particulate absorption
HHRA	Human Health Risk Assessment
HPLC	High-performance liquid chromatography
ID	Infantry Division
IEUBK	Integrated Exposure Uptake Biokinetic
IQ	Hazard Quotient
in.	Inch (es)
m	Meter
MDL	Method Detection Limit
mg/kg	Milligrams per Kilogram
MMR	Mākua Military Reservation
mph	Miles per Hour
N/A	Not Applicable
ng/kg	Nanograms per Kilograms
NOAA	National Oceanic and Atmospheric Administration
PARCC	Precision, Accuracy, Representativeness, Comparability, and Completeness
PbB	Blood-Lead
PeCDD	Pentachlorodibenzo-p-dioxin
QA	Quality Assurance
QC	Quality Control
RDX	Cyclotrimethylenetrinitramine
RL	Reporting Limit
RME	Reasonable Maximum Exposure
SA	Settlement Agreement
SAP	Sampling and Analysis Plan
SV	Screening Value
TCDD	Tetrachlorodibenzo-p-dioxin

TEQ	Toxicity Equivalence Factors
UCL	Upper Confidence Level
U.S.	United States
USACE	U.S. Army Corps of Engineers
USARHAW	U.S. Army Hawai‘i
USEPA	U.S. Environmental Protection Agency
USFWS	U.S. Fish and Wildlife Service
UTL	Upper Tolerance Limits

Executive Summary

This supplemental marine resources study is a follow-on assessment to the 2009 Marine Resources Study (United States [U.S.] Army Hawai'i [USARHAW] and 25th Infantry Division [25th ID] Light (L) 2009) that was conducted to address the following objectives defined by the 2007 partial Settlement Agreement (SA) entered into by the Army and Mālama Mākua:

- Objective #1: To evaluate whether fish, shellfish, limu (marine algae), and other marine resources near Mākua or muliwai (estuaries or stream mouths), which area residents rely on for subsistence are contaminated by substances associated with proposed military training at Mākua;
- Objective #2: To evaluate whether there is a potential that activities at Mākua Military Reservation (MMR) have contributed or will contribute to contamination in fish, shellfish, limu, and other marine resources; and
- Objective #3: To evaluate whether the proposed training activities pose a human health risk to area residents who rely on marine resources for subsistence.

This supplemental marine resources study was designed to address the 20 June 2012 ruling for the Mālama Mākua vs. Robert Gates, Secretary of Defense and John McHugh, Secretary of the United States Department of the Army (U.S. District Court 2012). In summary, this ruling established the following two additional objectives:

- Objective #4: Complete one or more studies of limu and other marine resources (e.g., octopus and sea cucumber) near Mākua Beach on which Wai'anae Coast residents rely for subsistence (obtaining food as a means of maintaining life), in accordance with the terms and conditions set forth in paragraphs 6, 7, and 10 of the 2007 SA (U.S. District Court 2007).
- Objective #5: Specify in the study whether arsenic, if present in limu or other marine resources, is organic or inorganic and determine background contamination by testing limu and other marine resources at locations in Hawai'i other than Mākua Beach.

MMR consists of approximately 4,190 acres of land that was used by United States armed forces for infantry training since the 1920s. An evaluation of the risks to human health of area residents relying on marine resources for subsistence was conducted based on the data and information collected during this study as well as on results from earlier studies undertaken in the area.

Specific tasks undertaken during this study to satisfy the aforementioned objectives are as follows:

- To address deficiencies identified in the Court Order of 20 June 2012 (U.S. District Court 2012), collect data concerning chemicals of potential concern (COPCs) that may be present in samples of selected species of limu, he‘e, and loli found near Mākua Beach and relied on for subsistence by area residents.
- Evaluate based on this study and the 2009 Marine Resources Report whether the presence of chemical constituents and non-chemical constituents in those marine species are posing an unacceptable human health risk.

Collect samples of limu kohu, he‘e, and loli found near Mākua Beach during two seasons of the year (dry and wet), and analyze samples for the COPCs (Table 2).

- Assess the organic and inorganic fractions of arsenic present in limu kohu, he‘e, and loli.
- Conduct a human health risk assessment (HHRA) using data collected during this study to evaluate whether the constituents detected in the samples pose an unacceptable threat to human health.
- Conduct all aspects of the study in a transparent manner and inform the community of the study’s findings.

This supplemental marine resources study was performed in accordance with the sampling and analysis plan (SAP) (U.S. Army 2013). The SAP documented the purpose, scope of work, strategy, and methodology used to complete the study and satisfy the 2012 court ruling (U.S. District Court 2012). This ruling stated that the defendants shall complete one or more studies of limu and other marine resources (e.g., octopus and sea cucumber) near Mākua Beach, in accordance with the terms and conditions set forth in paragraphs 6, 7, and 10 of the 2007 SA

(U.S. District Court 2007). Accordingly, the SAP documented the selection of seafood items selected for sampling and analysis in accordance with the settlement agreement and in consultation with the community (i.e., he‘e, loli, and limu kohu).

He‘e, loli, and limu kohu samples were collected from the coastal waters off Mākua Beach (Mākua) and two background locations (Mokulē‘ia and Ka‘ena Point). These two sites were chosen as representative background locations because they are relatively close to Mākua Beach geographically and are in areas that have a greatly reduced potential for the presence of constituents commonly associated with military training activities. The background locations were selected in accordance with United States Environmental Protection Agency (USEPA) background site selection criteria (USEPA 2002a). Sampling was conducted in dry and wet seasons to account for seasonal variability. The dry season sampling event was conducted in September and October 2013 and the wet season sampling event was conducted in January through March 2014.

To optimize the available sampling windows of opportunity during the dry and wet season sampling events, two types of sampling operations were conducted by the field team. These include shoreline operations and boat-based operations. Shoreline operations consisted of walking along the shoreline using a global positioning system (GPS) to navigate to the sampling segments after which the local fishermen would search for the organisms by walking and by snorkeling along the given segment. Boat operations consisted of using a GPS to navigate to the sampling segment, after which the local fishermen scuba dived along the given segment to search for the organisms of interest. There were some instances when the divers deployed from the boat and walked or snorkeled to search for limu kohu along the water edge located within the segment being sampled, owing to the propensity of this seaweed to grow along rocks that are exposed during low tides. During the dry season, seven days of boat operations and four days of shoreline operations were conducted. During the wet season, four days of boat operations and two days of shoreline operations were conducted.

A total of 144 samples (i.e., eight he‘e, eight loli, and eight limu kohu samples at each of the three study areas, during both dry and wet season sampling events) were collected and the samples were analyzed for volatile organic compounds (including gasoline), semivolatile organic compounds,

organochlorine pesticides, dioxins/furans (17 congeners of concern), energetic compounds, and metals. The selection of analytes was based on the 2009 Marine Resource Study and the 2007 SA, Exhibit 2 - List of Chemicals for Marine Resources Study (i.e., the 'Foran List'). Specific to this assessment was an evaluation of both inorganic and organic forms of arsenic. The full list of analytes is provided in the main body of the report (Table 2).

Analytical chemistry results

Constituents that exceeded concentrations detected at the background locations (Mokulēʻia and Kaʻena Point) and also exceeded screening values (SVs) were carried forward for the supplemental HHRA. SVs were established in the site specific Final SAP (U.S. Army 2013) using methods described in the USEPA Fish Advisories. SVs are not cleanup standards and concentration values above the SVs do not necessarily indicate a hazard to human health.

Volatile organic compounds were not detected above the laboratory method detection limits (MDLs) and reporting limits (RLs) in any heʻe, loli, or limu kohu samples collected from the coastal waters of Mākua and the two background locations (Mokulēʻia and Kaʻena Point) during the dry and wet season sampling events. Volatile organic compounds, therefore, were of no further concern in this study.

Semivolatile organic compounds were not detected above the MDLs and RLs in any samples collected from the coastal waters of Mākua. One limu kohu sample collected from Mokulēʻia during the wet season sampling event and two heʻe samples collected from Kaʻena Point during the dry season sampling event contained concentrations of diethyl phthalate and bis(2-ethyl hexyl)phthalate, respectively (phthalates are compounds present in plastic items such as toys). These detections are well below the SVs. Semivolatile organic compounds, therefore, were of no further concern in this study.

Organochlorine pesticides (alpha-benzene hexachloride [BHC], heptachlor, and heptachlor oxide [pesticides in common use until 1988]) were detected at concentrations above the SVs in seven limu kohu samples collected from Mākua during the dry season sampling event. Alpha-BHC was also detected at concentrations above the SV in limu kohu samples collected from Mokulēʻia during the dry season and Kaʻena Point during the

wet season. Organochlorine pesticides were not detected above the MDLs or RLs in any he‘e or loli samples collected from either Mākua or the two background locations.

Energetic compounds, 2,4-dinitrotoluene (DNT), nitroglycerine, and Cyclotrimethylenetrinitramine (RDX), were not detected above the MDLs and RLs in any he‘e, loli or limu kohu sample collected from Mākua or the two background locations either during the dry or wet season sampling event. Perchlorate, an energetic compound used extensively in fireworks and as a component of solid rocket fuel (as ammonium) was detected in a single he‘e sample collected from Mākua during the dry season, in one he‘e (dry season) and 14 limu kohu samples (seven dry season and seven wet season) collected from Mokulē‘ia, and in five loli (one dry season and four wet season) and 10 limu kohu samples (five dry season and five wet season) collected from Ka‘ena Point. All of the detections were at levels far below the SV of 2,800 micrograms per kilogram µg/kg; therefore, energetic compounds were of no further concern in this study.

Dioxins/dibenzofurans were detected above the RLs in all samples except for three he‘e and one loli samples collected from the three study areas; total tetrachlorodibenzo-p-dioxin (TCDD) dioxin isomers and pentachlorodibenzo-p-dioxin (PeCDD) dioxin isomers were the only constituents that were detected at concentrations above the SVs. Total TCDD dioxin isomers were detected at concentrations above the SV in six he‘e, five loli, and seven limu kohu samples collected during the dry season from Mākua; one he‘e, seven loli, and eight limu kohu samples collected during the dry season from Mokulē‘ia; five he‘e, seven loli, and eight limu kohu samples collected during the dry season and one he‘e sample collected during the wet season from Ka‘ena Point. PeCDD dioxin isomers were detected at concentrations above the SV in a single he‘e sample collected from Mākua during the wet season.

Metals were detected in samples collected during both dry and wet seasons at Mākua and the two background locations, which is common as some of these elements are present in the biota (he‘e, loli, limu kohu) owing to biological requirements. Chromium is the only metal with detected concentrations above the SV in samples collected from Mākua and the two background locations. Except for the chromium concentration that exceeded the SV in a single loli sample collected during the dry season from Mākua, none of the chromium concentrations that exceeded the SV

in samples collected from Mākua were significantly higher than their respective counterpart samples collected from Mokulēʻia and Kaʻena Point. The two-sample comparison test results do not show any significantly greater mean concentrations of chromium between biota from Mākua and Mokulēʻia, or between biota from Mākua and Kaʻena Point. The concentrations observed in this study are comparable to what was found at the control site of the Ordnance Reef (HI-06) study (USACE 2014). The lower concentrations in limu kohu samples collected from Kaʻena Point likely reflect the fact that this area gets the lowest runoff of the three areas studied (from soil/volcanic rock fragments from which chromium in Hawaiʻi is commonly derived). Chromium (VI) is readily reduced to chromium (III) by marine organisms (Nakayama et al. 1981). Any chromium detected in biota tissues is thus highly likely to be the non-carcinogenic chromium (III) as opposed to chromium (VI).

Inorganic arsenic was not detected above the MDL in heʻe samples collected from any of the three sites. Loli samples, however, did generally contain some inorganic arsenic as well as organic arsenic, but there were no significant differences between Mākua and the two background locations. That limu kohu had the highest concentrations of inorganic arsenic and highest ratio of inorganic to total arsenic was anticipated as seaweed and other plants take up inorganic arsenic because of its structural similarity with the essential plant nutrient phosphate. Thus, the proportion of inorganic arsenic to organic arsenic is often higher in (marine) plants than in animals, in which most of the arsenic tends to occur in the organic form(s) (e.g., see Ordnance Reef (HI-06) Final Report [USACE 2014]). While all samples of limu kohu collected from Mākua, Mokulēʻia, and Kaʻena Point contained concentrations of inorganic arsenic that exceeded the SV of 0.0267 milligrams per kilogram (mg/kg), mean concentrations of inorganic arsenic in samples collected from Mākua are statistically less than or similar to the mean concentrations of samples collected from either of the two background locations. This indicates that military activities at MMR are anticipated to have little influence on arsenic levels within marine resources in the Mākua nearshore or muliwai areas.

Human Health Risk Assessment

A supplemental HHRA was conducted to characterize potential human health risks from exposures to biota collected from coastal waters off of Mākua Beach (Mākua). The study was not designed to assess cumulative risk from all species and exposure pathways; neither was it designed to

perform a comprehensive epidemiological study that evaluates cancer or hazard rates across different population demographics. Rather, the study was specifically designed to assess risks and hazards from the consumption of seafood items in accordance with the SA (i.e., he‘e, loli, and limu kohu). The supplemental HHRA used an extremely conservative approach in order to be health-protective. Seafood consumption rates used in the risk assessment were adopted from a seafood consumption survey conducted in 2010 for the Ordnance Reef (HI-06) study (USACE 2014), and are thus tailored for the communities who consume marine resources from Mākua Beach. The risk assessment was also based on the extremely conservative assumption that 100 percent (%) of the hypothetical consumer's seafood was from Mākua alone, whereas surveys of area residents indicate that a significant portion of their seafood intake comes from markets and nonlocal sources. This scenario was chosen to assess the worst-case scenario for seafood consumption along the Wai‘anae coast.

Biota samples that were collected from Mākua were first compared against samples collected from two background locations, which were assumed unimpacted by MMR (i.e., Mokulē‘ia and Ka‘ena Point). Chemical concentrations in biota at Mākua were also compared to conservative SVs. In accordance with the methodology established in the SAP (U.S. Army 2013), any contaminant with detected concentrations (maximum detected value) greater than both the conservative SVs and calculated background concentrations in either dry or wet sampling season was carried forward for quantitative analysis.

Seafood consumers are classified into two categories: "average" consumers (those assumed to consume an average of 130.81 grams (g) of seafood per day) and "high-end" consumers (those assumed to consume an average of 250.08 g of seafood per day). The total cumulative risks and hazards from the consumption of a combination of all three biota types (i.e., he‘e, loli, and limu kohu) were within acceptable risk and hazard levels of concern for "average" consumers.

In evaluation of individual species, there were no unacceptable levels of risk calculated for consumption of loli or he‘e at either the "average" or "high-end" consumption rate. Carcinogenic risk due to the consumption of limu kohu for both the current and future "average" or "high-end" seafood consumers exceeded the point of departure regulatory level of concern of 1×10^{-06} but was within the regulatory risk range of 1×10^{-06} to 1×10^{-04}. The

regulatory risk range corresponds to the added cancer risk from exposure to site chemicals above normal background cancer rates. For example, if excess risk is 1×10^{-06} then it is estimated that an additional 1 person in 1 million individuals (roughly the population of O'ahu island) *may* experience cancer. In order to put this risk into further perspective, an individual would have to consume approximately two grams of limu kohu collected only from Mākua Beach every day for 30 years in order to reach the regulatory level of concern of 1×10^{-05}. This level of consumption is extremely unlikely, given that limu kohu at the study area is extremely scarce. This was corroborated during the sampling events and actually confirmed by a local fisherman at the public meeting (Appendix J).

The carcinogenic risk due to the consumption of limu kohu was primarily driven by the organochlorine pesticides heptachlor and heptachlor epoxide. These two compounds have been widely used in Hawai'i in large quantities by pest control operators, lawn and garden services, pineapple growers, and homeowners for the control of termites and other pests. The use of these compounds was discontinued in 1988 when their commercial sale was banned (USGS 1998; USEPA 2006), but State of Hawai'i Department of Health (HDOH) has acknowledged that soil contaminated with heptachlor and heptachlor epoxide is highly likely to be present in areas where these pesticides were historically applied (HDOH 2014). Organochlorine pesticides may have been used in the region in the past, but the use of heptachlor and heptachlor epoxide has been discontinued since the 1980s, they have not been used at MMR in the interim, and they will not be used at MMR in the future. If organochlorine pesticides were excluded from this assessment, estimated carcinogenic risk and noncarcinogenic hazards would be below all applicable regulatory levels of concern.

This supplemental marine resource study provides the data and analysis necessary to answer the objectives established in the 2007 SA and the 20 June 2012 ruling:

- Objective #1: Evaluate whether fish, shellfish, limu (marine algae), and other marine resources near Mākua Beach or muliwai (estuaries or stream mouths), which area residents rely on for subsistence are contaminated by substances associated with proposed military training at Mākua.

Concentrations of COPCs in fish and shellfish were evaluated during the 2009 study; please refer to that study for detailed results.

This 2015 study determined that several compounds associated with proposed military training activities at Mākua were present in limu kohu, he‘e, and loli collected from near Mākua Beach. These compounds included semivolatile organic compounds, organochlorine pesticides, perchlorate, dioxins/dibenzofurans, metals, and arsenic (inorganic and organic). Of these compounds, only zinc, dimethyl arsenic, and organochlorine pesticides were present in biota collected from near Mākua Beach at concentrations significantly higher than in samples collected from the two background locations.

- Objective #2: Evaluate whether there is a potential that activities at MMR have contributed or will contribute to contamination in fish, shellfish, limu and other marine resources.

In accordance with the methodology established in the SAP (U.S. Army 2013), this study measured concentrations of COPCs in biota collected from near Mākua Beach and compared them to concentrations of COPCs in biota collected from two background locations to evaluate the potential contribution of those COPCs in marine resources that could have resulted from military training activities at MMR. This study also examined planned future training activities at MMR to assess whether they could contribute an increased level of COPCs to marine resources at Mākua Beach.

All the analytes (the suite of substances that the laboratory analyzed) have a wide range of natural and anthropogenic (man-made) sources. Examples include volatile organic compounds (fuels and gasoline), semivolatile organic compounds (plastics, such as toys), energetics (military munitions and commercial fireworks), organochlorine pesticides (commercial agriculture such as pineapple and sugarcane and commercial/domestic pest control), perchlorate (commercial fireworks), dioxins/dibenzofurans (byproducts of burning any wood or woody material), metals (volcanic rocks, cars/trucks, fenceposts), and arsenic (natural geologic origin).

In this study, the majority of the COPCs were detected at similar levels in biota collected from near Mākua Beach compared to biota collected from the two background locations. Compounds detected in biota during this study are not unique to military training and are found at both Mākua and

background locations; therefore, proposed military activities are anticipated to have little or no influence, either currently or in the future, on contaminant levels within marine resources in the Mākua nearshore or muliwai areas.

Three COPCs were present at significantly higher concentrations in biota collected from near Mākua Beach than in biota samples collected from the two background locations: zinc in heʻe, dimethyl arsenic in limu kohu, and two types of organochlorine pesticides in limu kohu (heptachlor and heptachlor epoxide). The concentrations of zinc in heʻe did not exceed the screening value and dimethyl arsenic has no screening value, thus neither compound advanced to risk assessment and neither is of further concern in this study. Organochlorine pesticides may have been used in the region in the past, but the use of heptachlor and heptachlor epoxide has been banned since 1988, they have not been used at MMR in the interim, and they will not be used at MMR in the future.

There is some potential for past and future release of substances from military training activities at MMR. The low levels of most substances detected during this investigation supports the position that 60 years of live-fire training has not resulted in significant detectable levels of most substances in the area. Future monitoring will confirm this after live fire resumes. For those substances detected at higher levels, their occurrence in the area cannot uniquely be attributed to military activities because there are and have been many natural and anthropogenic sources that contribute substances to the Mākua area. The proposed training activities at MMR aren't anticipated to use additional types or quantities of munitions or equipment compared to what has been used historically, thus there is no anticipated increase in the potential sources or relative quantities of COPCs from MMR. Proposed training activities at MMR will be closely managed under a sustainable range program that will ensure that training activities do not introduce significant levels of energetics into the soil and will also employ Best Management Practices to control potential soil runoff or fugitive dust releases from the range. The Army will also conduct a long-term water quality monitoring program to assess current and future water quality. A monitoring program will provide the Army with another tool to evaluate potential pathways for substances to migrate beyond the boundaries of MMR. Compliance with the sustainable range program at MMR and adherence to the long-term water quality monitoring program will minimize or prevent the introduction of trace amounts of

COPCs from MMR to marine resources at Mākua Beach. By limiting the sources of potential COPCs to be used at MMR and by controlling the potential pathway for the introduction of potential COPCs from MMR to the marine resources at Mākua Beach, the proposed training activities are not anticipated to contribute to contamination in fish, shellfish, limu and other marine resources.

- Objective #3: Evaluate whether the proposed training activities pose a human health risk to area residents who rely on marine resources for subsistence.

The Army conducted a human health risk assessment in 2009 to evaluate potential risks to area residents who consume fish, shellfish, other marine resources, and limu from Mākua Beach. The 2009 human health risk assessment concluded that: "based on the general similarity of carcinogenic and noncarcinogenic health risks between the Mākua area and the background sites, it is apparent that the Army's past activities at MMR are not independently responsible for any human health risks from the substances detected in marine resources. Considering the level of substances found within the Mākua area, the numerous sources with which these substances are associated, and the ability of these substances from multiple sources to be transported by rain flow and ocean currents, it is not likely that future activities at MMR alone would contribute substances to the marine environment at a level sufficient to cause a human health risk." Refer to the 2009 study for additional details.

This 2015 study further evaluated potential human health risks to area residents who consume limu kohu, he'e, and loli from Mākua Beach. The methodology used for the 2014 risk assessment was incredibly conservative in its approach. Key points included the use of community-specific seafood consumption rates for average and high-end consumers, an assumption that 100% of the seafood consumed came from Mākua. The supplemental HHRA concluded that the total combined risk from the consumption of a combination of all three biota types (i.e., loli, he'e, and limu kohu) were within acceptable risk and hazard levels of concern for "average" consumers. In evaluation of individual species, there were no unacceptable levels of risk calculated for consumption of either loli or he'e at either the "average" or "high-end" consumption rate. The HHRA found that carcinogenic risk due to the consumption of limu kohu for both the "average" and "high-end" consumer exceeded regulatory levels of concern.

In order to put this risk into further perspective, an individual would have to consume approximately two grams of limu kohu collected only from Mākua Beach every day for 30 years in order to reach the regulatory level of concern of 1×10^{-05}.

The risk was primarily driven by two types of organochlorine pesticides: heptachlor and heptachlor epoxide. As discussed above, organochlorine pesticides may have been used in the region in the past, but the use of heptachlor and heptachlor epoxide has been banned since 1988, they have not been used at MMR in the interim, and they will not be used at MMR in the future. Proposed training activities at MMR will also employ Best Management Practices to control potential soil runoff or fugitive dust releases from the range. The Army will also conduct a long-term water quality monitoring program to assess current and future water quality. A monitoring program will provide the Army with another tool to evaluate potential pathways for substances to migrate beyond the boundaries of MMR. Compliance with the sustainable range program at MMR and adherence to the long-term water quality monitoring program will minimize or prevent the introduction of trace amounts of organochlorine pesticides that may be present in soils at MMR to marine resources at Mākua Beach. Because the use of organochlorine pesticides at MMR has been eliminated and because implementation of Best Management Practices will control the potential pathway for the introduction of residual organochlorine pesticides from MMR to the marine resources at Mākua Beach, the proposed training activities are not anticipated to pose an increased risk to human health to area residents who rely on marine resources for subsistence.

Further, on authorization to resume live-fire training at MMR, the Army would evaluate the potential impacts from the proposed training by conducting a long-term monitoring program to detect if there is a potential for substances to migrate off the installation and into the Mākua nearshore and muliwai areas. If a substance were identified during monitoring, the Army would conduct further analysis to verify the detection. If the identified substance were detected above the USEPA acceptable risk level, then the Army would take appropriate action to correct the situation and eliminate or minimize the potential for the substance to be released into the muliwai or nearshore areas of Mākua.

- Objective #4: Complete one or more studies of limu and other marine resources (e.g., octopus and sea cucumber) near Mākua Beach on which Waiʻanae Coast residents rely for subsistence (obtaining food as a means of maintaining life), in accordance with the terms and conditions set forth in paragraphs 6, 7, and 10 of the 2007 SA (U.S. District Court 2007).

This supplemental marine resource study included the collection of two rounds of samples from the ocean area adjacent to Mākua Beach, as well as from two background locations established in the SAP. This objective has thus been satisfied.

- Objective #5: Specify in the study whether arsenic, if present in limu or other marine resources, is organic or inorganic and determine background contamination by testing limu and other marine resources at locations in Hawaiʻi other than Mākua Beach.

This study included the speciation of arsenic into inorganic and organic forms, and established background concentrations by testing limu and other marine resources at locations in Hawaiʻi other than Mākua Beach. There were no statistically significant differences in concentrations of total arsenic or total inorganic arsenic (the more toxic form of arsenic) in biota samples collected from near Mākua Beach when compared to the two background locations. There was a statistically significant difference in the average concentration of dimethyl arsenic in limu kohu collected from Mākua compared to the background locations. Dimethyl arsenic is an organic form of arsenic that is not considered to be toxic, thus this compound has no screening value, and its elevated concentration in limu kohu samples collected from near Mākua Beach compared to the two background locations is considered to be of no concern in this study.

In summary, this study has provided the data and analyses necessary to satisfactorily answer the objectives established in the 2007 SA and the 2012 court ruling and these studies were performed in accordance with the terms and conditions set forth in paragraphs 6, 7, 10 of the 2007 SA. In this study, the majority of the COPCs were detected at similar levels in biota collected from near Mākua Beach compared to biota collected from the two background locations. Compounds detected in biota during this study are not unique to military training and are found at both Mākua and background locations; therefore, proposed military activities are antici-

pated to have little influence, either currently or in the future, on contaminant levels within marine resources in the Mākua nearshore or muliwai areas. While the HHRA found that carcinogenic risk due to the consumption of limu kohu for both the “average” and “high-end” consumer exceeded regulatory levels of concern, the primary risk driver was two types of organochlorine pesticides, heptachlor and heptachlor epoxide (now banned from commercial sale) that may have been used in the region of the past but are not currently used at MMR and will not be used at MMR in the future. Because there is not a current or future source of these two organochlorine pesticides at MMR and because implementation of Best Management Practices will control the potential pathway for the introduction of residual heptachlor/heptachlor epoxide from MMR to the marine resources at Mākua Beach, the proposed training activities are not anticipated to pose an increased risk to human health to area residents who rely on marine resources for subsistence.

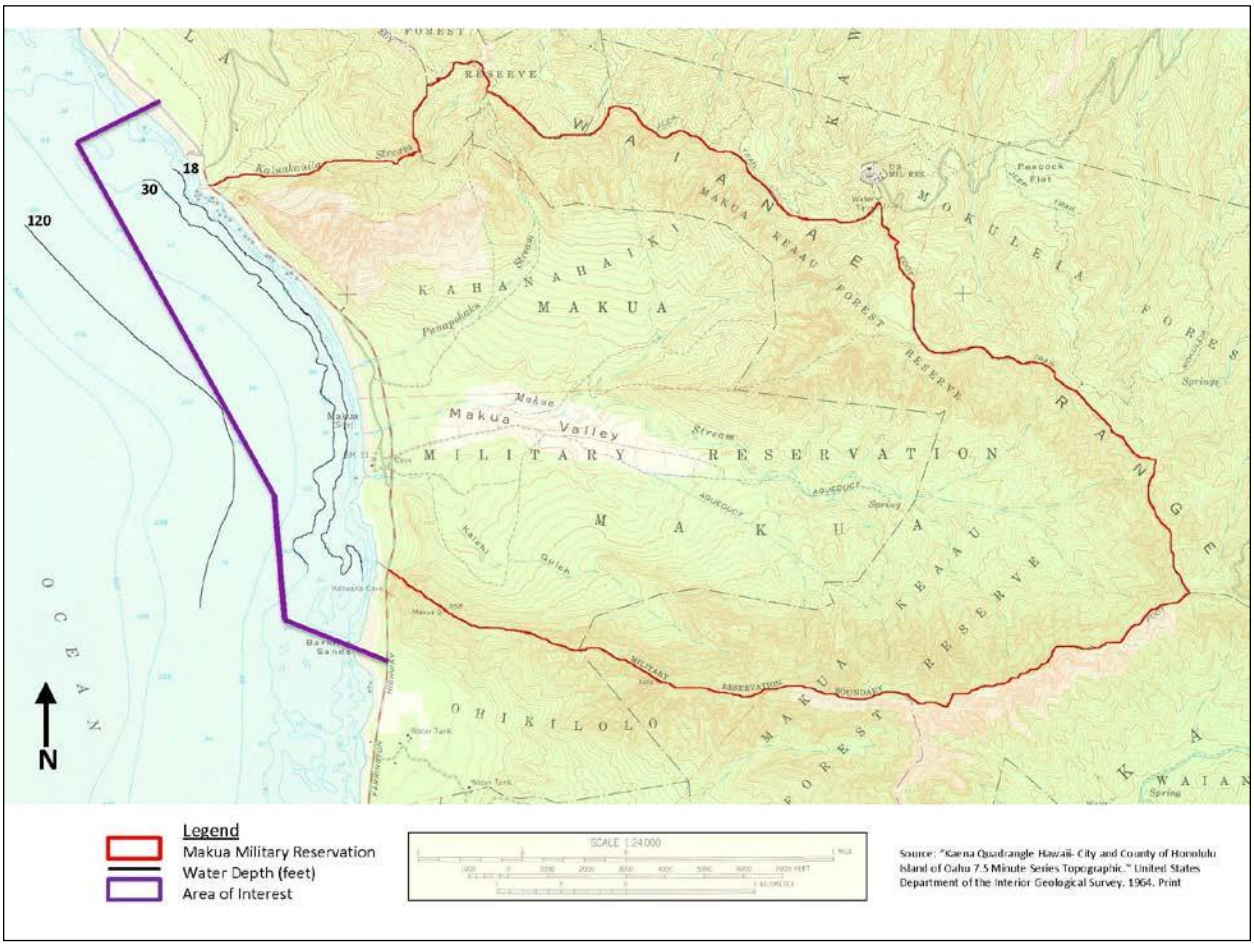
1 Introduction

1.1 Site description and history

Mākua Military Reservation (MMR) is approximately 38 miles northwest of Honolulu, on the leeward side of O‘ahu in the Mākua and Kahanahāiki valleys (Figures 1 and 2). MMR is bordered on the west by the Farrington Highway and extends mauka (inland) to the ridge of the Wai‘anae Mountains. The nearest township is Mākaha, approximately three miles south.

Figure 1. Location of the Mākua Military Reservation on the leeward side of O‘ahu.

Figure 2. Map of the Mākua Military Reservation showing the study area.



The installation encompasses almost 4,190 acres with annual rainfall ranging around 50 inches (in.) toward the head of the valley to less than 15 in. at the mouth of the valley (Giambelluca, Nullet, and Schroeder 1986). The high precipitous valley walls surrounding the installation reach heights of 2,100 to 2,900 feet (ft). The broad range in rainfall and topography results in a diversity of vegetation types within the valley.

Use of Mākua Valley by U.S. armed forces dates back to the 1920s when three parcels on the upper Mākua Valley floor were purchased for howitzer emplacements. After the bombing of Pearl Harbor in 1941, the Army used its authority under martial law to take over the entire Mākua-Ka‘ena Point area for security and training. In 1942, the Army issued a real estate directive for 6,600 acres of land at Mākua that were already being used.

Private parcels within the property were obtained by condemnation, whereas territorial lands were conferred by the territorial governor’s

consent. In 1943, the territorial government granted a revocable permit for the military to use 6,600 acres, "to assist in the present war effort extending for the duration of the present war and six months thereafter." The site was used for infantry training, but no records of munitions expended on Mākua were kept. Mākua has remained under Army control ever since. After Hawai'i was granted statehood in 1959, the federal government exercised its option to set aside lands for its continued use.

1.2 Previous investigations

On 4 October 2001, Mālama Mākua and the U.S. Department of Defense (DoD) entered into a Settlement Agreement and Stipulated Order (referred to herein as the Settlement Agreement [U.S. District Court 2001]). The 25th ID agreed to complete an Environmental Impact Statement (EIS) regarding the proposal to resume live-fire training at MMR. Under the terms of the Settlement Agreement, the Army could conduct a limited number of Combined Arms Live-Fire Exercises (CALFEX) for up to three years (through October 2004). In October 2004, the Army started preparing the EIS required under the Settlement Agreement and has since only conducted limited, nonlive-fire training at MMR. On 8 January 2007, Mālama Mākua and the DoD entered into a partial Settlement Agreement (referred to herein as the 2007 SA [U.S. District Court 2007]), in which the 25th ID agreed to undertake a marine resources study to evaluate if the marine resources near MMR were impacted by military training.

The Army conducted a marine resources study to evaluate whether marine resources (i.e., fish, shellfish and other invertebrates, and seaweed) near Mākua Beach and in the Mākua *muliwai* (temporary brackish water pond) bioaccumulate constituents (e.g., energetic compounds and some metals) associated with proposed training activities at MMR. In addition to evaluating chemicals that are associated with military training, that study also included the analysis of a wide variety of constituents, including energetic compounds, dioxins/furans, metals, organochlorine pesticides, volatile organic compounds, and semivolatile organic compounds. That study also evaluated whether the proposed training activities at MMR pose a human health risk to area residents from the consumption of marine resources for subsistence. The results of the marine resources study were published by the Army as the "Marine Resources Study, Field Sampling Results and Risk Assessment, Mākua Military Reservation, O'ahu, Hawai'i" (USARHAW and 25th ID (L) 2009), which is referred to as the "2009 Marine Resources Study." That report identified a number of constituents

in fish, shellfish and other invertebrates, and limu that were detected during analysis and are also known to be associated with the type of military training being proposed at MMR. These constituents were RDX (cyclotrimethylenetrinitramine), perchlorate, arsenic, chromium, cobalt, nitroglycerin, and manganese. While other detected analytes may be associated with military training as well as civilian and industrial activities, these were the analytes for which potential health risks were believed to exist. The 2009 Marine Resources Study concluded that although these and other constituents may have been associated with military training at MMR; all except RDX were also linked to geologic (e.g., volcanic rock) and anthropogenic (i.e., human) sources (e.g., fireworks, rodenticides, medication, and gasoline). A comparison of the site data with the available background data showed little if any difference between constituents found in the Mākua area and the background locations. It was concluded that constituents identified for analysis by the Settlement Agreement are not unique to military training and are found at both Mākua and background locations; therefore, it was submitted that proposed military activities were anticipated to have little influence on contaminant levels in marine resources in the Mākua nearshore or muliwai areas.

The 2009 Marine Resources Report concluded that the target species of fish, shellfish and other invertebrates, and limu investigated were adequate representatives of the marine resources within the Mākua area. It was suggested that other species occupying trophic levels and ecological niches similar to the target species would contain similar concentrations as those reported for the target species.

In addition, based on the general similarity of carcinogenic and noncarcinogenic health risks from marine resources between the Mākua area and the background locations, it was apparent that the Army's past activities at MMR were not independently responsible for human health risks from the constituents detected in marine resources. Considering the concentrations of constituents found in the Mākua area, the numerous possible sources of these constituents, the mobility of these constituents and the fact that they can originate from multiple sources, the report concluded that it was unlikely that future military activities at MMR would cause unacceptable risk to human health.

1.3 Objectives and scope of work

The 20 June 2012 ruling states that the Defendants (the U.S. Army) shall:

- Complete one or more studies of limu and other marine resources (e.g., heʻe [octopus] and loli [sea cucumber]) near Mākua Beach on the Waiʻanae Coast where residents rely on these resources for subsistence.
- Specify whether arsenic in the limu or other marine resources is organic or inorganic.
- Determine background contamination by testing limu and other marine resources.

As a result of the above ruling, marine resources were sampled in the near-shore waters of the Pacific Ocean just west of the MMR as part of this study. They represent marine resources that were not sampled in the 2009 Marine Resources Study and were evaluated via public input to be significant to the local community. Additional marine resources were also sampled from two nearby background locations on Oʻahu that are not expected to have been impacted by activities at MMR, as detailed below.

The objective of this study was to investigate whether constituents potentially associated with military training are present in samples of target species of limu, heʻe, and loli found near Mākua Beach and relied on for subsistence by area residents. An evaluation of the risks to human health was also conducted based on the data and information collected during this study as well as on results from earlier studies undertaken in the area (Section 5).

This study also assessed the organic and inorganic fractions of arsenic present in limu, heʻe, and loli. These objectives satisfy the Court Order of 20 June 2012.

Specific project objectives were:

- To address deficiencies identified in the Court Order of 20 June 2012 (U.S. District Court 2012), collect data concerning COPCs that may be present in samples of selected species of limu, heʻe, and loli found near Mākua Beach and relied on for subsistence by area residents.

- Determine based on this study and data in the 2009 Marine Resources Report whether the presence of chemical constituents and non-chemical constituents in those marine species are posing an unacceptable human health risk (Section 5).
- Collect samples of limu, he‘e, and loli found near Mākua Beach during two seasons of the year (dry and wet), and analyze samples for the COPCs (Table 2).
- Determine the organic and inorganic fractions of arsenic present in limu and other marine resources.
- Conduct a HHRA using data collected during this study and applicable data from prior studies to determine whether the constituents detected in the samples pose an unacceptable threat to human health.
- Conduct all aspects of the study in a transparent manner and inform the community of the study’s findings.

2 Field Sampling

2.1 Species of interest

A list of species of interest was created based on surveys and discussions with local residents from the Waiʻanae Coast, regional commercial fisherpersons, local recreational fisherpersons, area divers, and spear fisherpersons. In addition, information collected using a survey distributed throughout the Waiʻanae Coast resulted in a variety of helpful information that included 21 online surveys, two surveys submitted by mail, as well as eight surveys, and five personal interviews from the "talk story" meeting as well as the public and information meetings listed above. This information provided by the community was used to develop the list of limu and invertebrates identified by island residents as food sources collected in the nearshore waters of Mākua and considered for sampling for the supplemental marine resources study (U.S. Army 2013). Fish were not targeted for sampling in the supplemental marine resources study because four species of fish from the nearshore area and four species of fish from Mākua were analyzed and evaluated in the 2009 Marine Resources Study. Based on the information obtained from the public and results from preliminary surveys (U.S. Army 2013), target species for sampling were the limu kohu, (seaweed, *Asparagopsis taxiformis*), the heʻe (day octopus, *Octopus cyanea*), and the loli (black sea cucumber, *Holothuria atra*) (Figures 3 through 5).

2.2 Background locations and background samples

To provide data that could be compared to those obtained from biota collected at Mākua, two background locations were selected. Sampling for this purpose was conducted at two locations along the north shore of Oʻahu: Mokulēʻia and Kaʻena Point (Figure 6).

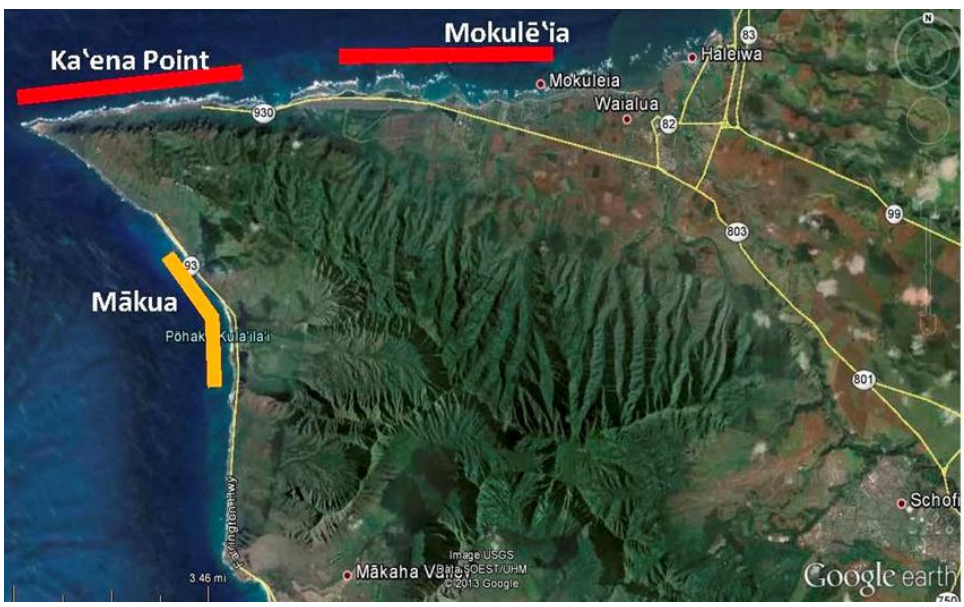
These two sites were chosen as representative background locations because they are relatively geographically close to Mākua and are in areas that have a very low potential for the presence of constituents commonly associated with military training activities. These areas have comparable ocean currents (although currents may vary in strength between the locations) and wave regimes generally similar to those observed at Mākua

Figure 3. Limu Kohu.

Figure 4. He‘e.

Figure 5. Loli.

Figure 6. Background sampling locations
in relation to Mākua Beach.



Beach. These background locations were selected in accordance with USEPA background site selection criteria (USEPA 2002a; 2002b).

Guidance for selection of background locations is provided by the USEPA. "A background reference area, or control site, is the area where background samples will be collected for comparison with the samples collected on the site. A background reference area should have the same

physical, chemical, geological, and biological characteristics as the site being investigated, but has not been affected by activities on the site" (USEPA 1989). USEPA (1989) further states that "the locations of the background samples must be areas that could not have received contamination from the site, but that do have the same basic characteristics as the medium of concern at the site."

USEPA (2002b) states that, "The ideal background reference area would have the same distribution of concentrations of the chemicals of concern as those which would be expected on the site if the site had never been impacted. In most situations, this ideal reference area does not exist. If necessary, more than one reference area may be selected if the site exhibits a range of physical, chemical, geological, or biological variability. Background reference areas are normally selected from off-site areas, but are not limited to natural areas undisturbed by human activities."

Each island in the Hawaiian Archipelago has its own unique currents and oceanographic conditions as well as certain minor but potentially important differences in the chemical composition (particularly in case of trace element compositions) of the lavas that constitute the shoreline and extend onto the ocean floor; therefore, it is most appropriate to select background locations on the same island as close in proximity as possible to MMR, but without the impact of military training. In addition, Kaʻena Point and Mokulēʻia are largely rural areas similar to Mākua Beach. These two locations represent suitable background locations on Oʻahu and samples collected in these areas are referred to as background samples for this study.

2.3 Other marine resources study sampling strategy

The sampling strategy involved collection of other marine resources consumed by the local community along the length of Mākua Beach and two background locations. This involved the initial identification of the target species though discussions with members of the local community and fishermen. The proposed sampling areas were surveyed to verify that the target species were present in sufficient numbers to support the sampling effort. The selected species and local preparation methods were then reviewed by many key individuals and groups; their interest and involvement enabled the team to ensure that the primary concerns of the community were identified and could be considered during the planning phase of the study. The study team was able to continue involving community

members during the fieldwork phase of the study by incorporating the aid of local fishermen to collect biota samples. This participation provided a wealth of local knowledge and fishing expertise to the study team. A pre-fieldwork planning meeting was held with the local fisherman and scientists to review the project sampling strategy (Figure 7). The field team consisted of a team of local fishermen and project scientists.

Figure 7. Scientists meeting with a local fisherman to review project sampling strategy.

Nearshore habitats were sampled by the team of local fishermen. Samples of the target species of limu kohu, heʻe, and loli were collected in the nearshore waters of Mākua Valley (Figures 8 through 10), Kaʻena Point (Figures 11 and 12), and Mokulēʻia (Figure 13) from areas of the shoreline down to depths necessary for the collection of the target number or mass of specimens.

The sampling strategy for each location, Mākua, and the two background locations at Mokulēʻia, and Kaʻena Point, was to collect samples from a wide spatial distribution. For this effort, the entire length of shoreline at each study area was broken up into 656-ft- (200-meter [m]-) wide segments (transects), perpendicular to the shore. Each segment was assigned a number, and the order of sampling of the various segments was

Figure 8. View of the Mākua nearshore water facing northeast.

Figure 9. Local fisherman (project field team) on a fishing boat at Mākua nearshore water.

Figure 10. Orange buoy deployed within a Mākua sampling segment.

Figure 11. View of the Ka‘ena Point nearshore water facing south.

Figure 12. View of the Ka‘ena Point coastline facing north from the shore.

Figure 13. View of the Mokulē‘ia nearshore water facing south.

determined using a computer based random number generator. This strategy allowed for a wide geographic region to be sampled and reduced potential bias in the sampling. The Mākua region was divided into seventeen 656-ft- (200-m-) wide segments (Figure 14). Both the Mokulēʻia (Figure 15) and Kaʻena Point (Figure 16) regions were each divided into twenty-six 656-ft- (200-m-) wide segments.

The random number generator was used to select the order of the first eight segments, and subsequent segments as necessary based on meeting the number and amount of each species collected, from the 17, 26, and 26 segments for Mākua, Mokulēʻia, and Kaʻena Point, respectively. The field team collected the target species across sampling areas from the first randomly selected eight sampling segments, and subsequently from other segments as necessary, at each of the study locations. This work was completed in accordance with the approved 2013 Final SAP (U.S. Army 2013).

Sampling was conducted within selected segments from the shoreline out to sea and down to a maximum depth of no more than 125 ft (38 m).

To obtain statistically representative samples, a collection goal of eight replicate samples of each of the target species was set for collection at each of the three sampling areas once during the dry season and a second time during the wet season. This level of sampling allowed for a sufficient number of samples for calculation of average concentrations of the COPCs in target species with a sufficient level of confidence necessary for a HHRA. Tissue mass in excess of 200 g for each replicate sample was targeted to obtain sufficient material for all required analyses and laboratory batch quality assurance (QA)/quality control (QC) (i.e., matrix spikes and matrix spike duplicates).

2.4 Field sampling methods

Sampling was conducted during two seasons. The first, in September and October 2013, represented conditions that exist during and towards the end of the calm and dry season (summer) and the second, from January through March 2014, represented the conditions that exist during the highly active wave and wet season (winter). Because wintertime on the west and north coasts of Oʻahu usually brings open ocean wave swells traveling from the North Pacific and traveling across the ocean from the northwest through north to northeast directions and can result in large and dangerous wave conditions, daily weather and wave condition

Figure 14. Mākua Study Area showing sampling transects.

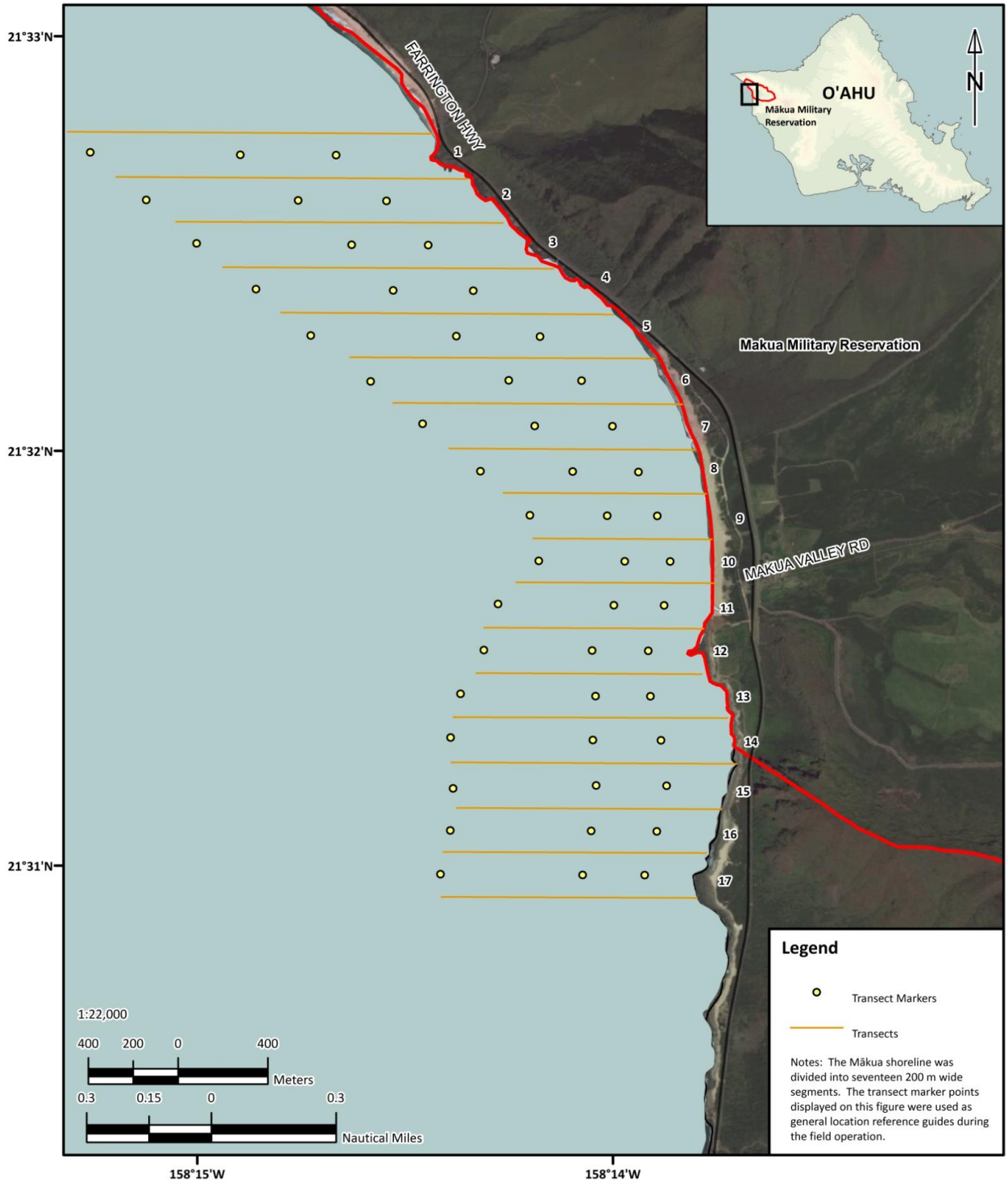


Figure 15. Mokulēʻia Study Area showing sampling transects.

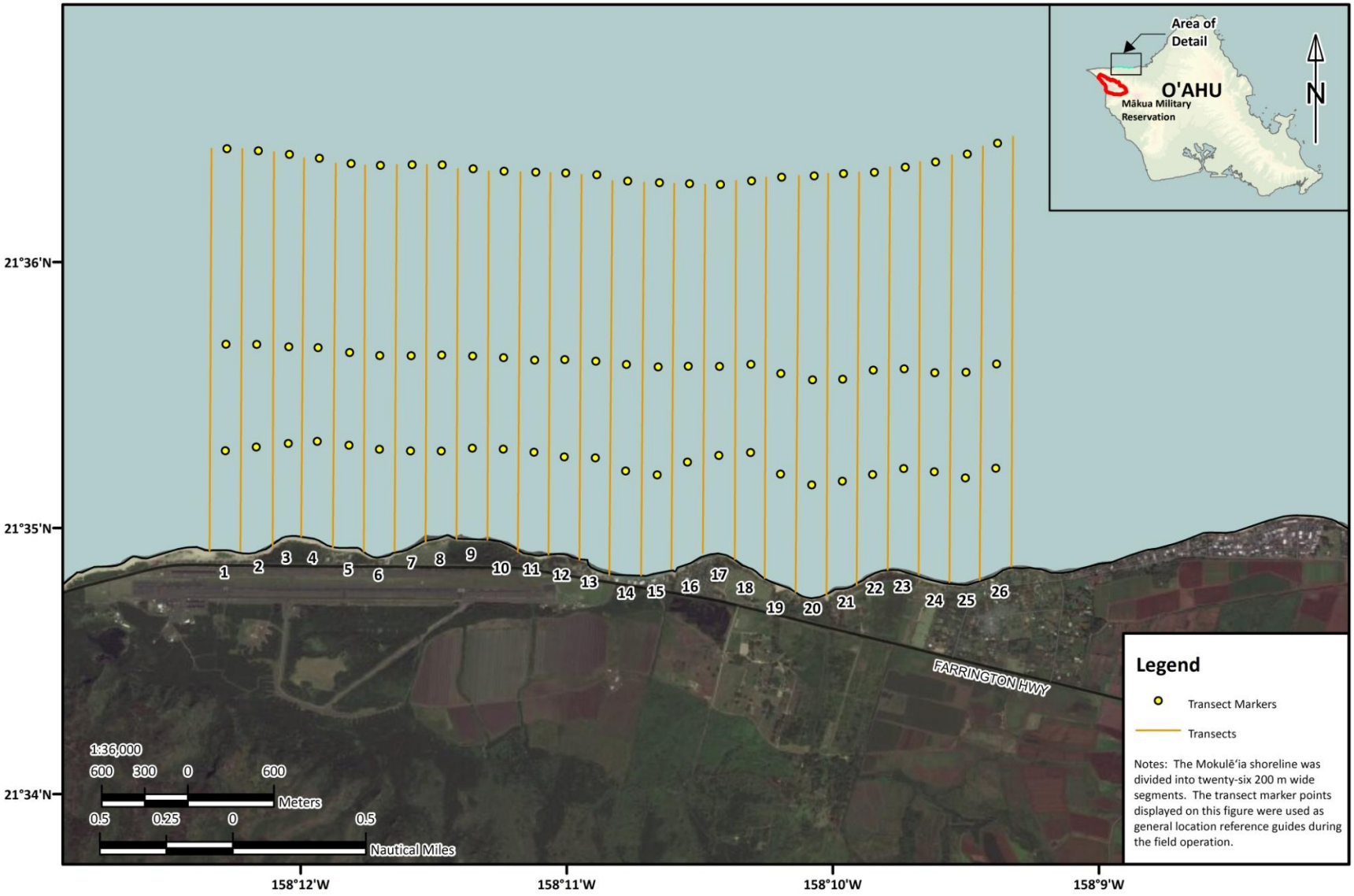
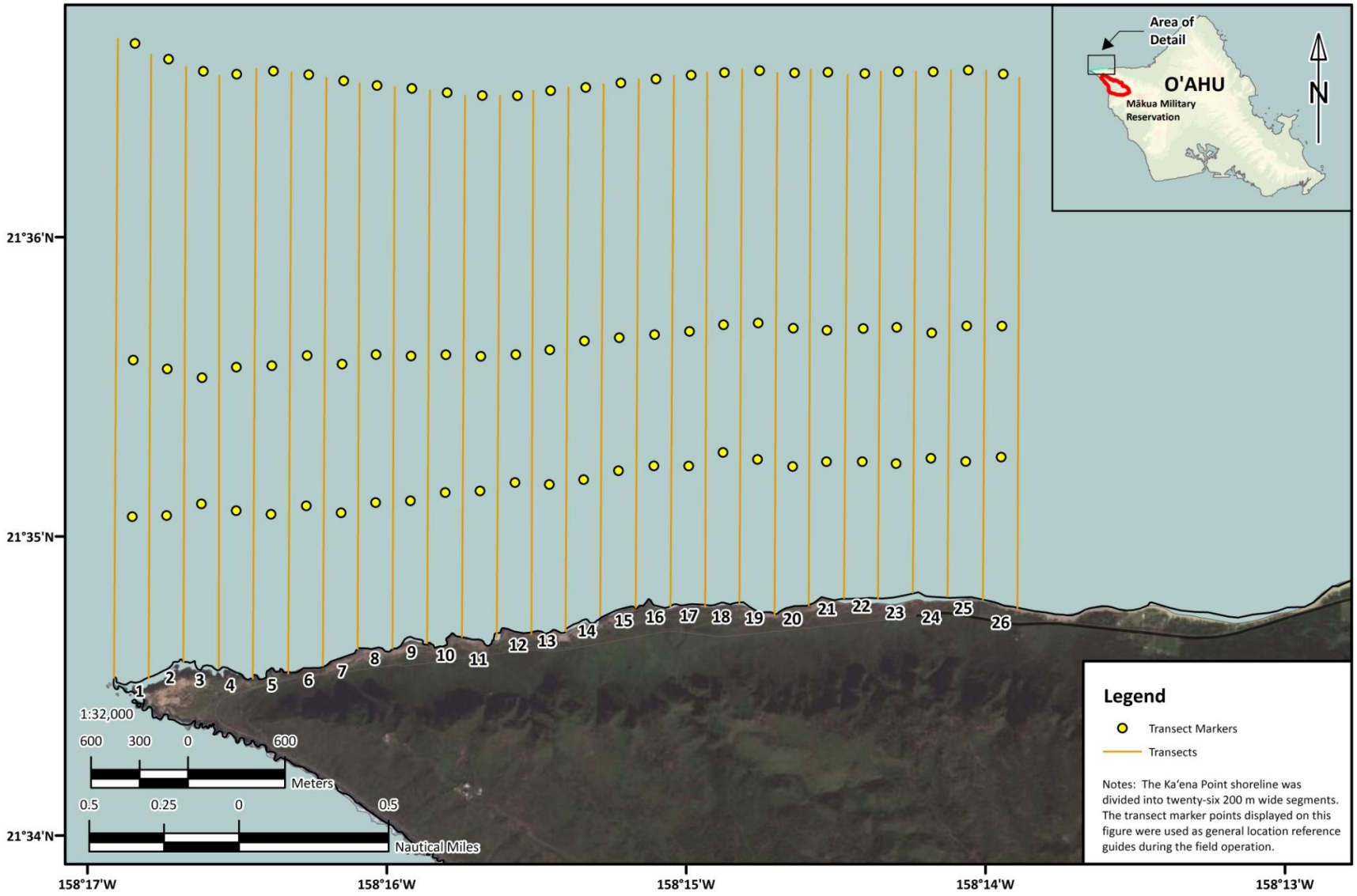


Figure 16. Ka‘ena Point Study Area showing sampling transects.



monitoring was implemented during the wet season to ensure the safety of the sampling team and to determine windows of opportunity for sampling. Favorable and, most importantly, safe sampling conditions were defined by the following criteria, based on consultation with the local fisherman and National Oceanic and Atmospheric Administration (NOAA) (surf) forecasters at the University of Hawaiʻi for what constituted potentially threatening conditions:

- beach waves less than 3 ft (NOAA scale),
- winds less than 11.5 miles per hour (mph) (10 knots) if trade winds (i.e., east to northeast) or from north northwest, or winds less than 17.5 mph (15 knots) if from west to south,
- open ocean swell less than 2 ft (0.6 m) if originating from 270 through 45 degrees, and
- on-site observations by experts and local fisherman that conditions were indeed safe for water-based operations.

To optimize the available sampling windows of opportunity, two types of sampling operations were conducted by the field team. These include shoreline operations (Figures 17 through 19) and boat-based operations (Figures 20 and 21).

Figure 17. Local fishermen snorkeling to search for samples at Mokulēʻia during shoreline operations.

Figure 18. Local fishermen walking along Ka‘ena Point shoreline-
in search of samples during shoreline operations.

Figure 19. Local fishermen searching for samples in a
cove at Ka‘ena Point during shoreline operations.

Figure 20. Mobilizing from Waiʻanae Boat Harbor to the Mākua nearshore water on a fishing boat.

Figure 21. Local scuba diver with Hawaiian sling (3-prong spear) entering the water at Mākua.

Shoreline operations consisted of walking along the shoreline using a GPS to navigate to the sampling segments after which the local fishermen would search for the organisms by walking and by snorkeling along the given segment. Shoreline operations were conducted on days when waters outside the reef flat were too rough to safely conduct boat operations. Boat operations consisted of using a GPS to navigate to the sampling segment, after which the local fishermen scuba dived along the given segment to search for the organisms of interest. There were some instances when the divers deployed from the boat and walked or snorkeled to search for limu kohu along the water edge (Figure 22) within the segment being sampled, owing to the propensity of this seaweed to grow along rocks that are exposed during low tides.

Figure 22. View of reef shelf at Mākua during low tide facing southeast.

Information for each sample collected (e.g., name of the study location, segment number, field identification number, date and time of collection, depth) was documented on waterproof Sample Collection Sheets (Figure 23) (Appendix A). The location where each sample was collected was recorded using a GPS receiver with meter to sub-meter accuracy (Trimble® GeoXH Handheld from the GeoExplorer® 2008 Series).

Figure 23. Documenting field information in a Sample Collection Sheet and recording sample locations on a GPS data logger.

Samples collected were double bagged in plastic freezer type Ziploc® bags. Both the inner and outer bags were labeled with the sample's unique field identification, date, and time collected. Immediately after specimens were caught/collected, bagged, and labeled, they were placed into a cooler on ice for preservation. Samples were then transferred to the University of Hawai'i where they were processed and frozen to -4 degrees Fahrenheit (°F) (-20 degrees Celsius [°C]) before shipping to the analytical laboratories. Sampling methods for each type of organism collected in this study are described in the subsections below.

2.4.1 Sampling of Limu kohu

Limu kohu was handpicked by the team of local fishermen by walking along exposed reefs, snorkeling, or scuba diving (Figures 24 through 26).

The potential for regrowth of the limu kohu was ensured by avoiding the removal of the holdfast. At Mākua, all attempts were made to harvest limu kohu with scissors to cut the upper part of the shoots and leave the holdfast in place. In some instances when safety issues were encountered, the traditional native Hawaiian practice of using fingernails to "clip" the limu

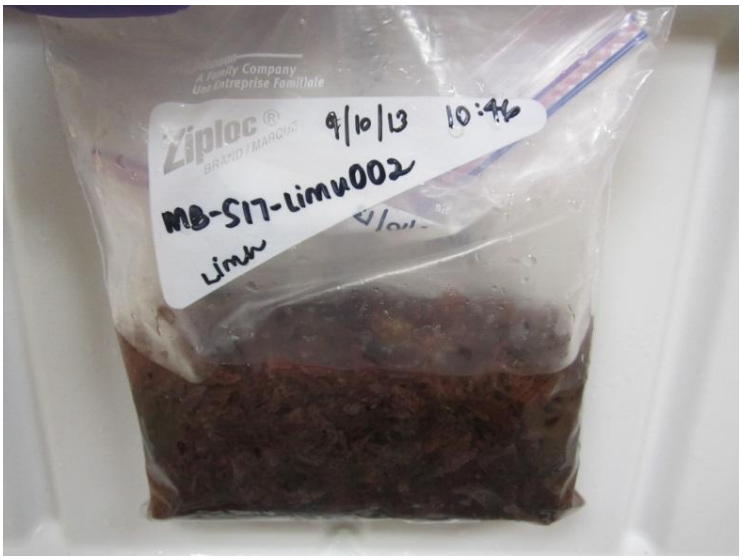
Figure 24. Searching for limu kohu along
a reef shelf at Mākua.

Figure 25. Collecting limu kohu with scissors
from a Mākua reef shelf.

Figure 26. Short limu kohu growing on a shallow reef at Mokulēʻia.

kohu was used, but leaving the holdfast in place. Limu kohu was collected directly into freezer type Ziploc® bags by the team of local fisherman (Figure 27).

Figure 27. Double bagged limu kohu sample collected from Mākua.



After collection, the fishermen relinquished the sample bag to the on-board scientist who then labeled, double bagged, determined an estimated field weight using a handheld fish scale, photographed, and immediately placed the sample on ice in a cooler. Sample information (e.g.,

location, date, time, field identification, depth) was immediately documented on the Sample Collection Sheets (Appendix A).

In accordance with the SAP, representative aliquots of limu kohu samples were provided to a University of Hawaiʻi marine algae expert, Dr. Heather L. Spalding, for definitive taxonomic identification. Samples were confirmed as *Asparagopsis taxiformis* using traditional taxonomic methodologies (Appendix B). The samples used for taxonomic confirmation were preserved in triplicate as herbarium presses in formalin and silica gel for molecular analyses. The herbarium specimens were deposited at the Herbarium Pacificum, Bernice Pauahi Bishop Museum.

2.4.2 Sampling of Heʻe

Divers searched for heʻe by snorkeling during shoreline operations and scuba diving during boat operations. The divers used a tactical spearing technique using Hawaiian slings (3-prong spears) to capture the heʻe (Figures 28 and 29).

Figure 28. Local scuba diver with a heʻe caught using a Hawaiian sling at Mokulēʻia.

Figure 29. Local fisherman removing he‘e from a Hawaiian sling caught at Mokulē‘ia during shoreline operations.

Once a he‘e was caught, divers returned to the surface as soon as practical, met with the boat/field team, and placed the he‘e in a freezer type Ziploc® bag (Figure 30).

Figure 30. Double bagged he‘e sample caught at Mokulē‘ia during shoreline operations.

The on-board scientist then labeled, double bagged, weighed using a handheld fish scale, photographed, and placed the sample immediately on ice in a cooler. Sample information (e.g., location, date, time, field identification, depth) was immediately documented on the Sample Collection Sheets (Appendix A).

2.4.3 Sampling of Loli

Divers searched the sea floor for loli by snorkeling during shoreline operations and scuba diving during boat operations (Figure 31).

Figure 31. Local scuba diver with a loli collected at Mākua.

After a loli was collected, the fishermen relinquished the sample bag with the loli, or the loli itself, to the on-board scientist who labeled, double bagged, obtained an estimated field weight using a handheld fish scale, photographed, and placed the sample immediately on ice in a cooler (Figure 32).

If only small sized loli could be found (less than 200 g) an attempt was made to collect more than one loli to generate a composite sample. For sample bags that contained more than one loli, the number of loli contained in the bag was noted. Sample information (e.g., location, date, time, field identification, depth, and number of loli [if applicable]) was immediately documented on the Sample Collection Sheets (Appendix A).

Figure 32. Double bagged loli sample collected at Mokulēʻia during shoreline operations.

2.5 Field sampling results

Sampling was conducted in September and October 2013 (dry season) and January through March 2014 (wet season). During both seasons, the sampling goal was achieved and involved collecting eight samples each of limu kohu, heʻe, and loli, from each of the nearshore waters of Mākua and two background locations (i.e., Mokulēʻia and Kaʻena Point) (Figures 33 to 38). Detailed information for all field samples is provided in Appendix A and Appendix C.

Size constraints for each sample type were met but the number of individuals collected differed between species. Because of the large size of the animal, all samples of heʻe consisted of a single specimen. Because the consumable portions of individuals of limu kohu and loli were smaller, in some cases multiple discrete samples from each sampling area were pooled to accumulate sufficient mass needed for the multiple chemical analyses and used as single tissue sample. A total of 48 samples (including composite samples) were collected for each target species (8 per each of the three sites during each of the two seasons). Each of the 144 tissue samples was analyzed for a suite of select constituents (Table 2) as per the 2007 SA (U.S. Army 2013).

Figure 33. 2013 Sample locations at Mākua.

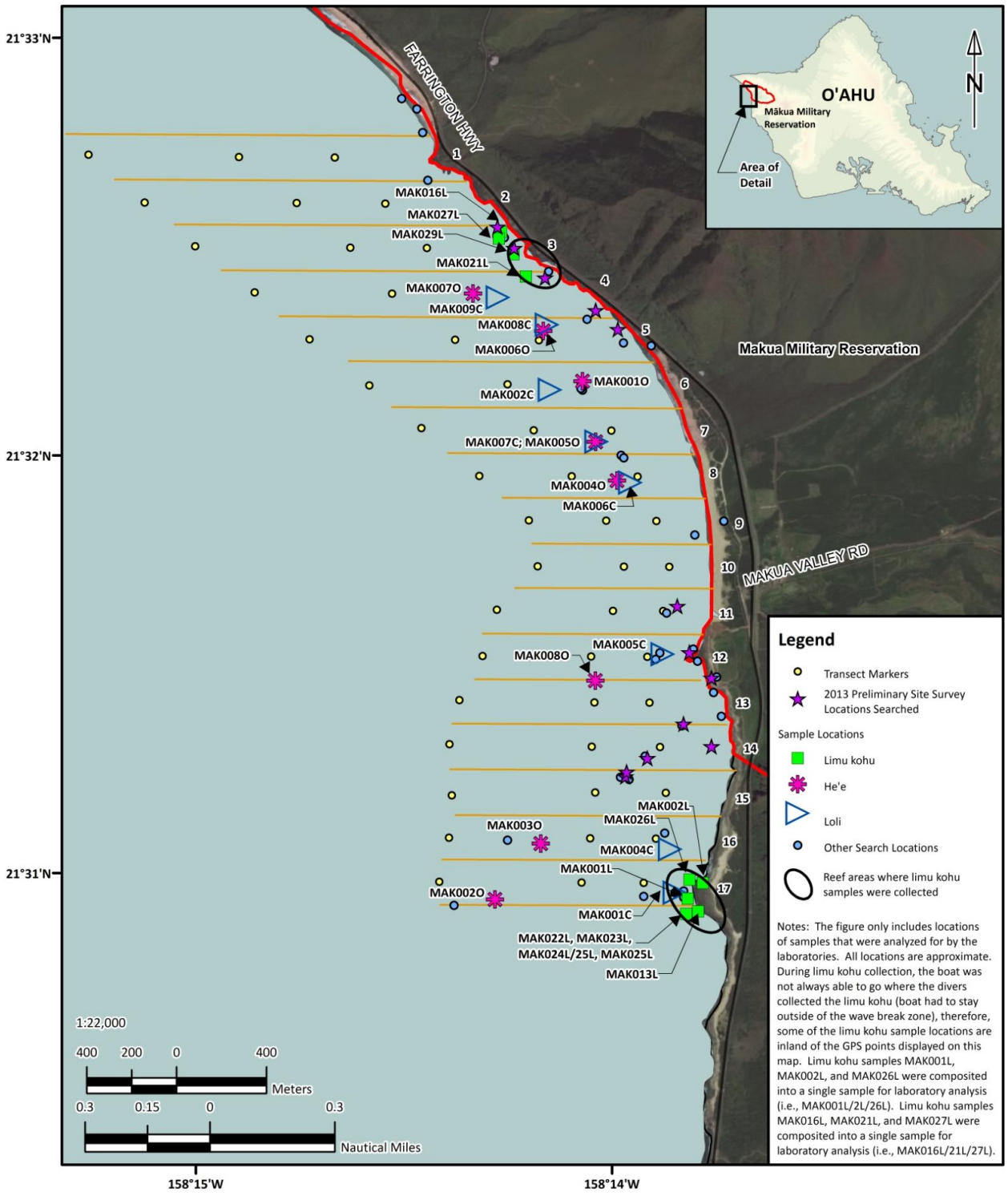


Figure 34. 2013 Sample locations at Mokulēʻia.

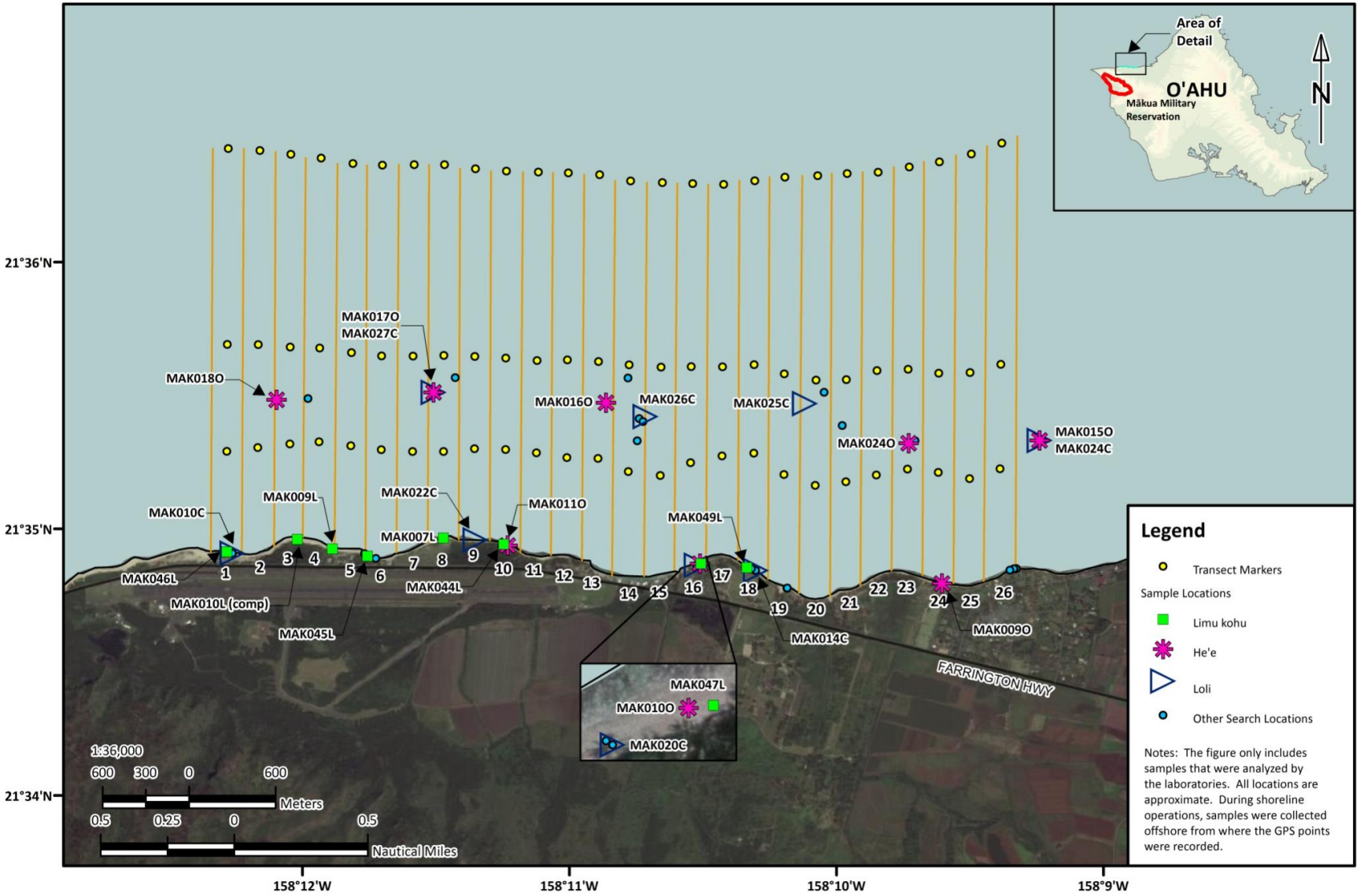


Figure 35. 2013 Sample locations at Ka‘ena Point.

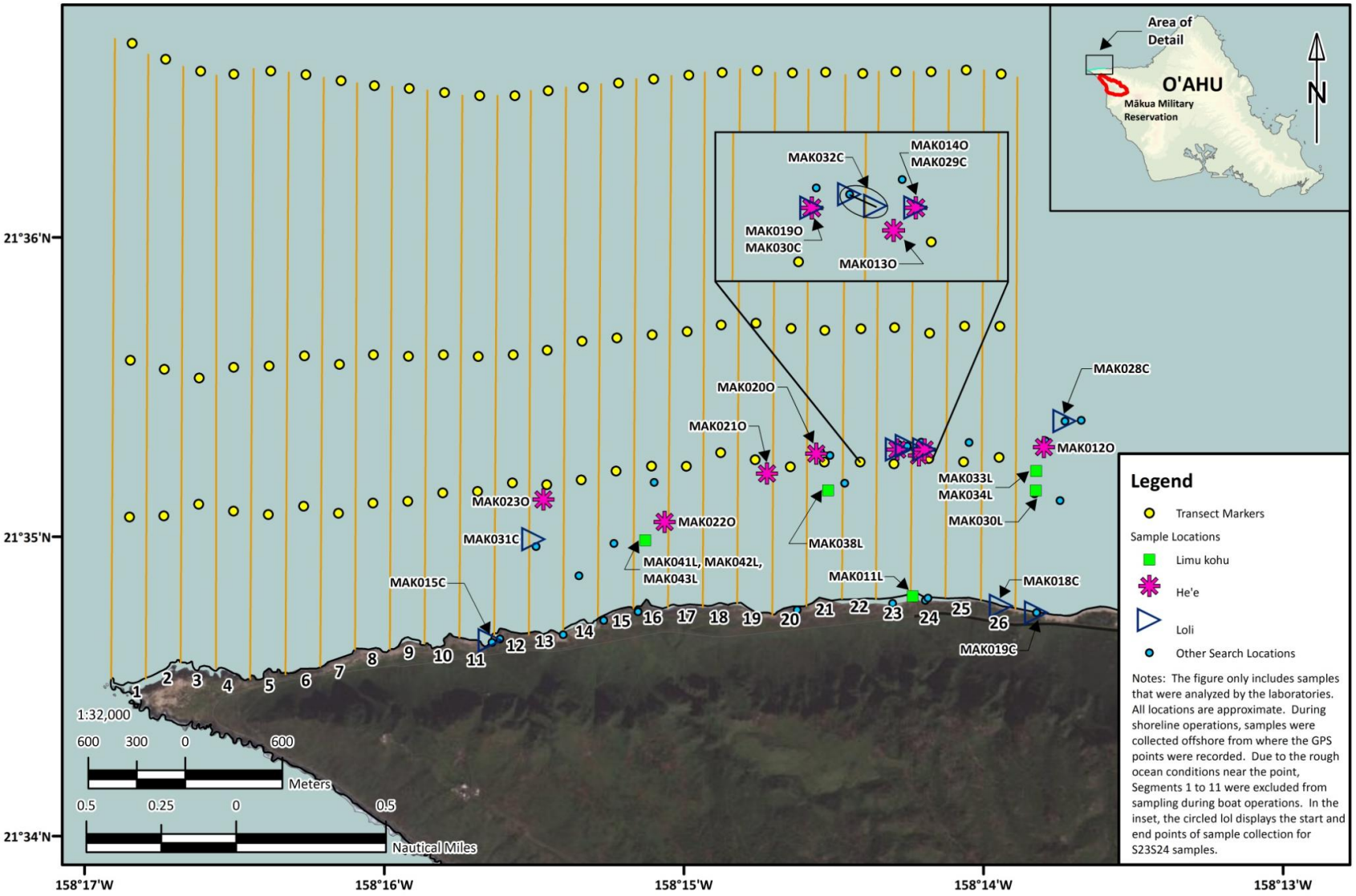


Figure 36. 2014 Sample locations at Mākua.

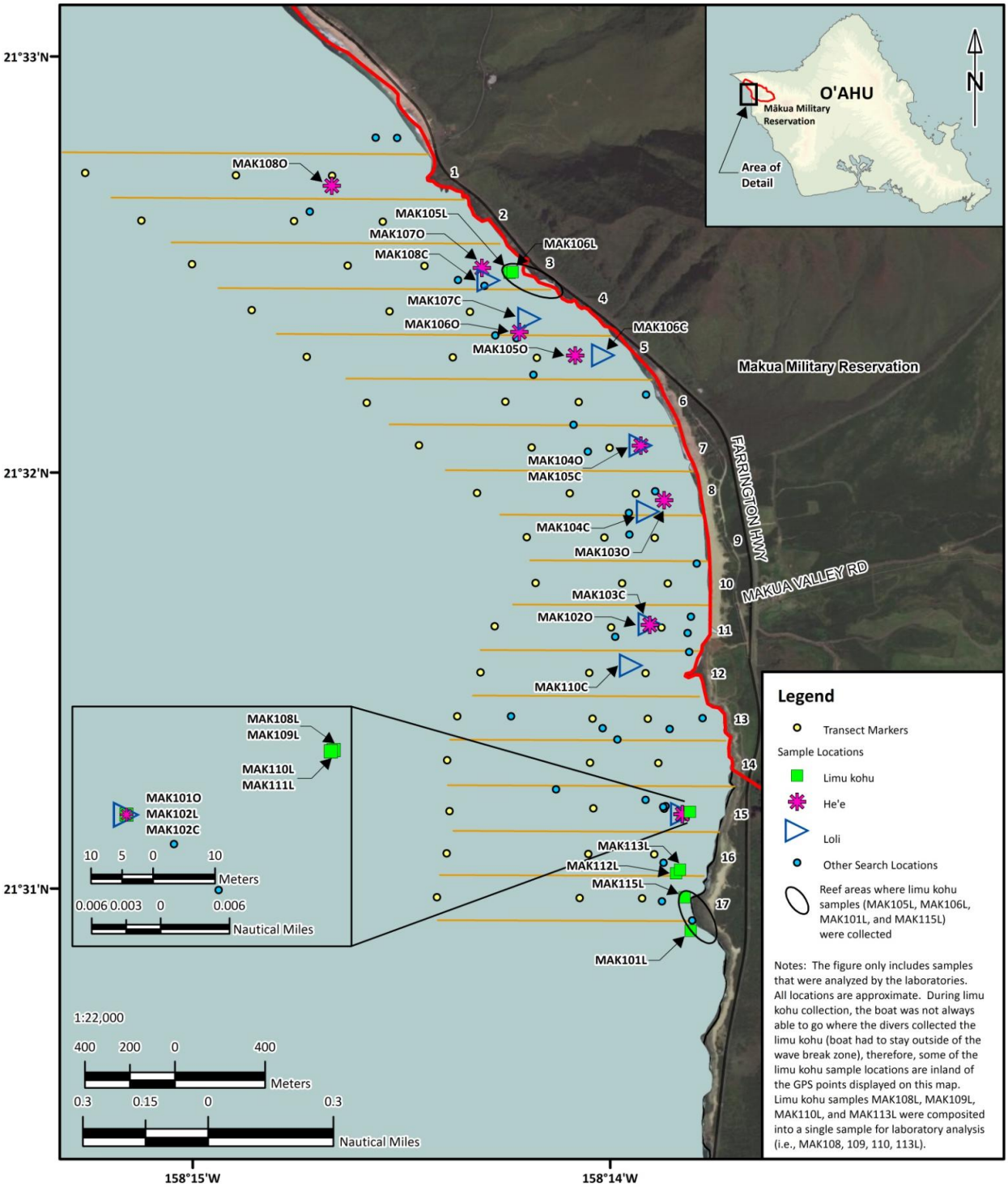


Figure 37. 2014 Sample locations at Mokulēʻia.

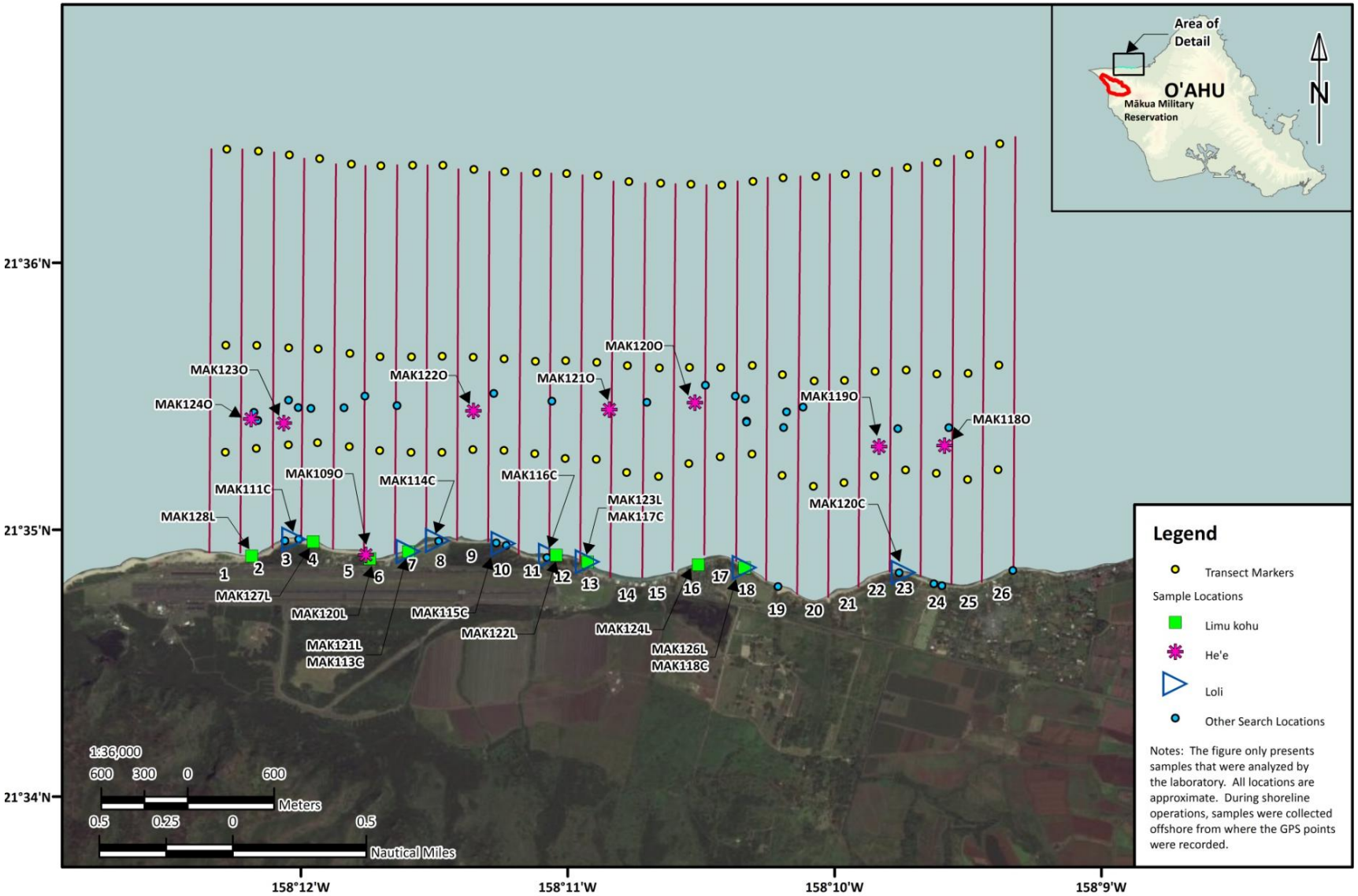
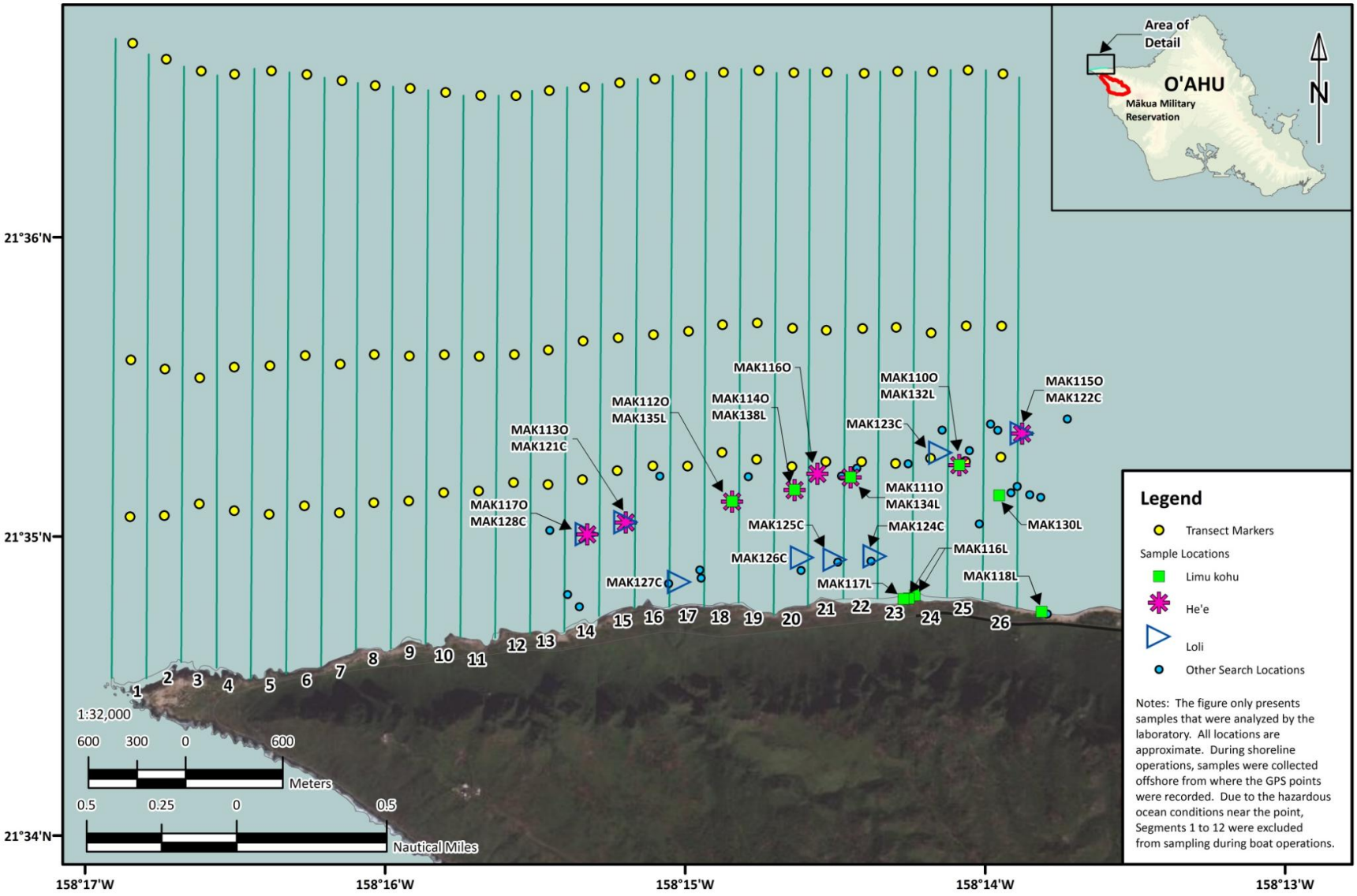


Figure 38. 2014 Sample locations at Ka‘ena Point.



Additional sample material of the three species of biota, beyond the 200 g for each species required for laboratory analysis, was labeled as extra samples, preserved at -4°F (-20°C), and shipped to the Applied Research and Development Laboratory (ARDL), Akron, Ohio, to be archived for subsequent analysis if deemed necessary.

Limu kohu was difficult to find in the nearshore waters during the dry season. This was expected because, according to local fishermen, limu kohu is typically scarce during dry season months and is also aggressively harvested by the community. The field team conducted both shoreline operations and boat operations to search for limu kohu at Mākua. The field team also revisited specific sites where limu kohu was observed in abundance during the Preliminary Site Survey (U.S. Army 2013) and limu kohu was not found at those locations during the dry season. The Preliminary Site Survey was conducted in April and May 2013 to verify sufficient biomass of the three species of interest at the locations. At some locations, the divers found limu kohu, but the shoots were too short to harvest. The differences in availability between the Preliminary Site Survey and the actual sampling period were likely due to seasonal variations because the original survey was conducted during the wet season (April/May 2013). As a result, there were only two general (and relatively large) reef locations at Mākua where limu kohu was found and collected during the dry season (one location in Segments 3 and 4 and one location in Segment 17) (Figure 33). During the wet season, limu kohu was found and collected from a greater number of sampling sites, including locations where it was absent during the dry season (Figure 36). During both dry and wet seasons, he‘e and loli were comparably more abundant than limu kohu.

Both shoreline and boat sampling operations were conducted in nearshore waters at Mokulē‘ia during the dry and wet seasons (Figures 34 and 37). Limu kohu seemed to be more abundant and easier to find in this area during the dry season than the wet season. During the wet season, it was noted that the limu kohu at two search locations were short with few blades and local fishermen commented that they may have been grazed by herbivorous fish such as surgeonfish, locally known as manini. Additionally, the large ocean swells that occur during the wet winter season cause migration of sand that may have affected the abundance of limu kohu at Mokulē‘ia. As predicted by the local fishermen, he‘e were more difficult to find during the wet season sampling period because they are typically scarce during the winter months. Despite difficulties in finding he‘e, eight

samples were collected from distinct locations. Loli samples were less challenging to find during both seasons than either limu kohu or he‘e.

Shoreline and boat operations were conducted in the nearshore waters of Ka‘ena Point during both dry and wet seasons (Figures 35 and 38). Due to the unsafe ocean conditions (i.e., rough waters and strong currents) closest to the actual point, Segments 1 through 12 were eliminated from sampling by boat. Samples were difficult to locate and collect during the shore based operations at Ka‘ena Point. Three loli samples were collected during the dry season, and four limu kohu samples were collected from the shore during both seasons (one during the dry season and three during the wet season). During the dry season, limu kohu was more difficult to find than during the wet season. Loli samples were difficult to find during both seasons. He‘e samples were more difficult to find during the wet season than the dry season; nonetheless, sampling goals were still achieved, reflecting the high professionalism and skill of the fishermen.

2.6 Sample preparation and handling

The biota samples were transported on ice in a cooler to Dr. Eric De Carlo’s chemical oceanography laboratory at the University of Hawai‘i at Mānoa. Dr. De Carlo is an experienced researcher and expert in the field of marine chemistry and serves as a technical advisor for this supplemental marine resources study. Samples were then processed, prior to freezing and subsequent shipping to the analytical laboratories. Sample processing was performed, as necessary and following locally used practices, to remove the inedible parts of the samples, retaining only the portions known to be consumed by the local community. The laboratory team in Hawai‘i was specifically trained in how to process the samples by community experts. Michael Kumukauoha Lee, a Kahunalapaauokekai (Specialist of the Sea) provided training for loli processing (Figure 39) and Carl Jellings, a well-respected expert local fisherman provided training for he‘e and limu kohu processing.

Detailed descriptions of the processing of different biota types are provided in the subsections below.

Figure 39. Michael Kumukauoha Lee (third from left) instructing scientist how to process the loli sample.

Biota specimens were processed using "trace element clean" techniques to minimize the potential for cross contamination of samples. These techniques are designated to prevent the introduction of contamination to the samples by analytes of interest from sample handling and processing. The scientific literature is replete with detailed descriptions of methods of preparation used to minimize contamination with (trace) metals but the methods are equally applicable (with appropriate modifications) to organic substances (e.g., Spencer et al. 2000; De Carlo et al. 2002, 2004; Bienfang et al. 2009). The reader is referred to the Ordnance Reef (HI-06) Final Environmental Study report for methods applicable to discarded military munitions (USACE 2014), but a brief description is also provided here. Sample handling was conducted in a Class 100 laminar flow hood (positive pressure hood) with air forced through a high efficiency particulate absorption (HEPA) filter to minimize contamination by trace metals and other COPCs. Bagged samples were handled by a team of two, one designated "dirty hands"; the other "clean hands." The dirty hands person handled the double bagged sample and opened it, while the clean hands person, wearing semiconductor industry grade (i.e., Class 10) vinyl gloves, only handled the inner bag and transferred it to the laminar hood, where subsequent handling/processing was conducted only by the clean hands

person. Subsequent to the sample-appropriate processing, the clean hands person re-bagged the sample in a new clean plastic bag and transferred it, with the assistance of the dirty hands person to a second bag, which was then sealed, ready for shipment to the analytical labs. Sample handling equipment was washed with diluted Liquinox in water and thoroughly rinsed with ultra-high purity (18 megohm-centimeter) water before processing, after processing, and in between samples. Prior to use, any plastic needed for processing was also acid rinsed overnight in 10% (percentage by volume) hydrochloric acid rinsed with ultra-high-purity water and dried in the laminar flow hood.

To meet analytical requirements, the mass of each sample needed to reach or exceed approximately 200 g. If a sample did not fulfill the mass requirement, two or more specimens from the same sampling segment or segments that were adjacent to each other were combined to generate a composite sample. Composite samples were indicated as such in the laboratory notebook and on the chain-of-custody (COC) sheets (Appendix D) which accompanied each sample shipment to the analytical laboratory.

Samples submitted to analytical laboratories were assigned unique laboratory identification numbers. To avoid potential bias by the laboratory, the laboratory identification numbers did not provide indication of the study location from which the samples were collected. The format for the laboratory sample identification numbers was:

MAKxyz#

where:

- xyz represents consecutive numbering beginning with 001 for the dry season and 101 for the wet season for each organism type
- # represents the organism type (i.e., L for limu, O for he‘e, and C for loli)

Processed samples were double bagged in freezer type Ziploc® and labeled appropriately with the laboratory identifications and collection date and time (both inner and outer bags). The processed samples were then photographed, weighed, stored in labeled coolers and transferred as soon as possible to the -4°F (-20°C) walk-in freezer in the Oceanography Department at the University of Hawai‘i at Mānoa. Samples were kept frozen prior to shipping to the contract laboratories under COC.

Frozen samples were shipped to the analytical laboratories in "five-day coolers" (i.e., insulated coolers capable of keeping contents cold for up to five days) with special synthetic Cold Ice or dry ice. Accompanying each sample shipment was a COC sheet, temperature blank, and trip blanks. Custody seals were placed on the coolers to enable identification of tampering during transit from the University of Hawai'i to the laboratory. Following delivery of the sample coolers to the carrier service for shipment (i.e., FedEx), copies of the COC sheets and the shipment tracking number were provided to the point of contact at the analytical contract laboratory. Once the shipment reached the laboratory, the point of contact emailed or called to provide confirmation of receipt and to describe the conditions of the samples upon arrival.

Specific procedures for each species of interest are described below.

2.6.1 Limu kohu

The limu kohu samples were rinsed thoroughly in the Class 100 laminar flow hood at the University of Hawai'i using ultra-pure water to remove adhering sediment particles (Figure 40).

Maintaining trace element clean protocols, samples were hand-compressed to remove excess water by a lab technician wearing semiconductor grade clean vinyl gloves, and then placed into a new clean, pre-labeled freezer type Ziploc® bag (Figure 41).

Each sample was then double bagged, photographed, and weighed to assure that the required sample weight was achieved (i.e., approximately equal to or greater than 200 g). Fully processed and packaged limu kohu samples were kept in the University of Hawai'i freezer at -4°F (-20°C) until shipment. As noted in Section 2.4.1, a portion of the sample was kept for taxonomic confirmation at the University of Hawai'i at Mānoa and subsequently preserved at the Bishop Museum (Appendix B).

2.6.2 He'e

In the Class 100 laminar flow hood at the University of Hawai'i, he'e samples were laid horizontally on a flat surface (Figure 42).

Figure 40. Limu kohu to be rinsed with ultra pure water in the Class 100 laminar flow hood.

Figure 41. Processed limu kohu sample which is double bagged and labeled with a unique laboratory identification number.

Figure 42. He‘e to be processed in the Class 100 laminar flow hood.

Then, an incision at the base of the he‘e hood was made using a ceramic knife and the eyes, beak, and ink sac were removed (Figure 43).

The processed he‘e was rinsed with ultra pure water and placed into a clean, labeled freezer type Ziploc® bag. Each sample was double bagged, photographed, and weighed (Figure 44) to assure that the required sample weight was achieved (i.e., greater or approximately equal to 200 g). Fully processed and packaged he‘e samples were kept in the University of Hawai‘i freezer at -4°F (-20°C) until shipment.

2.6.3 Loli

On 12 September 2013, Michael Kumukauoha Lee conducted a demonstration and carried out training at the processing laboratory in the Oceanography Department at the University of Hawai‘i for processing the loli samples. Individual loli samples were laid horizontally on a clean flat surface in the Class 100 laminar flow hood at the University of Hawai‘i (Figure 45).

Figure 43. Removing the he‘e beak and ink sac using a ceramic knife in the Class 100 laminar flow hood.

Figure 44. Scale used to weigh samples after they have been processed in the Class 100 laminar flow hood.

Figure 45. Loli prior to sample processing in the Class 100 laminar flow hood at the University of Hawai‘i laboratory.

The skin of the loli was scraped off using the back of a ceramic knife or a stainless steel peeler, to mimic the native Hawaiian practice of using a rock to scrape off the skin, and the loli was then cut lengthwise (like a fillet) using a ceramic knife, yielding two similarly-sized halves (Figures 46 and 47).

The internal lining and organs of the loli were removed from each half by scraping using a disposable plastic spoon (Figure 48).

Once all internal organs were removed, the loli samples were rinsed with ultrapure water. The processed halves of each loli were placed into a new clean, pre-labeled freezer type Ziploc® bag. Each sample was double bagged, photographed, and weighed to ensure that the required sample weight was achieved. If more than one specimen was required to meet the required sample weight, the sample was designated as a composite sample on the COC and in the laboratory notebook. Fully processed and packaged loli samples were kept in the University of Hawai‘i freezer at -4°F (-20°C) until shipment.

Figure 46. Scraping off the skin of a loli using a ceramic knife in the Class 100 laminar flow hood.

Figure 47. Cutting loli lengthwise using a ceramic knife in the Class 100 laminar flow hood.

Figure 48. Removing the loli's internal lining and organs using a disposable plastic spoon in the Class 100 laminar flow hood.

3 Analytical Chemistry

Contract laboratories providing testing services had expertise and demonstrated proficiency in each of the required methods for the investigation. Four different labs were selected based on specific expertise for various analyses (Table 1). There are no commercial laboratories that can perform these analyses in Hawai‘i, so all analyses were performed by mainland USA laboratories, as is typical for these types of studies. Prior to initiation of collection and analysis of samples for this study, test samples of tissues were sent to contract laboratories to minimize the potential for known and unknown matrix effects and interferences that could generate unusable data.

Samples were maintained under COC, and were stored frozen prior to processing, homogenizing, and subsequent extraction and analysis. Unless otherwise noted, samples were prepared as described in the USEPA guidance manual for Assessing Chemical Contaminant Data for Use in Fish Advisories (USEPA 2000). The selection of analytes included in the supplemental marine resources study was based on the 2009 Marine Resource Study and the 2007 SA, Exhibit 2 - List of Chemicals for Marine Resources Study (i.e., the 'Foran List'). Analytical procedures and reporting limits are shown in Table 2. Details are provided in the Final SAP (U.S. Army 2013). There are many compounds included on the “Foran List” that are in no way related to military training and there was no evidence of use in Mākua Valley. Rather the “Foran List” is one reviewer’s assessment and understanding of all the compounds that required evaluation for this project. SVs were established in the site-specific Final SAP (U.S. Army 2013) and are also provided in Table 2. For this assessment, multiple screening level approaches were used, including those promulgated by the USEPA Fish Advisories guidance document (USEPA 2000) and the USEPA Regional Screening Levels Fish Consumption Guidance (USEPA 2012). SVs are not cleanup standards and concentration values above the SV do not necessarily indicate a hazard to human health, however they do provide a useful reference standard. During the site-specific HHRA, site-specific SVs were conservatively calculated using standard equations and the “high-end” fish consumption rate from the 2010 seafood consumption survey for the Ordnance Reef (HI-06) study (USACE 2014). The site-specific SVs are presented and discussed in more detail in the HHRA (Appendix I).

Table 1. Classes of compounds determined by each contract laboratory for this study.

Analyte Group	Contract Laboratory
Dioxins/Furans (17 congeners of concern)	Pace Analytical Minneapolis, Minnesota 55414
Volatile Organic Compounds Energetic compounds (Nitroaromatics/Nitramines) Organochlorine Pesticides SVOCs (Pyrene/Phthalates)	ARDL Mount Vernon, Illinois 62864
Perchlorate	Test America- Sacramento West Sacramento, California 95605
Metals (total) Arsenic Speciation	Brooks Rand Laboratories Seattle, Washington 98107
Energetic Compounds (2,4-DNT) SVOCs (Pentachlorophenol)	ERDC- ECB Vicksburg, Mississippi 39180

Samples were collected and shipped to the contract laboratories for processing and analysis as quickly as possible. As stated in the Final SAP (U.S. Army 2013), regulatory holding times for many classes of analytes have not been established for tissue matrices (e.g., arsenic speciation, volatile organic compounds and semivolatile organic compounds, energetic compounds, and perchlorate); therefore, samples were stored frozen and analyzed as quickly as possible. For analytes that have established regulatory hold times (e.g., metals, six months), samples were extracted and analyzed within these time constraints. Analytical results were reported by the laboratories in wet weight.

Biological materials represent a complex matrix that renders chemical analysis, especially for trace constituents, difficult. This arises as a result of the major matrix components interfering with determination of the trace analytes of interest. The list of potential matrix effects and interferences is extensive, and could not be completely predicted. Fortunately, however, only minor matrix effects were encountered during sample analysis. The most notable issues observed were interferences with perchlorate and 2,4-DNT analyses. Issues with perchlorate were related to the matrix suppressing analyte recovery, requiring clean-up procedures to be used. After

Table 2. Estimated analytical reporting limits by method and contract laboratory.

Analyte	Analytical Procedure	Extraction Procedure	Reporting Limit[1]	Screening Value	Analytical Lab
Dioxins/Dibenzofurans (congeners of concern)					
HpCDD	USEPA Method 1613B	USEPA Method 1613B	5 ng/kg	30.8 ng/kg	Pace
HpCDF	USEPA Method 1613B	USEPA Method 1613B	5 ng/kg	30.8 ng/kg	Pace
HxCDD	USEPA Method 1613B	USEPA Method 1613B	5 ng/kg	3.08 ng/kg	Pace
HxCDF	USEPA Method 1613B	USEPA Method 1613B	5 ng/kg-	3.08 ng/kg	Pace
PeCDD	USEPA Method 1613B	USEPA Method 1613B	5 ng/kg	0.308 ng/kg	Pace
PeCDF	USEPA Method 1613B	USEPA Method 1613B	5 ng/kg	1.03 ng/kg	Pace
OCDD	USEPA Method 1613B	USEPA Method 1613B	10 ng/kg	1,030 ng/kg	Pace
OCDF	USEPA Method 1613B	USEPA Method 1613B	10 ng/kg	1,030 ng/kg	Pace
TCDF	USEPA Method 1613B	USEPA Method 1613B	1 ng/kg	3.08 ng/kg	Pace
TCDD	USEPA Method 1613B	USEPA Method 1613B	1 ng/kg	0.308 ng/kg	Pace
Volatile Organic Compounds (Purgeable Organics)					
Ethylbenzene	USEPA Method 8260B	USEPA Method 5030A	25 µg/kg	3,640 µg/kg	ARDL
m-Xylene	USEPA Method 8260B	USEPA Method 5030A	25 µg/kg	800,000 µg/kg	ARDL
p-Xylene	USEPA Method 8260B	USEPA Method 5030A	25 µg/kg	800,000 µg/kg	ARDL
o-Xylene	USEPA Method 8260B	USEPA Method 5030A	25 µg/kg	800,000 µg/kg	ARDL
Toluene	USEPA Method 8260B	USEPA Method 5030A	25 µg/kg	320,000 µg/kg	ARDL
Stryrene	USEPA Method 8260B	USEPA Method 5030A	25 µg/kg	800,000 µg/kg	ARDL
1,2,4-Trimethylbenzene	USEPA Method 8260B	USEPA Method 5030A	25 µg/kg	not defined	ARDL
Metals					
Aluminum	USEPA Method 200.8	USEPA Method 200.8	0.28 mg/kg	4,000 mg/kg	Brooks Rand
Antimony	USEPA Method 200.8	USEPA Method 200.8	0.005 mg/kg	1.60 mg/kg	Brooks Rand
Arsenic (total)	USEPA Method 200.8	USEPA Method 200.8	0.14 mg/kg	not defined	Brooks Rand
Barium	USEPA Method 200.8	USEPA Method 200.8	0.06 mg/kg	800 mg/kg	Brooks Rand
Beryllium	USEPA Method 200.8	USEPA Method 200.8	0.008 mg/kg	8.00 mg/kg	Brooks Rand
Cadmium	USEPA Method 200.8	USEPA Method 200.8	0.003 mg/kg	4.00 mg/kg	Brooks Rand
Chromium	USEPA Method 200.8	USEPA Method 200.8	0.018 mg/kg	0.08 mg/kg	Brooks Rand
Cobalt	USEPA Method 200.8	USEPA Method 200.8	0.06 mg/kg	1.20 mg/kg	Brooks Rand
Copper	USEPA Method 200.8	USEPA Method 200.8	0.03 mg/kg	160 mg/kg	Brooks Rand
Iron	USEPA Method 200.8	USEPA Method 200.8	0.08 mg/kg-	2,800 mg/kg	Brooks Rand
Lead	USEPA Method 200.8	USEPA Method 200.8	0.004 mg/kg	not defined	Brooks Rand

Analyte	Analytical Procedure	Extraction Procedure	Reporting Limit[1]	Screening Value	Analytical Lab
Metals (cont'd)					
Manganese	USEPA Method 200.8	USEPA Method 200.8	0.024 mg/kg	560 mg/kg	Brooks Rand
Mercury	USEPA Method 1631 Appendix	USEPA Method 1631 Appendix	0.12 ng/g	1,200 ng/g	Brooks Rand
Methyl Mercury	USEPA Method 1630	USEPA Method 1630	1.0 ng/g	400 ng/g	Brooks Rand
Selenium	USEPA Method 200.8	USEPA Method 200.8	0.06 mg/kg	20 mg/kg	Brooks Rand
Silver	USEPA Method 200.8	USEPA Method 200.8	0.02 mg/kg	20 mg/kg	Brooks Rand
Thallium	USEPA Method 200.8	USEPA Method 200.8	0.04 mg/kg	0.04 mg/kg	Brooks Rand
Vanadium	USEPA Method 200.8	USEPA Method 200.8	0.014 mg/kg	20 mg/kg	Brooks Rand
Zinc	USEPA Method 200.8	USEPA Method 200.8	0.002 mg/kg	1,200 mg/kg	Brooks Rand
Energetic Compounds					
2,4-DNT	USEPA Method 8330A*	USEPA Method 8330A	500µg/kg	129 µg/kg	ARDL
2,4-DNT	USEPA Method 8330B modified	USEPA Method 8330B modified	100 µg/kg	129 µg/kg	ECBC-ECB
RDX (Cyclonite)	USEPA Method 8330A	USEPA Method 8330A	500 µg/kg	364 µg/kg	ARDL
Nitroglycerine	USEPA Method 8330A modified	USEPA Method 8330A	500 µg/kg	400 µg/kg	ARDL
Perchlorate	USEPA Method 6850	USEPA Method 6850	50 µg/kg	2,800 µg/kg	Test America Sacramento
Organochlorine Pesticides					
p,p'-DDT	USEPA Method 8081B	USEPA Method 3550A	10 µg/kg	118 µg/kg	ARDL
Aldrin	USEPA Method 8081B	USEPA Method 3550A	5 µg/kg	2.35 µg/kg	ARDL
alpha-BHC	USEPA Method 8081B	USEPA Method 3550A	5 µg/kg	6.35 µg/kg	ARDL
beta-BHC	USEPA Method 8081B	USEPA Method 3550A	5 µg/kg	22.2 µg/kg	ARDL
delta-BHC	USEPA Method 8081B	USEPA Method 3550A	5 µg/kg	not defined	ARDL
gamma BHC (Lindane)	USEPA Method 8081B	USEPA Method 3550A	5 µg/kg	36.4 µg/kg	ARDL
Heptachlor	USEPA Method 8081B	USEPA Method 3550A	5 µg/kg	8.89 µg/kg	ARDL
Heptachlor epoxide	USEPA Method 8081B	USEPA Method 3550A	5 µg/kg	4.40 µg/kg	ARDL
Semivolatile Organic Compounds					
Pentachlorophenol	USEPA Method 8270C**	USEPA Method 8270C**	600 µg/kg	100 µg/kg	ERDC-ECB
Pyrene	USEPA Method 8270C	USEPA Method 3550A	1,980 µg/kg	120,000 µg/kg	ARDL
Bis(2-ethylhexyl) phthalate	USEPA Method 8270C	USEPA Method 3550A	1,980 µg/kg	2,860 µg/kg	ARDL
Di-n-butyl phthalate	USEPA Method 8270C	USEPA Method 3550A	1,980 µg/kg	400,000 µg/kg	ARDL
Diethyl phthalate	USEPA Method 8270C	USEPA Method 3550A	1,980 µg/kg	3,200,000 µg/kg	ARDL
Dimethyl phthalate	USEPA Method 8270C	USEPA Method 3550A	1,980 µg/kg	not defined	ARDL
Di-n-octyl phthalate	USEPA Method 8270C	USEPA Method 3550A	1,980 µg/kg	48,000 µg/kg	ARDL

Analyte	Analytical Procedure	Extraction Procedure	Reporting Limit[1]	Screening Value	Analytical Lab
Arsenic Speciation					
Inorganic Arsenic	USEPA Method 1632 Mod.	USEPA Method 1632 Mod.	0.01 mg/kg	0.0267 mg/kg	Brooks Rand
Arsenic(III)	USEPA Method 1632 Mod.	USEPA Method 1632 Mod.	0.01 mg/kg	0.0267 mg/kg	Brooks Rand
Arsenic(V)	Determined by Calculation (difference of As(III) and As(Inorg))	N/A	0.01 mg/kg	0.0267 mg/kg	Brooks Rand
Dimethyl arsenic	USEPA Method 1632 Mod.	USEPA Method 1632 Mod.	0.01 mg/kg	not defined	Brooks Rand
Monomethyl arsenic	USEPA Method 1632 Mod.	USEPA Method 1632 Mod.	0.01 mg/kg	not defined	Brooks Rand

Notes:
*2,4-DNT in Limu kohu samples analyzed by ERDC-ECB using a modified version of USEPA method 8330 due to interferences observed by the contract laboratory on this specific analyte.
**PCP was analyzed by ERDC-ECB using a modified version of USEPA method 8270 to reach lower reporting limits.
[1] Estimated RLs were provided by the laboratory prior to analysis.
N/A - not applicable.
mg/kg - milligrams per kilogram-wet weight.
ng/g - nanograms per gram-wet weight.
µg/kg - micrograms per kilogram-wet weight.

the modified clean-up procedure, acceptable method QA/QC results were obtained. An unknown tissue constituent interfered with 2,4-DNT detection in limu kohu samples; this was not observed in other tissue types. The interference could not be eliminated even after several clean-up procedures that were evaluated by the contract laboratory. Therefore, analysis of 2,4-DNT was conducted at the Environmental Chemistry Branch of the U.S. Army Engineer Research and Development Center (ERDC-ECB) which utilized a modified USEPA method 8330 that did not result in the interference reported by the contract laboratory. The ERDC-ECB has extensive experience in development and optimization of analytical methods, and use a modified version of USEPA method 8330 to provide lower reporting limits than is normally achievable as well as improve separation from co-occurring analytes and interference. It is common for research laboratories such as ERDC-ECB to be capable of providing higher resolution (lower detection limits) than commercial laboratories.

4 Analytical Chemistry Results

This section presents a detailed discussion of the analytical results for the biota samples from all three sampling areas. Concentrations in the analytical samples are presented on a wet-weight bases, i.e., mass of target analyte divided by the wet mass of the sample. Note that much of the discussion revolves around presenting the concentration of compounds detected in each sample in relation to two laboratory-specific values, the MDL and the RL. The MDL is the lowest level of an analyte that can be measured using a specific testing method. The RL is the lowest level that a specific laboratory can reliably achieve within specified limits of precision and accuracy during routine laboratory conditions.

Data in this section are reported in terms of whether COPCs were detected at concentrations exceeding the MDL and/or RL. Data are also presented relative to the SVs. SVs were established in the site specific Final SAP (U.S. Army 2013) using methods described in the USEPA Fish Advisories. SVs are not cleanup standards and concentration values above the SV do not necessarily indicate a hazard to human health. They do provide a useful reference standard, however. If a compound was detected at concentrations below the SV, it is considered to be of no concern, particularly if the concentration was several orders of magnitude below the SV. During the site-specific HHRA, SVs were in some instances recalculated to represent higher consumption rates than what was used in the USEPA Fish Advisories (USEPA 2000). This is discussed in more detail in the HHRA. All data discussed in this section, including MDL and RL values, can be found in Appendix F, Tables F-1 through F-7.

4.1 Mākua, Mokulēʻia, and Kaʻena Point

4.1.1 Volatile organic compounds (purgeable organics)

Volatile organic compounds are typically the components of fuels such as gasoline. No volatile organic compounds were detected at concentrations exceeding the MDLs or RLs in any of the limu kohu, heʻe, and loli samples collected from Mākua during either the dry or wet seasons (Table 3 for summary, also Table F-1 [Appendix F], Appendix D, and Appendix E). All

the MDLs and RLs were below the SVs (if defined in the Final SAP) for the volatile organic compounds.

Table 3. Summary of analytical results for volatile organic compounds.

Site	Biota	Season	Results
Mākua	He‘e	Dry	• No detections above the MDL or RL.
		Wet	• No detections above the MDL or RL.
	Loli	Dry	• No detections above the MDL or RL.
		Wet	• No detections above the MDL or RL.
	Limu Kohu	Dry	• No detections above the MDL or RL.
		Wet	• No detections above the MDL or RL.
Background Location Mokulē‘ia	He‘e	Dry	• No detections above the MDL or RL.
		Wet	• No detections above the MDL or RL.
	Loli	Dry	• No detections above the MDL or RL.
		Wet	• No detections above the MDL or RL.
	Limu Kohu	Dry	• No detections above the MDL or RL.
		Wet	• No detections above the MDL or RL.
Background Location Ka‘ena Point	He‘e	Dry	• No detections above the MDL or RL.
		Wet	• No detections above the MDL or RL.
	Loli	Dry	• No detections above the MDL or RL.
		Wet	• No detections above the MDL or RL.
	Limu Kohu	Dry	• No detections above the MDL or RL.
		Wet	• No detections above the MDL or RL.

4.1.2 Semivolatile organic compounds

Semivolatile organic compounds are typically found in common household plastics such as toys and household kitchen items. Semivolatile organic compounds used in munitions include di-n-butyl phthalate and di-n-octyl phthalate (plasticizers associated with propellants or explosives) and diphenylamine (a propellant stabilizer). No semivolatile organic compounds were detected at concentrations exceeding the MDLs and RLs in any of the he‘e, loli, and limu kohu samples collected from Mākua during either the dry or wet seasons (see Table 4 for summary, also Appendix F [Table F-2], Appendix D, and Appendix E). One detection of diethylphthalate (limu kohu) occurred at Mokulē‘ia and two detections of

bis(2-ethylhexyl)phthalate occurred at Ka‘ena Point. All three detections at the background locations were below the SVs.

Table 4. Summary of analytical results for semivolatile organic compounds.

Site	Biota	Season	Results
Mākua	He‘e	Dry	• No detections above the MDL or RL.
		Wet	• No detections above the MDL or RL.
	Loli	Dry	• No detections above the MDL or RL.
		Wet	• No detections above the MDL or RL.
	Limu Kohu	Dry	• No detections above the MDL or RL.
		Wet	• No detections above the MDL or RL.
Background Location Mokulē‘ia	He‘e	Dry	• No detections above the MDL or RL.
		Wet	• No detections above the MDL or RL.
	Loli	Dry	• No detections above the MDL or RL.
		Wet	• No detections above the MDL or RL.
	Limu Kohu	Dry	• No detections above the MDL or RL.
		Wet	• One detection of diethylphthalate (Sample MAK123L) at an estimated concentration of 1,520 µg/kg; three orders of magnitude less than the SV of 3,200,000 µg/kg.
Background Location Ka‘ena Point	He‘e	Dry	• Two detections of Bis(2-ethylhexyl)phthalate (MAK019O, MAK020O) at estimated concentrations of 214 µg/kg and 413 µg/kg, respectively, both below the SV of 2,860 µg/kg.
		Wet	• No detections above the MDL or RL.
	Loli	Dry	• No detections above the MDL or RL.
		Wet	• No detections above the MDL or RL.
	Limu Kohu	Dry	• No detections above the MDL or RL.
		Wet	• No detections above the MDL or RL.

Although pentachlorophenol was not detected above the MDLs and RLs in any of the he‘e, loli, or limu kohu samples, the RLs were above the SV of 100 µg/kg. In the State of Hawai‘i guidance documents, it is recognized that not all detection limits for target analytes will be below screening levels. The state guidance advises in these instances that the laboratory’s reported MDL becomes the screening value (HDOH 2011a); therefore, the RL exceedance does not impact the usability of the data or the conclusions of this report.

4.1.3 Organochlorine pesticides

Organochlorine pesticides include compounds that have been widely used in Hawai‘i in large quantities by pest control operators, lawn and garden services, pineapple growers, and homeowners for the control of termites and other pests. The use of these compounds was discontinued in 1988 when their commercial sale was banned (USGS 1998; USEPA 2006), but HDOH has acknowledged that soil contaminated with heptachlor and heptachlor epoxide is highly likely to be present in areas where these pesticides were historically applied (HDOH 2014). These organochlorine pesticides have been replaced with less hazardous chemicals that perform similar functions.

No organochlorine pesticides were detected at concentrations exceeding the MDLs and RLs in any of the he‘e and loli samples collected from Mākua or the two background locations during either the dry or wet seasons (Table 5 for summary, also Appendix F [Table F-3], Appendix D, and Appendix E).

No organochlorine pesticides were detected at concentrations exceeding the MDLs and RLs in any of the limu kohu samples collected from Mākua during the wet season. One or more organochlorine pesticides, alpha-BHC, heptachlor, and/or heptachlor epoxide, were detected at concentrations exceeding the MDLs and RLs in seven limu kohu samples collected from Mākua during the dry season.

Alpha-BHC was detected in four limu kohu samples collected from Mokulē‘ia during the dry season. The organochlorine pesticide analytical results for one limu kohu sample collected from Mokulē‘ia during the dry season (MAK120L) were deemed unusable (R-flagged) by the third-party data validation due to a low recovery of the surrogate spikes (Table 5 for summary, also Appendix F [Table F-3], Appendix D, and Appendix E).

Alpha-BHC was detected in two limu kohu samples collected from Ka‘ena Point during the wet season. Due to matrix interference, five limu kohu samples that were collected during the wet season were diluted by the analytical laboratory by either two or five times (Appendix D, ARDL SDG 6620). Due to the dilutions, the RLs exceeded the SVs in four of the samples for alpha-BHC, three of the samples for heptachlor, and five of the samples for heptachlor epoxide (Table 5 for summary, also Appendix F [Table F-3], Appendix D, and Appendix E). In the State of Hawai‘i

guidance documents, it is recognized that not all detection limits for target analytes will be below screening levels.

Table 5. Summary of analytical results for organochlorine pesticides.

Site	Biota	Season	Results
Mākua	He‘e	Dry	• No detections above the MDL or RL.
		Wet	• No detections above the MDL or RL.
	Loli	Dry	• No detections above the MDL or RL.
		Wet	• No detections above the MDL or RL.
	Limu Kohu	Dry	• Alpha-benzene hexachloride (BHC) detected in six samples (MAK013L, MAK022L, MAK023L, MAK024L/25L, MAK025L, MAK029L) with five concentrations ranging from 9.05 µg/kg to 14.0 µg/kg; all above the SV of 6.35 µg/kg. • Heptachlor detected in six samples (MAK013L, MAK016L/21L/27L, MAK022L, MAK023L, MAK024L/25L, MAK025L) with concentrations ranging from 27.3 µg/kg to 67.0 µg/kg; all above the SV of 8.89 µg/kg. • One detection of heptachlor epoxide (MAK016L/21L/27L) at a concentration of 83.9 µg/kg which is above the SV of 4.40 µg/kg.
		Wet	• No detections above the MDL or RL.
Background Location Mokulē‘ia	He‘e	Dry	• No detections above the MDL or RL.
		Wet	• No detections above the MDL or RL.
	Loli	Dry	• No detections above the MDL or RL.
		Wet	• No detections above the MDL or RL.
	Limu Kohu	Dry	• Alpha-BHC detected in four samples (MAK045L, MAK046L, MAK047L, and MAK049L) with concentrations ranging from 9.80 µg/kg to 22.7 µg/kg; all above the SV of 6.35 µg/kg.
		Wet	• No detections above the MDL or RL.
Background Location Ka‘ena Point	He‘e	Dry	• No detections above the MDL or RL.
		Wet	• No detections above the MDL or RL.
	Loli	Dry	• No detections above the MDL or RL.
		Wet	• No detections above the MDL or RL.
	Limu Kohu	Dry	• No detections above the MDL or RL.
		Wet	• Alpha-BHC detected in two samples (MAK117L, MAK130L) with concentrations of 23.5 µg/kg and 42.2 µg/kg; both above the SV of 6.35 µg/kg. • Due to matrix interference, five samples were diluted by the laboratory resulting in RLs above the SVs for alpha-BHC in four samples, heptachlor in three samples, and heptachlor epoxide in all five samples.

The state guidance advises in these instances that the laboratory’s reported MDL becomes the screening value (HDOH 2011a); therefore, the RL

exceedances do not impact the data usability or the conclusions of this report.

Although aldrin was not detected at concentrations exceeding the MDLs and RLs in any of the he‘e, loli, or limu kohu samples, the RLs were above the SV of 2.35 µg/kg. The SV exceedance for the aldrin RLs was anticipated, as indicated in Table 9 of the Final SAP (U.S. Army 2013). In the State of Hawai‘i guidance documents, it is recognized that not all detection limits for target analytes will be below screening levels. The state guidance advises in these instances that the laboratory’s reported MDL becomes the screening value (HDOH 2011a). Therefore the RL exceedance does not impact the usability of the data or the conclusions of this report.

4.1.4 Energetic compounds

Energetic compounds are present in military munitions and some are used in commercially available fireworks (Wilkin et al. 2007). Of the energetics compounds analyzed, perchlorate was the only compound detected in any of the samples from Mākua or the two background locations. Perchlorate is both a naturally occurring and man-made chemical that is used to produce rocket fuels, fireworks, flares, and energetic compounds. Perchlorate can be present in bleach and in some agricultural fertilizers. Perchlorate was detected in one sample at Mākua, 15 samples at Mokulē‘ia, and 15 samples at Ka‘ena Point; all concentrations were well below the SV (Table 6 for summary, also Appendix F [Table F-4], Appendix D, and Appendix E).

None of the he'e, loli, or limu kohu samples contained concentrations of 2, 4-DNT, RDX, or nitroglycerine at concentrations exceeding the MDLs and RLs. The RLs for these constituents were above the SVs of 129 µg/kg, 364 µg/kg, and 400 µg/kg, respectively, except for limu kohu samples collected during the dry season at all locations and analyzed for 2, 4-DNT by ERDC-ECB (see below and Appendix F [Table F-4], Appendix D, and Appendix E). As indicated in Table 9 of the Final SAP (U.S. Army 2013), a compound having an RL that exceeds the SV is not anticipated to cause negative impacts to data quality, as the laboratory detection limits were below the SVs. This means that low-level detections would have been reported as present, but at an estimated concentration. Further, in the State of Hawai‘i guidance documents, it is recognized that not all detection limits for target analytes will be below screening levels. The state guidance advises in these instances that the laboratory’s reported MDL becomes the

screening value (HDOH 2011a); therefore, the RL exceedances do not impact the data usability or the conclusions of this report.

Table 6. Summary of analytical results for energetic compounds.

Site	Biota	Season	Results
Mākua	He‘e	Dry	• Perchlorate was detected in one sample (MAK007O) at an estimated concentration of 0.62 µg/kg, above the MDL but below the RL and far below the SV of 2,800 µg/kg.
		Wet	• No detections above the MDL or RL.
	Loli	Dry	• No detections above the MDL or RL.
		Wet	• No detections above the MDL or RL.
	Limu Kohu	Dry	• No detections above the MDL or RL.
		Wet	• No detections above the MDL or RL.
Background Location Mokulē‘ia	He‘e	Dry	• No detections above the MDL or RL.
		Wet	• Perchlorate was detected in one sample (MAK118O) at an estimated concentration of 0.45, far below the SV of 2,800 µg/kg.
	Loli	Dry	• No detections above the MDL or RL.
		Wet	• No detections above the MDL or RL.
	Limu Kohu	Dry	• Perchlorate was detected in seven samples (MAK007L, MAK009L, MAK010L (comp), MAK045L, MAK046L, MAK047L, and MAK049L) at estimated concentrations ranging from 0.32 µg/kg to 3.9 µg/kg far below the SV of 2,800 µg/kg.
		Wet	• Perchlorate was detected in seven samples (MAK120L, MAK121L, MAK122L, MAK124L, MAK026L, MAK127L, and MAK128L) at concentrations ranging from 0.41 µg/kg to 12 µg/kg, far below the SV of 2,800 µg/kg.
Background Location Ka‘ena Point	He‘e	Dry	• No detections above the MDL or RL.
		Wet	• No detections above the MDL or RL.
	Loli	Dry	• Perchlorate in one sample (MAK029C) at an estimated concentration of 0.58 µg/kg, far below the SV of 2,800 µg/kg.
		Wet	• Perchlorate was detected in four samples (MAK121C, MAK126C, MAK127C, and MAK128C) at estimated concentrations ranging from 0.31 µg/kg to 0.79 µg/kg, far below the SV of 2,800 µg/kg.
	Limu Kohu	Dry	• Perchlorate was detected in five samples (MAK033L, MAK034L, MAK041L, MAK042L, and MAK043L) at estimated concentrations ranging from 0.30 µg/kg to 0.55 µg/kg, far below the SV of 2,800 µg/kg.
		Wet	• Perchlorate was detected in five samples (MAK130L, MAK132L, MAK134L, MAK135L, and MAK138L) at estimated concentrations ranging from 0.32 µg/kg to 0.74 µg/kg, far below the SV of 2,800 µg/kg.

Note, sample aliquots of all limu kohu were provided to ERDC-ECB for analysis of 2,4-DNT using a modification of USEPA Method 8330 because matrix interferences encountered by ARDL prevented analysis by USEPA Method 8330A (high performance liquid chromotography [HPLC]). ARDL also attempted analysis using an alternate method (USEPA Method 8270C), but these results were ultimately discarded due to lack of appropriate QA/QC samples in favor of using the higher resolution data from ERDC-ECB (i.e., results achieved using the modified USEPA Method 8330). Data from all three analytical methods are included in the tables, but due to the interference, and requirement for acceptable QA/QC, only the results of the USEPA Method 8330 analyses conducted by ERDC-ECB were included in statistical comparisons and risk assessment (Appendix F [Table F-4], Appendix D, and Appendix E).

4.1.5 Dioxins/dibenzofurans

Low levels1 of dioxins and dibenzofurans compounds are common in areas such as the Waiʻanae Coast that are subject to occasional brush fires as a result of burning any wood or woody material (USARHAW and 25th ID (L) 2009). In addition, the background or off-site soil samples collected as part of the Hydrogeologic Assessment (USARHAW and 25th ID (L) 2009) from other valleys along the Waiʻanae Coast contained dioxin and dibenzofuran compounds in areas without military operations.

All detections of dioxins/dibenzofurans were below their respective SVs with the exceptions of total tetrachlorodibenzo-p-dioxin (TCDD) dioxin isomers and total pentachlorodibenzo-p-dioxin (PeCDD) dioxin isomers (Table 7 for summary, also Appendix F [Table F-5a, Table F-5b], Appendix D, and Appendix E). Total TCDD dioxin isomers were detected at concentrations exceeding the SV in six heʻe samples, five loli samples, and seven limu kohu samples collected from Mākua, while total PeCDD dioxin isomers were detected at concentrations exceeding the SV in one heʻe sample collected from Mākua. Total TCDD dioxin isomers were detected at concentrations exceeding the SV in one heʻe sample, seven loli samples, and eight limu kohu samples collected from Mokulēʻia, and in six heʻe samples, seven loli samples, and eight limu kohu samples collected from Kaʻena Point.

Other detections of dioxins/dibenzofurans were observed but the concentrations were below their respective SVs (Appendix F [Table F-5a, Table F-5b], Appendix D, and Appendix E).

Table 7. Summary of analytical results for dioxins/dibenzofurans.

Site	Biota	Season	Results
Mākua	He‘e	Dry	• Total TCDD dioxin isomers detected in six samples (MAK001O, MAK002O, MAK003O, MAK004O MAK005O, and MAK006O) at concentrations ranging from 0.350 ng/kg to 0.580 ng/kg; all above the SV of 0.308 ng/kg. • Total PeCDD dioxin isomers were detected in a single sample (MAK004O) at a concentration of 1.40 ng/kg; above the SV of 0.308 ng/kg.
		Wet	• No detections above the SVs.
	Loli	Dry	• Total TCDD dioxin isomers detected in five samples (MAK001C, MAK004C, MAK006C, MAK007C, and MAK008C) at concentrations ranging from 0.360 ng/kg to 0.91 ng/kg; all above the SV of 0.308 ng/kg.
		Wet	• No detections above the SVs.
	Limu Kohu	Dry	• Total TCDD dioxin isomers detected in seven samples (MAK001L/2L/26L, MAK013L, MAK016L/21L/27L, MAK022L, MAK023L, MAK025L, and MAK029L) at concentrations ranging from 0.400 ng/kg to 1.00 ng/kg; all above the SV of 0.308 ng/kg.
		Wet	• No detections above the SVs.
Background Location Mokulē‘ia	He‘e	Dry	• Total TCDD dioxin isomers were detected in one sample (MAK024O) at a concentration of 0.59 ng/kg; above the SV of 0.308 ng/kg.
		Wet	• No detections above the SVs.
	Loli	Dry	• Total TCDD dioxin isomers were detected in seven samples (MAK014C, MAK020C, MAK022C, MAK024C, MAK025C, MAK026C, and MAK027C) at concentrations ranging from 0.490 ng/kg to 1.40 ng/kg; all above the SV of 0.308 ng/kg.
		Wet	• No detections above the SVs.
	Limu Kohu	Dry	• Total TCDD dioxin isomers were detected in eight samples (MAK007L, MAK009L, MAK010L (comp), MAK044L, MAK045L, MAK046L, MAK047L, and MAK049L) at concentrations ranging from 0.38 ng/kg to 0.960 ng/kg; above the SV of 0.308 ng/kg.
		Wet	• No detections above the SVs.
Background Location Ka‘ena Point	He‘e	Dry	• Total TCDD dioxin isomers were detected in five samples (MAK012O, MAK014O, MAK020O, MAK022O, and MAK023O) at concentrations ranging from 0.310 ng/kg to 0.460 ng/kg, above the SV of 0.308 ng/kg.
		Wet	• Total TCDD dioxin isomers were in one sample (MAK114O) at a concentration of 0.48 ng/kg, above the SV of 0.308 ng/kg.
	Loli	Dry	• Total TCDD dioxin isomers were detected in seven samples (MAK015C, MAK018C, MAK019C, MAK028C, MAK029C, MAK031C, and MAK032C) at concentrations ranging from 0.91 ng/kg to 1.3 ng/kg, above the SV of 0.308 ng/kg
		Wet	• No detections above the SVs.
	Limu Kohu	Dry	• Total TCDD dioxin isomers were detected in eight samples (MAK011L, MAK030L, MAK033L, MAK034L, MAK038L, MAK041L, MAK042L, and MAK043L) at concentrations ranging from 0.38 ng/kg to 0.650 ng/kg, above the SV of 0.308 ng/kg.
		Wet	• No detections above the SVs.

4.1.6 Metals

Metal compounds are contained in the volcanic rocks of Hawai‘i as well as common items such as fence posts and cars/trucks. All detections of metals were below their respective SVs (if defined in the Final SAP) with the exception of chromium (Table 8 for summary, Appendix F [Table F-6a, Table F-6b], Appendix D, and Appendix E). Chromium found in soils and sediments from Hawai‘i is primarily derived from volcanic mineral and is present in the (insoluble) trivalent form (i.e., chromium (III)) (De Carlo et al. 2004, 2005; Frey et al. 1994). This form of chromium is naturally occurring, non-carcinogenic, and is an essential micronutrient for marine organisms and humans. Chromium concentrations in Hawai‘i are commonly elevated since volcanic rocks contain more metals naturally (Presley et al. 1997). Chromium (VI), however, is man-made and carcinogenic (Sadiq 1992). Sources of chromium (VI) include atmospheric pollution, water discharged from electroplating and metal finishing industries and runoff from urban areas. Chromium (VI) is readily reduced to chromium (III) by marine organisms (Nakayama et al. 1981). Any chromium detected in biota tissues is thus highly likely to be the non-carcinogenic chromium (III) as opposed to chromium (VI).

Chromium was detected at concentrations exceeding the SV in one he‘e sample, eight loli samples, and sixteen limu kohu samples collected from Mākua. Chromium was detected at concentrations exceeding the SV in one he‘e sample, eight loli samples, and sixteen limu kohu samples collected from Mokulē‘ia, and in four he‘e samples, seven loli samples, and sixteen limu kohu samples collected from Ka‘ena Point.

4.1.7 Arsenic speciation

In accordance with the SAP, biota samples collected during this study were analyzed for arsenic speciated into organic and inorganic forms. This study determined arsenic as total arsenic, total inorganic arsenic, as well as several individual species (i.e., arsenic (III), arsenic (V), monomethyl arsenic, and dimethyl arsenic). Organic forms of arsenic are known to be less toxic than inorganic species. Inorganic arsenic species such as arsenite, arsenic (III), and arsenate, arsenic (V) are significantly more toxic and carcinogenic than organic species of arsenic so they were analyzed separately and results are presented in this section. For the overall discussion of arsenic in this study, and to answer the study objectives presented at the beginning of this document, the primary focus in this study is on the

Table 8. Summary of analytical results for metals.

Site	Biota	Season	Results
Mākua	He‘e	Dry	• Chromium was detected in one sample (MAK001O) at a concentration of 0.298 mg/kg, above the SV of 0.08 mg/kg.
		Wet	• No detections above the SV.
	Loli	Dry	• Chromium was detected in one sample (MAK001C) at a concentration of 0.261 mg/kg, above the SV of 0.08 mg/kg.
		Wet	• Chromium was detected in seven samples (MAK103C, MAK104C, MAK105C, MAK106C, MAK107C, MAK108C, and MAK110C) at concentrations ranging from 0.095 mg/kg to 0.326 mg/kg, above the SV of 0.08 mg/kg.
	Limu Kohu	Dry	• Chromium was detected in eight samples (MAK001L/2L/26L, MAK013L, MAK016L/21L/27L, MAK022L, MAK023L, MAK024L/25L, MAK025L, and MAK029L) at concentrations ranging from 0.170 mg/kg to 0.528 mg/kg, above the SV of 0.08 mg/kg.
		Wet	• Chromium was detected in eight samples (MAK101L, MAK102L, MAK105L, MAK106L, MAK108,109,110,113L, MAK111L, MAK112L, and MAK115L) at concentrations ranging from 0.128 mg/kg to 3.06 mg/kg, above the SV of 0.08 mg/kg.
Background Location Mokulē‘ia	He‘e	Dry	• Chromium was detected in one sample (MAK017O) at a concentration of 0.388 mg/kg, above the SV of 0.08 mg/kg.
		Wet	• No detections above the SV.
	Loli	Dry	• No detections above the SV.
		Wet	• Chromium was detected in eight samples (MAK111C, MAK113C, MAK114C, MAK115C, MAK116C, MAK117C, MAK118C, and MAK120C) at concentrations ranging from 0.119 mg/kg to 0.596 mg/kg, above the SV of 0.08 mg/kg.
	Limu Kohu	Dry	• Chromium was detected in eight samples (MAK007L, MAK009L, MAK010L (comp), MAK044L, MAK045L, MAK046L, MAK047L, and MAK049L) at concentrations ranging from 0.766 mg/kg to an estimated 4.19 mg/kg, above the SV of 0.08 mg/kg.
		Wet	• Chromium was detected in eight samples (MAK120L, MAK121L, MAK122L, MAK123L, MAK124L, MAK126L, MAK127L, and MAK128L) at concentrations ranging from 0.301 mg/kg to 3.65 mg/kg, above the SV of 0.08 mg/kg.
Background Location Ka‘ena Point	He‘e	Dry	• Chromium was detected in one sample (MAK012O) at a concentration of 0.192 mg/kg, above the SV of 0.08 mg/kg.
		Wet	• Chromium was detected in three samples (MAK111O, MAK113O and MAK114O) at concentrations ranging from an estimated 0.108 mg/kg to 0.249 mg/kg, above the SV of 0.08 mg/kg.
	Loli	Dry	• No detections above the SV.
		Wet	• Chromium was detected in seven samples (MAK122C, MAK123C, MAK124C, MAK125C, MAK126C, MAK127C, and MAK128C) at concentrations ranging from 0.148 mg/kg to 0.317 mg/kg, above the SV of 0.08 mg/kg.
	Limu Kohu	Dry	• Chromium was detected in eight samples (MAK011L, MAK030L, MAK033L, MAK034L, MAK038L, MAK041L, MAK042L, and MAK043L) at concentrations ranging from 0.164 mg/kg to 2.24 mg/kg, above the SV of 0.08 mg/kg.

Site	Biota	Season	Results
		Wet	• Chromium was detected in eight samples (MAK116L, MAK117L, MAK118L, MAK130L, MAK132L, MAK134L, MAK135L, and MAK138L) at concentrations ranging from an estimated 0.081 mg/kg to 1.14 mg/kg, above the SV of 0.08 mg/kg.

speciation of total inorganic arsenic (which includes all of the individual inorganic species). While this section presents the results for arsenic (III), arsenic (V), monomethyl arsenic, and dimethyl arsenic, the substantive discussion at the end of this section focuses on the total inorganic arsenic, and it is not necessary to examine each of the speciated forms.

The detections of inorganic arsenic species at concentrations exceeding their respective SVs are described below (Table 9 for summary, also Appendix F [Table F-7] and Appendix E). Inorganic arsenic was detected at concentrations exceeding the SV in four loli samples and sixteen limu kohu samples collected from Mākua. Inorganic arsenic was detected at concentrations exceeding the SV in five loli samples and sixteen limu kohu samples collected from Mokulēʻia, and in five loli samples and sixteen limu kohu samples collected from Kaʻena Point.

Arsenic (III) was detected at concentrations exceeding the SV in sixteen limu kohu samples collected from Mākua, sixteen limu kohu samples collected from Mokulēʻia, and sixteen limu kohu samples collected from Kaʻena Point. Arsenic (V) was detected at concentrations exceeding the SV in three loli samples and nine limu kohu samples collected from Mākua, in two loli samples and nine limu kohu samples collected from Mokulēʻia, and in five loli and thirteen limu kohu samples collected from Kaʻena Point.

As described in the laboratory report case narratives (Appendix D, SDG 1345019 and SDG 1408020), the RLs and MDLs for limu kohu samples were adjusted to account for sample aliquot size. Therefore, even though the analyses yielded non-detects, the RL and MDLs exceeded the SVs for four limu kohu samples collected during the dry season and three limu kohu samples collected during the wet season from Mākua, one limu kohu sample collected during the dry season and six limu kohu samples collected during the wet season from Mokulēʻia, and two limu kohu samples collected during the dry season and one limu kohu sample collected during the wet season from Kaʻena Point (Appendix F [Table F-7], Appendix D, and Appendix E). In State of Hawaiʻi guidance documents, it is

Table 9. Summary of analytical results for arsenic speciation.

Site	Biota	Season	Results
Mākua	He‘e	Dry	• No detections above the SV.
		Wet	• No detections above the SV.
	Loli	Dry	• Inorganic arsenic was detected in one sample (MAK009C) at a concentration of 0.034 mg/kg, above the SV of 0.0267 mg/kg.
		Wet	• Inorganic arsenic was detected in three samples (MAK103C, MAK106C, and MAK108C) at concentrations ranging from 0.037 mg/kg to 0.071 mg/kg, above the SV of 0.0267 mg/kg. • Arsenic (V) was detected in three samples (MAK103C, MAK106C, and MAK108C) at concentrations ranging from 0.027 mg/kg to 0.052 mg/kg, above the SV of 0.0267 mg/kg.
	Limu Kohu	Dry	• Inorganic arsenic was detected in all eight samples (MAK001L/2L/26L, MAK013L, MAK016L/21L/27L, MAK022L, MAK023L, MAK024L/25L, MAK025L, and MAK029L) at concentrations ranging from 0.177 mg/kg to 0.605 mg/kg, above the SV of 0.0267 mg/kg. • Arsenic (III) was detected in all eight samples at concentrations ranging from 0.142 mg/kg to 0.511 mg/kg, above the SV of 0.0267 mg/kg. • Arsenic (V) was detected mg/kg in four samples (MAK001L/2L/26L, MAK016L/21L/27L, MAK025L, and MAK029L) at concentrations ranging from 0.035 mg/kg to 0.126 mg/kg, above the SV of 0.0267 mg/kg.
		Wet	• Inorganic arsenic was detected in all eight samples (MAK101L, MAK102L, MAK105L, MAK106L, MAK108, 109,110,113L, MAK111L, MAK112L, and MAK115L) at concentrations ranging from 0.175 mg/kg to 1.43 mg/kg, above the SV of 0.0267 mg/kg. • Arsenic (III) was detected in all eight samples at concentrations ranging from 0.159 mg/kg to 0.848 mg/kg, above the SV of 0.0267 mg/kg. • Arsenic (V) was detected in five samples (MAK102L, MAK105L, MAK108, 109,110,113L, MAK111L, and MAK112L) at concentrations ranging from 0.106 mg/kg to 0.581 mg/kg, above the SV of 0.0267 mg/kg.
Background Location Mokulē‘ia	He`e	Dry	• No detections above the SV.
		Wet	• No detections above the SV.
	Loli	Dry	• No detections above the SV.
		Wet	• Inorganic arsenic was detected in five samples (MAK111C, MAK115C, MAK116C, MAK117C, and MAK118C) at concentrations ranging from 0.029 mg/kg to 0.072 mg/kg, above the SV of 0.0267 mg/kg. • Arsenic (V) was detected in two loli samples (MAK111C and MAK116C) at concentrations of 0.038 mg/kg and 0.051 mg/kg, respectively, above the SV of 0.0267 mg/kg.

Site	Biota	Season	Results
	Limu Kohu	Dry	• Inorganic arsenic was detected in all eight samples (MAK007L, MAK009L, MAK010L (comp), MAK044L, MAK045L, MAK046L, MAK047L, and MAK049L) at concentrations ranging from 0.619 mg/kg to 1.66 mg/kg, above the SV of 0.0267 mg/kg. • Arsenic (III) was detected in all eight samples at concentrations ranging from 0.530 mg/kg to 1.32 mg/kg, above the SV of 0.0267 mg/kg. • Arsenic (V) was detected in seven samples (MAK007L, MAK009L, MAK010L (comp), MAK044L, MAK046L, MAK047L, and MAK049L) at concentrations ranging from an estimated 0.089 mg/kg to 0.535 mg/kg, above the SV of 0.0267 mg/kg.
		Wet	• Inorganic arsenic was detected in all eight samples (MAK120L, MAK121L, MAK122L, MAK123L, MAK124L, MAK126L, MAK127L, and MAK128L) at concentrations ranging from an estimated 0.224 mg/kg to an estimated 1.42 mg/kg, above the SV of 0.0267 mg/kg. • Arsenic (III) was detected in all eight limu kohu samples at concentrations ranging from 0.217 mg/kg to 1.39 mg/kg, above the SV of 0.0267 mg/kg. • Arsenic (V) was detected in two limu kohu samples (MAK124L and MAK126L) with estimated concentrations of 0.236 mg/kg and 0.332 mg/kg, respectively, above the SV of 0.0267 mg/kg.
Background Location Ka‘ena Point	He`e	Dry	• No detections above the SV.
		Wet	• No detections above the SV.
	Loli	Dry	• No detections above the SV.
		Wet	• Inorganic arsenic was detected in five samples (MAK124C, MAK125C, MAK126C, MAK127C, and MAK128C) at concentrations ranging from 0.040 mg/kg to 0.071 mg/kg, above the SV of 0.0267 mg/kg. • Arsenic (V) was detected in five samples (MAK124C, MAK125C, MAK126C, MAK127C, and MAK128C) at concentrations ranging from 0.032 mg/kg to 0.057 mg/kg, above the SV of 0.0267 mg/kg.
	Limu Kohu	Dry	• Inorganic arsenic was detected in all eight samples (MAK011L, MAK030L, MAK033L, MAK034L, MAK038L, MAK041L, MAK042L, and MAK043L) at concentrations ranging from 0.512 mg/kg to 1.61 mg/kg, above the SV of 0.0267 mg/kg. • Arsenic (III) was detected in all eight samples at concentrations ranging from 0.420 mg/kg to 1.45 mg/kg, above the SV of 0.0267 mg/kg. • Arsenic (V) was detected in six samples (MAK011L, MAK030L, MAK033L, MAK034L, MAK038L, and MAK042L) collected during the dry season at concentrations ranging from an estimated 0.087 mg/kg to an estimated 0.189 mg/kg, above the SV of 0.0267 mg/kg.

Site	Biota	Season	Results
		Wet	• Inorganic arsenic was detected in all eight samples (MAK116L, MAK117L, MAK118L, MAK130L, MAK132L, MAK134L, MAK135L, and MAK138L) at concentrations ranging from an estimated 0.184 mg/kg to 0.482 mg/kg, above the SV of 0.0267 mg/kg. • Arsenic (III) was detected in all eight samples at concentrations ranging from 0.163 mg/kg to 0.410 mg/kg, above the SV of 0.0267 mg/kg. • Arsenic (V) was detected in seven samples (MAK116L, MAK117L, MAK130L, MAK132L, MAK134L, MAK135L, and MAK138L) at concentrations ranging from 0.041 mg/kg to 0.082 mg/kg, above the SV of 0.0267 mg/kg.

recognized that not all detection limits for target analytes will be below screening levels. The state guidance advises in these instances that the laboratory's reported MDL becomes the screening value (HDOH 2011a). Therefore the limited RL exceedances do not impact the usability of the data or the conclusions of this report.

4.2 Comparison of Mākua results to background locations

One of the integral questions of this study was to evaluate whether COPCs detected in biota collected from the Mākua sampling area were attributable to activities at MMR versus resulting from other sources (e.g., geologic origin, land-based non-point source pollution runoff). This question was established during the data quality objective formulation step of the SAP (U.S. Army 2013). In order to answer this question, the results of samples collected from the Mākua sampling area were compared against the results of samples collected from the two background locations (Mokulēʻia and Kaʻena Point). Data (i.e., mean values calculated for the concentration of each COPC in each biota type at each background location) were evaluated using Wilcoxon-Mann-Whitney two-sample comparison test for datasets without non-detect values on ProUCL version 5.0. ProUCL is a comprehensive software package developed by EPA use to establish background levels, and compare background and site sample datasets for site evaluation and risk assessment. As a conservative measure and to provide meaningful data for statistical analysis, all non-detect values were deleted from the statistical analyses. Mean concentrations of each COPC in each biota type were then compared to the mean values of that COPC in the same biota type at the two background locations to look for a statistically significant difference (using a confidence level of 95%). The data comparison is presented in the remainder of this section and summarized in

Appendix G, Tables G-1 through Table G-5 and the corresponding Appendix G graphs.

4.2.1 Volatile organic compounds

Volatile organic compounds were not detected at concentrations exceeding the MDLs or RLs in any he‘e, loli, and limu kohu samples from either the dry or wet season at Mākua or the background locations. The volatile organic compounds, therefore, are considered to be of no further concern in this study.

4.2.2 Semivolatile organic compounds

None of the samples from Mākua contained concentrations of semivolatile organic compounds exceeding the MDLs or RLs. Two he‘e samples collected from Ka‘ena Point and one limu kohu sample collected from Mokulē‘ia had detections of semivolatile organic compounds, but at levels well below the SVs. Semivolatile organic compounds, therefore, are considered to be of no further concern in this study.

4.2.3 Organochlorine pesticides

Organochlorine pesticides were not detected above MDLs or RLs in any he‘e and loli samples from either the dry or wet season in any of the samples (i.e., either at Mākua or the background locations). However, seven of the eight limu kohu samples collected from Mākua during the dry season had concentrations of one or more of the organochlorine pesticides, alpha-BHC (benzene hexachloride), heptachlor, and/or heptachlor epoxide that exceeded SVs. Alpha-BHC was also detected at concentrations exceeding the SV in four limu kohu samples collected from Mokulē‘ia during the dry season and in two limu kohu samples from Ka‘ena Point during the wet season. The limu samples collected from Mākua during the dry season had a mean concentration of alpha-BHC that was statistically lower, or with a similar mean concentration, to the limu kohu samples collected from Mokulē‘ia and Ka‘ena Point. The average concentration of heptachlor and heptachlor epoxide in limu samples collected from Mākua was numerically higher than that of samples from Mākua and Mokulē‘ia, and the difference was statistically significant. As a result, heptachlor and heptachlor epoxide were carried forward for risk assessment in limu kohu (Section 5).

Four limu kohu samples from Mokulēʻia collected during the dry season showed an average of ~14 µg/kg of alpha-BHC, a value slightly more than two times greater than the SV. Two samples of limu kohu from Kaʻena Point collected during the wet season contained alpha-BHC at concentrations nearly four times and nearly seven times the SV (6.35 µg/kg), respectively. The average concentration for these two samples from Kaʻena Point (32.9 µg/kg) is numerically much higher than found in samples from Mākua and Mokulēʻia collected in the dry season.

Both alpha-BHC and heptachlor are organochlorine pesticides intended for use as insecticides that were banned by the USEPA for commercial sale in the USA over twenty years ago. Both compounds were used extensively by the sugarcane and pineapple plantation agriculture prevalent in Hawaiʻi through the 1980s (e.g., see Section 9.1, HDOH 2014; HDOH 2011b). Alpha-BHC has a long history of use in treatment against agricultural pests on cotton, rice, and other cereals in tropical climates (e.g., see Mehrotra 1985). Heptachlor was also used as a termiticide but was primarily applied to kill other agricultural pests. It was used extensively in the 1960s and 1970s, its manufacture ceased in 1987 (Laws 2000), and the use of these compounds was discontinued in 1988 when their commercial sale was banned (USGS 1998; USEPA 2006).

Organochlorine compounds such as heptachlor and alpha-BHC are highly persistent in the environment, and also accumulate in fatty tissue. Studies were conducted in the late 1970s and 1980s to evaluate the impact that exposure to heptachlor in the form of "Green Chop," fed to cows, had on the animals, their milk and those who consumed it (e.g., see Agency for Toxic Substances and Disease Registry [ATSDR] 2007; USEPA 2006). The occurrence of alpha-BHC at all three sites is consistent with its use in sugarcane agriculture as it would potentially runoff from land along the Mokulēʻia coastline, a prior site of sugarcane cultivation, or be carried by wind from sugarcane fields to which it was applied on the Wahiawa Plateau.

Organochlorine pesticides such as heptachlor, heptachlor epoxide and alpha-BHC may have been used in the region in the past. These pesticides may have been transported across the Waianae Mountains from off-site agricultural uses by trade winds, or may have been introduced by bringing wood treated for termite control onto MMR. For example, wooden pallets, often treated with pesticides for termite control, may have been brought

into the training areas. Known past and current herbicide and pesticide use at MMR is limited to the use of Triclopyr, Imazapyr, and Glyphosate Salt (commonly called Roundup). None of these chemicals are the organochlorine pesticide type, rather this family of herbicides listed work inhibiting enzymes that are essential to the formation of specific amino acids in plants and prevent growth (Duke and Powles 2008). This type of herbicide is the only class of herbicide used in the Mākua Valley with an average annual application of approximately one gallon/acre of Roundup to control weeds on approximately 75 acres of land per year.

In summary, the only marine biological resource that showed detections for organochlorine pesticides was limu kohu. Of the three detected organochlorine pesticides, heptachlor and heptachlor epoxide were found only in limu kohu samples collected from Mākua, and thus these two organochloride pesticides were carried forward for risk analysis (Section 5). Alpha-BHC was found in limu kohu samples collected from Mākua and from the two background locations, but the mean concentration in samples collected from Mākua was not higher than the background locations. Alpha-BHC is thus of no further concern for this study.

4.2.4 Energetic compounds

The energetic compounds, 2,4-DNT, RDX, and nitroglycerine, were not detected at or above the MDLs in any he‘e, loli, and limu kohu samples collected from the three sites during either the dry or wet sampling seasons.

Perchlorate was detected at an estimated concentration of 0.62 µg/kg in a single he‘e sample (MAK007O) collected from Mākua during the dry season. Perchlorate was also detected at concentration of 0.45 µg/kg in a single he‘e sample collected from Mokulē‘ia during the wet season. Both concentrations are nearly 5,000 times lower than the SV of 2,800 µg/kg.

Perchlorate was detected in seven of the eight limu kohu samples collected from Mokulē‘ia during the dry season sampling and seven of the eight limu kohu samples and in one he‘e sample collected during the wet season. All concentrations are at least approximately three orders of magnitude below the SV.

Perchlorate was detected in one sample of loli collected from Ka‘ena Point during the dry season and four loli samples collected during the wet sea-

son. All detections were well below the SV. Five limu kohu samples collected from Ka‘ena Point during the dry season and five samples of limu kohu collected at this location during the wet season also had concentrations that exceeded the RL but were well below the SV.

None of the samples collected from any of the three sites contained concentrations of energetic compounds that exceeded the SVs. Energetic compounds are therefore considered to be of no further concern for this study.

4.2.5 Dioxins/dibenzofurans

Total TCDD dioxin isomers were detected at concentrations that exceeded the SV in he‘e, loli, and limu kohu samples collected from Mākua and from the two background locations (Mokulē‘ia and Ka‘ena Point) during the dry season sampling event. None of the TCDD dioxin isomers that exceeded the SV in samples collected from Mākua were significantly higher than their respective counterpart samples collected from Mokulē‘ia and Ka‘ena Point. Total TCDD dioxin isomers were also detected at concentrations that exceeded the SV in he‘e samples collected from Ka‘ena Point during the wet season.

Total PeCDD dioxin isomers were detected at a concentration that exceeded the SV in a single he‘e sample collected from Mākua during the dry season. All other samples were either non detected or detected at concentrations below the SVs of the dioxins/dibenzofurans.

At Mākua, six samples of he‘e collected during the dry season sampling event showed detections of total TCDD dioxin isomers that exceeded the SV. These were only about 14% above to twice the SV of 0.308 ng/kg. Five samples of loli collected during the dry season also show concentrations of total TCDD dioxin isomers that exceed the SV. The exceedances range from about 17% above to about three times the SV. Seven samples of limu kohu collected during the dry season also show concentrations of total TCDD dioxin isomers that exceed the SV. The exceedances range from about one third more than to slightly more than three times the SV.

One sample of he‘e collected at Mokulē‘ia during the dry season sampling event showed detection of total TCDD dioxin isomers that exceeded the SV. The concentration was about twice the SV of 0.308 ng/kg but the average of all detections for this constituent in he‘e is below the SV. Seven samples of loli collected at this same location during the dry season showed

concentrations of total TCDD dioxin isomers that exceed the SV. The exceedances range from about 1.6 to about five times the SV. All eight samples of limu kohu collected during the dry season also show concentrations of total TCDD dioxin isomers that exceed the SV. The exceedances range from about 23% to slightly more than three times the SV.

Five he‘e samples collected at Ka‘ena Point during the dry season sampling event contained concentrations of total TCDD dioxin isomers that exceeded the SV. The measured concentrations range from just above to about 50% greater than the SV of 0.308 ng/kg. Seven samples of loli collected during the dry season also contained concentrations of total TCDD dioxin isomers that exceed the SV. The exceedances range from approximately three to four times the SV. All eight samples of limu kohu collected during the dry season also contained concentrations of total TCDD dioxin isomers that exceed the SV. The exceedances range from about 23% to twice the SV.

Statistical analysis of the dioxins/dibenzofurans data revealed no significant differences between the mean concentrations at the three sites for any given species or constituent having an exceedance of the SV. There were, however, some statistically significant (i.e., $p < 0.05$) differences for OCDD dioxin isomers between sites in he‘e and loli and for OCDF dioxin isomers in limu kohu, but all the detected concentrations were approximately three orders of magnitude or more below the SV. Because of the conservative approach used in this study for risk assessment however, dioxins were carried forward for risk analysis in he‘e and limu kohu (Section 5).

4.2.6 Metals

Chromium is the only metal with concentrations exceeding the SV in a significant number of the 144 biota samples collected from Mākua, Mokulē‘ia, and Ka‘ena Point. Chromium was consistently found at concentrations above the SV of 0.08 mg/kg in all 48 limu kohu samples collected from the three sites during both the dry and wet season sampling events. This metal was also found at concentrations above the SV in 23 of 24 loli samples collected from the three sites during the wet season sampling event. Except for the chromium concentration that exceeded the SV in a single loli sample collected during the dry season from Mākua, none of the chromium concentrations that exceeded the SV in samples collected from Mākua were significantly higher than their respective counterpart samples collected from Mokulē‘ia and Ka‘ena Point. The two-sample comparison

test results do not show any significantly greater mean concentrations of chromium between biota from Mākua and Mokulēʻia, or between biota from Mākua and Kaʻena Point. The lower concentrations in limu kohu samples collected from Kaʻena Point during the wet season may reflect the fact that this area receives less runoff carrying soils and volcanic rock fragments from which chromium in Hawaiʻi is commonly derived than Mākua and Mokulēʻia.

The concentrations observed in this supplemental study are also comparable to what was previously found at the control site of the Ordnance Reef (HI-06) study (USACE 2014). Chromium is known to bioaccumulate in marine organisms. However, the toxicological impact of bioaccumulated chromium, and its biomagnification potential to humans, is complicated by the initial form and reactivity of chromium upon entering the organism. Chromium (VI) is readily reduced to chromium (III) by marine organisms (Nakayama et al. 1981). Any chromium detected in biota tissues is thus highly likely to be chromium (III) as opposed to chromium (VI). Chromium (III) is itself not carcinogenic, and no mechanisms are known for transforming chromium (III) to the carcinogenic form, chromium (VI) within the human digestive system (De Flora et al. 1990). Therefore it is unlikely that small amounts of chromium found in seafood pose a significant hazard to human consumers of seafood (Neff 2002). Many other metals/metalloids were detected in the biota samples collected during both seasons. This is common and some of these elements are present in the biota owing to biological requirements. Exceptions to the latter include lead (Pb), mercury (Hg), and cadmium (Cd), for which there is no biological requirement. There are many factors that can control element concentrations in organisms including maturity, feeding habits, metabolism, etc., in addition to trophic level, and elucidating the cause(s) of differences between trophic levels is not as simple as invoking only bioaccumulation and/or biomagnification. Furthermore, the concentrations of different metals and metalloids in the biota from the three sites were not found to be significantly different based on statistical analysis of the data, except in several instances. These were for copper, lead, methyl mercury, selenium, and zinc. The concentrations the elements in question, however, were about two orders of magnitude lower than the respective SVs; hence, these are of no further concern to this study.

An element that is generally of high concern with respect to potential toxicity associated with the consumption of marine organisms is mercury

(e.g., Laws 2000). In this study, the majority of the mercury present in the he‘e collected during both the dry and wet seasons was indeed found to be in the form of the more highly toxic methyl mercury, albeit always at concentrations well below the SV. Hence, mercury and methyl mercury are not of further concern to this study.

Most of the metals/metalloids that were found to be present in the biota from the three survey areas occur at concentrations between one to three orders of magnitude below the SV. Hence, they should be of little to no concern with respect to consumption of the marine resources that were evaluated.

Another means of evaluating whether the presence of certain elements is natural or added (e.g., by human activity) is to examine the mean concentrations in various samples of the same type of biota. If the concentrations cluster tightly, it is reasonable to assume that the amount present is natural, because the distribution of elements (metals/metalloids) in a contaminated site is typically not uniform, thus incorporation of these elements associated with contamination should not be constant across a given species. Examination of the box plots presented in Appendix G shows that the concentrations of most metals are quite similar between the three study sites, with some differences observed between wet and dry sampling seasons. The latter may simply reflect incorporation of some runoff-derived materials into these organisms during the wet season. This is particularly noticeable for lead in limu kohu collected from Mākua during the wet season, with a much broader range of concentrations found there than in samples collected during the dry season sampling. No SV has been defined for lead, however, levels are all quite low and comparable to what has been found in biota from the Ordnance Reef (HI-06) study, with slightly higher levels found in limu kohu than in other organisms (USACE 2014). The lead concentrations in loli collected from Mokulēʻia during the wet sampling season, however, show a statistically significant difference with concentrations in loli collected from Mākua, albeit the mean concentrations are extremely low (0.037 mg/kg and 0.084 mg/kg, respectively).

Other factors that can affect the concentration(s) of metals present in marine organisms are seasonal effects. Such effects may arise if the abundance of water or the different temperature influences the occurrence of biotic or abiotic factors that are involved in the incorporation of the trace elements into the biota. This can be a chemical or purely physical effect.

For example, the conditions in the ocean (e.g., salinity, temperature, oxidation/reduction potential) may change the rates of biochemical transformation reactions involved in the incorporation of various elements into organisms. Additionally abundant freshwater runoff during rainy periods may simply change (increase) the amount of sediment containing certain elements that is delivered into the coastal ocean compared to the dry season. The latter argument may explain the difference in chromium abundance in the biological resources between dry and wet seasons, because the abundance of this element in aquatic sediments from Hawai‘i has been previously shown to derive primarily from land input of volcanic material (e.g., De Carlo et al. 2004, 2005; Frey et al. 1994). This is entirely consistent with more abundant chromium in samples collected during the winter (i.e., rainy season).

In conclusion, the relatively constant concentrations of metals across the biota types sampled and between the various sites investigated indicate that the metals observed are of a natural origin. Because of the conservative approach used in this study for risk assessment however, several metals were carried forward for risk analysis: chromium in loli, lead in he‘e and limu kohu, and cobalt and thallium in limu kohu (Section 5).

4.2.7 Arsenic speciation

This study determined arsenic as total arsenic (Appendix F [Table F-6]), total inorganic arsenic (Appendix F [Table F-7]) as well as several individual species (i.e., arsenic (III), arsenic (V), monomethyl arsenic, and dimethyl arsenic). As mentioned earlier, the organic forms of arsenic are known to be less toxic than inorganic species. For the overall discussion of arsenic in this study, and to answer the study objectives presented at the beginning of this document, the primary focus in this study is on the speciation of total inorganic arsenic (which includes all of the individual inorganic species). Thus, for this discussion we will only consider the total arsenic and the total inorganic arsenic results.

Total arsenic (Appendix F [Table F-6a]) occurs at measurable concentrations in all samples of all biological resources collected during the dry and wet seasons in each the three study areas. Concentrations of total arsenic were highest in he‘e, ranging from 18.2 mg/kg to 46.2 mg/kg. He‘e collected from Mākua during the dry and wet seasons averaged 27.9 mg/kg and 28.7 mg/kg, respectively. The samples collected from Mokulē‘ia

during dry and wet seasons averaged 30.1 mg/kg and 36.0 mg/kg, respectively. He‘e collected from Ka‘ena Point during these two seasons averaged 25.6 mg/kg and 31.1 mg/kg. The latter indicates a slightly greater abundance of total arsenic in animals collected during the wet season than during the dry season. Comparing the data from all animals collected from the three study sites during both seasons using the two-sample comparison test shows no significantly greater difference in total arsenic from samples collected from Mākua. This is a clear indication that the arsenic content in the biological resources from Mākua likely represents naturally occurring arsenic from the local geology or other anthropogenic sources and that proposed military activities are anticipated to have little influence on arsenic levels within marine resources in the Mākua nearshore or muliwai areas.

Examination of Table F-7 (Arsenic Speciation Data Summary) in Appendix F, shows that the concentrations of inorganic arsenic determined in the he‘e and loli collected from the three study sites during both seasons are extremely low relative to the total arsenic concentrations shown in Table F-6a (Appendix F). Hence, the majority of the arsenic is present as organic forms of arsenic, which are considerably less toxic than the inorganic forms of arsenic. For limu kohu, however, the inorganic forms of arsenic account for a minimum of about 9% to a maximum of 26% in samples collected from Mākua during the dry season and from 10% to 57% for samples collected during the wet season. This difference in range (i.e., higher in the wet sampling season) may reflect greater input of land-derived arsenic from Mākua during the wet season than during the dry season, accompanied by uptake of arsenic as arsenate (AsO_4^{-3}) during the wet winter season although, it could also represent different biological processes affecting arsenic speciation within biota at different times of the year. For limu kohu samples collected from Mokulē‘ia, the inorganic forms of arsenic account for a minimum of 29% to a maximum of 44% during the dry season and 14% to 46% during the wet season. Thus, there appears to be proportionally more inorganic arsenic in limu kohu from the Mokulē‘ia coast than from the Mākua coastline, at least in samples collected during the dry season, although the two-sample comparison test does not show this difference to be statistically different (if not less than Mākua). Examination of the same ratio in limu kohu collected from Ka‘ena Point shows a range of 28% to 59% in limu kohu collected during the dry season and 15% to 28% during the wet season. Although higher concentrations of inorganic arsenic might be expected in the winter (ostensibly derived from

land runoff) along the Mokulēʻia and Kaʻena Point coastlines, it is noteworthy that the range of values of the inorganic to total arsenic ratio overlaps, again suggesting a lack of contamination with arsenic from activities specifically attributable to MMR. This further supports the idea of the arsenic source being naturally derived from the local geology or other anthropogenic sources unrelated to military activities at MMR.

Table F-7 (Appendix F) shows that inorganic arsenic was not detected above the MDL in any samples of heʻe collected from Mākua during either the dry or wet season. Thus, the overwhelming majority of the arsenic present in the heʻe collected from Mākua is organic and of considerably lower concern with respect to toxicity. The same was true for he'e collected from both Mokulēʻia and Kaʻena Point: during both the wet and dry season the he'e samples showed no detectable concentrations of inorganic arsenic.

Inorganic arsenic was detected in loli collected at Mākua during both seasons, with a total of four detections above the SV. Concentrations of these four detections ranged from 0.034 mg/kg to 0.071 mg/kg. All loli collected from Mokulēʻia during the dry season contained detectable concentrations of inorganic arsenic that were about two to six times the MDL. None of the samples of loli collected at Mokulēʻia during the dry season displayed any inorganic arsenic (in any form) above the SV of 0.0267 mg/kg. Loli collected from Mokulēʻia during the wet season showed, on average, about twice the content of inorganic arsenic (0.033 mg/kg) than observed in the dry season (0.016 mg/kg), with all samples showing concentrations about four to 20 times the MDL. Five of these samples were above the SV of 0.0267 mg/kg, with concentrations ranging from 0.029 mg/kg to a maximum of 0.072 mg/kg. This range of concentrations is very similar to what was observed at Mākua. Loli collected from Kaʻena Point during both the dry and wet seasons all showed detectable concentrations of inorganic arsenic, but much higher levels were observed in samples from the wet season (average 0.043 mg/kg) than the dry season (0.013 mg/kg). Five out of eight samples of loli collected at Kaʻena Point during the wet season exceeded the SV for inorganic arsenic, with concentrations ranging from 0.040 mg/kg to 0.071 mg/kg. This range of concentrations is very similar to what was observed at both Mākua and Mokulēʻia. The reason for the apparent seasonal difference in the concentration of inorganic arsenic in loli samples collected from Kaʻena Point is uncertain, but land derived arsenic associated with fertilizer use in the watershed is more likely to have

drained into the near-shore marine environment during the wet season and, ostensibly, was quickly assimilated by the bottom dwelling loli. All holothurians are detrital feeders that basically extract food from particles (e.g., sediment) that they ingest as they move from place to place on the ocean floor.

As shown in Table F-7 (Appendix F), all samples of limu kohu collected from Mākua, Mokulēʻia, and Kaʻena Point contained concentrations of inorganic arsenic that exceeded the SV of 0.0267 mg/kg. The range of concentrations varied between seasons and between sites, with both Mokulēʻia and Kaʻena Point having higher mean concentrations of inorganic arsenic in samples collected during the dry season compared to the wet season (Table G-5, Appendix G). The highest mean concentrations of inorganic arsenic in limu kohu samples were observed at Mokulēʻia and Kaʻena Point during the dry season. The two-sample comparison results showed no statistically significant differences in the mean concentration of inorganic arsenic in limu kohu samples collected from Mākua compared to the two background locations.

In summary, there were no detections of inorganic arsenic in heʻe samples collected from any of the three sites. All samples of limu kohu collected from Mākua, Mokulēʻia, and Kaʻena Point contained concentrations of inorganic arsenic that exceeded the SV of 0.0267 mg/kg, but there were no statistically significant differences in the mean concentration of inorganic arsenic in limu kohu samples collected from Mākua compared to the two background locations. Loli samples contained concentrations of inorganic arsenic as well as organic arsenic, but there were no significant differences in the mean concentrations in samples collected from Mākua compared to the two background locations (Appendix F). Because of the conservative approach used in this study for risk assessment however, inorganic arsenic was carried forward for risk analysis in loli (Section 5).

That limu kohu had the highest concentrations of inorganic arsenic and highest ratio of inorganic to total arsenic was anticipated as seaweed and other plants take up inorganic arsenic because of its structural similarity with the essential plant nutrient phosphate. Thus, the proportion of inorganic arsenic to organic arsenic is often higher in (marine) plants than in animals, in which most of the arsenic tends to occur in the organic form(s) (e.g., see Ordnance Reef (HI-06) Final Report [USACE 2014]). While all samples of limu kohu collected from Mākua, Mokulēʻia, and Kaʻena Point

contained concentrations of inorganic arsenic that exceeded the SV of 0.0267 mg/kg, there were no statistically significant differences between Mākua and the two background locations. This indicates that military activities at MMR are anticipated to have little influence on arsenic levels within marine resources in the Mākua nearshore or muliwai areas.

4.3 Data validation summary

A detailed evaluation of precision, accuracy, representativeness, comparability, and completeness (PARCC) parameters is provided in Appendix H and Data Validation Reports are provided in Appendix E. All PARCC goals were met, and the data are considered usable for this study.

5 Human Health Risk Assessment

A supplemental HHRA was conducted to characterize potential human health risks from exposures to biota collected from coastal waters off of Mākua (for the full HHR, see Appendix I). The supplemental HHRA provides further characterization of the potential risks at MMR and is a supplemental assessment to a 2009 HHRA conducted in relation to the Marine Resources Study (USARHAW and 25th ID (L) 2009). The study was not designed to assess cumulative risk from all species and exposure pathways; neither was it designed to perform a comprehensive epidemiological study that evaluates cancer or hazard rates across different population demographics. Rather, the study was specifically designed to assess risks and hazards from the consumption of seafood items selected in accordance with the settlement agreement and in consultation with the community (i.e., heʻe, loli, and limu kohu).

The HHRA conducted in 2009 was determined to have been performed in an acceptable manner; therefore, the data collected from the 2009 HHRA was not reassessed in the supplemental HHRA. The supplemental HHRA focuses on data gaps identified on review of the 2009 report and discussion with the regulatory agencies and the community. The results of the 2009 assessment were taken into account when designing the SAP for the supplemental marine resources study and similar methods for risk characterization were conducted. The current HHRA was performed in accordance with standard USEPA methodology.

As discussed in previous sections of this report, biota samples were collected from Mākua and two background locations, which were assumed unimpacted by MMR (i.e. , Mokulēʻia and Kaʻena Point). The background locations were selected in accordance with USEPA background site selection criteria (USEPA, 2002a; 2002b) (refer to Section 2.2). Samples of target species, heʻe, loli, and limu kohu were collected in the near-shore waters of Mākua and the two near-shore background sampling locations. Sampling was conducted in two rounds to account for seasonal variability. The first round of sampling was conducted during the dry season (September and October 2013). The second round of sampling was conducted during the wet season (January through March 2014).

The selection of analytes was based on the 2007 SA, Exhibit 2 - List of Chemicals for Marine Resources Study. In addition, analysis of inorganic and organic forms of arsenic was performed. The full list of analytes is provided in Table 2.

Risk estimates were calculated for current and future seafood consumers who reside near and consume seafood collected from the study area. Seafood consumers are classified into two categories: "average" consumers (those assumed to consume an average of 130.81 g per day of seafood) and "high-end" consumers (those assumed to consume an average of 250.08 g per day of seafood). Fishermen are considered "high-end" consumers, while the remaining local population is classified as "average" consumers. Seafood consumption rates used in the risk assessment were adopted from a seafood consumption survey conducted in 2010 for the 2009 Ordnance Reef (HI-06) study (USACE 2014). Several assumptions were required to complete this human health risk assessment as part of the 2009 previous study (USARHAW and 25th ID (L) 2009). These assumptions greatly overestimated the potential human health risk at Mākua and the background locations, as it is highly unlikely that a subsistence fisherman could rely entirely on the marine resources within the muliwai or the Mākua nearshore area for 250 g of seafood every day for 30 years. The muliwai are short-lived environments and are only intermittently open to the ocean. This significantly restricts the movement of marine resources into the muliwai to replenish depleted populations.

As with the 2009 study (USARHAW and 25th ID (L) 2009), the current and future seafood consumers evaluated in this assessment were conservatively assumed to obtain and consume 100% of their seafood from the Mākua study area. This assumption is extremely health-protective. Many of the participants surveyed in 2010 stated that seafood was generally acquired from markets and nonlocal sources. Based on informal surveys with fishermen in the area and direct observation of fishermen conducting the sampling for this study, marine seafood resources at Mākua Beach could not support the ingestion rate used in the supplemental HHRA. Risks and hazards for the "high end" seafood consumer should be considered conservative and not indicative of risks and hazards for the general population. To provide a range of risk estimates, an "average" seafood consumer was also evaluated.

5.1 Risk assessment results

5.1.1 2014 supplemental HHRA

The first step of the risk assessment process was to compare Mākua chemical concentrations and concentrations from the background locations. The background locations were used to determine naturally occurring concentrations of inorganic contaminants (i.e., metals) or contaminants assumed present due to bioaccumulation from other anthropogenic sources (i.e., organic compounds from other anthropogenic sources that bioaccumulate in the biota). The 95% upper tolerance limits (UTLs) for the background location dataset was determined to be the site-specific background threshold value (BTV). The 95% UTLs were calculated using USEPA's Statistical Software ProUCL Version 5.0 (USEPA 2013). ProUCL 5.0 computes UTLs which adjust for data skewness. ProUCL 5.0 computes upper limits using estimates based on normal, lognormal, gamma or nonparametric distributions. The BTV selected was based on the ProUCL recommended distribution.

Chemical concentrations in biota at Mākua were also compared to conservative SVs. SVs were calculated based on methods derived by the USEPA Fish Advisories using site-specific consumption rates for "high-end" fish consumption in the Human Health Risk Assessment for the 2009 Ordnance Reef (HI-06) study area in 2010 (USACE 2014). The use of "high-end" fish consumption rates was determined to be conservative for screening consumption of the media of concern (he'e, loli, and limu kohu).

Calculation of background concentrations and screening was conducted for the dry and wet sampling seasons individually. Any contaminant with detected concentrations (maximum detected value) greater than both the conservative SVs and calculated background concentrations in either dry or wet sampling season were carried forward for quantitative analysis.

Arsenic was speciated into organic and inorganic fractions. In he'e and limu kohu, concentrations of total and inorganic arsenic were not elevated in relation to the two background locations and therefore not carried forward into the baseline supplemental HHRA. In loli, inorganic arsenic was found at concentrations exceeding that of the background locations. Inorganic arsenic in loli was carried forward for quantitative analysis.

Potential Excess Lifetime Cancer Risks were calculated and compared to the USEPA regulatory risk range of 1×10^{-06} to 1×10^{-04}. The regulatory risk management range (1×10^{-06} to 1×10^{-04}) corresponds to the added cancer risk from exposure to site chemicals above normal background cancer rates. For example, if excess risk is 1×10^{-06} then it is estimated that an additional one person in one million individuals (roughly the population of O'ahu island) *may* experience cancer. Estimated non-carcinogenic hazards are presented as total site Hazard Indices that sum the Hazard Quotients of each environmental contaminant of potential concern at Mākua and via each specific medium. A total Hazard Index of 1 was considered the regulatory level of concern. The risk and hazard summary is provided in Tables 10 and 11.

The results of the supplemental HHRA for Mākua indicate that risks are within the regulatory risk range and hazards are less than the regulatory level of concern if consumption is limited to reasonable quantities and the human food items (i.e., invertebrates and seaweed) generally consumed by an "average" consumer. Site-specific risk and hazard estimates for the current and future "average" consumer are presented in Table 10 below. Total cumulative carcinogenic risk estimated due to consumption of biota from MMR was 1×10^{-05}. The cumulative non-carcinogenic hazard index was 0.5, which does not exceed the regulatory level of concern.

For this 2014 HHRA, site-specific carcinogenic risk estimates for the current and future "high-end" seafood consumers were within the regulatory risk range. Total cumulative carcinogenic risk estimated due to "high-end" consumption of biota from Mākua was 8×10^{-05}. The cumulative non-carcinogenic hazard index was 3, which exceeded the regulatory level of concern.

The biota types sampled in this assessment were also evaluated individually. There were no unacceptable levels of risk calculated for consumption of he'e, for either the "average" or "high-end" seafood consumers. There were no unacceptable levels of risk calculated for consumption of loli, for either the "average" or "high-end" seafood consumers. Carcinogenic risk due to the consumption of limu kohu for both the current and future "averages" or "high-end" seafood consumers exceeded the point of departure regulatory level of concern of 1×10^{-06} but was within the regulatory risk range of 1×10^{-04} to 1×10^{-06}. The primary risk driver in this assessment was organochlorine pesticides in limu kohu samples (heptachlor and

Table 10. Summary of risks and hazards, average consumer.

Sampling Season	Biota	Chemical	Carcinogenic Risk				Noncarcinogenic Hazard Index			
			Child	%	Adult	%	Child	%	Adult	%
Dry	Octopus (he‘e)	Lead	NA	NA	NA	NA	NA	NA	NA	NA
		Dioxins TEQ	1.2E-08	0.3%	2.4E-08	0.3%	NA	NA	NA	NA
		Octopus Total:	1.2E-08		2.4E-08		NA		NA	
	Sea Cucumber (loli)	Arsenic	3.3E-08	0.8%	6.6E-08	0.8%	0.0008	0.2%	0.0004	0.2%
		Chromium	NA	NA	NA	NA	NA	NA	NA	NA
		Sea Cucumber Total:	3.3E-08		6.6E-08		0.0008		0.0004	
	Seaweed (limu kohu)	Cobalt	NA	NA	NA	NA	0.03	6.9%	0.02	6.9%
		Lead	NA	NA	NA	NA	NA	NA	NA	NA
		Thallium	NA	NA	NA	NA	0.08	15.9%	0.04	15.9%
		Heptachlor	**2.2E-06**	52.4%	**4.5E-06**	52.4%	0.01	2.4%	0.006	2.4%
		Heptachlor epoxide	**1.7E-06**	39.3%	**3.4E-06**	39.3%	0.2	34.8%	0.08	34.8%
		Dioxins TEQ	1.7E-07	3.9%	3.3E-07	3.9%	NA	NA	NA	NA
		Seaweed Total:	4.1E-06		8.2E-06		0.3		0.1	
Wet	Octopus (he‘e)	Lead	NA	NA	NA	NA	NA	NA	NA	NA
		Dioxins TEQ	5.0E-08	1.2%	1.0E-07	1.2%	NA	NA	NA	NA
		Octopus Total:	5.0E-08		1.0E-07		NA		NA	
	Sea Cucumber (loli)	Arsenic	6.5E-08	1.5%	1.3E-07	1.5%	0.002	0.4%	0.0009	0.4%
		Chromium	NA	NA	NA	NA	NA	NA	NA	NA
		Sea Cucumber Total:	6.5E-08		1.3E-07		0.002		0.0009	
	Seaweed (limu kohu)	Cobalt	NA	NA	NA	NA	0.1	24.8%	0.1	24.8%
		Lead	NA	NA	NA	NA	NA	NA	NA	NA
		Thallium	NA	NA	NA	NA	0.07	14.6%	0.03	14.6%
		Heptachlor	NA	NA	NA	NA	NA	NA	NA	NA
		Heptachlor epoxide	NA	NA	NA	NA	NA	NA	NA	NA
		Dioxins TEQ	2.9E-08	0.7%	5.8E-08	0.7%	NA	NA	NA	NA
		Seaweed Total:	2.9E-08		5.8E-08		0.2		0.1	
TOTAL			**4E-06**		**9E-06**		0.5		0.2	
RESIDENTIAL TOTAL			**1E-05**				0.5			

Notes:

ELCR within 1E-06 to 1E-04 and HI greater than 1 are bolded in the table.

Residential Totals for carcinogenic risk are the summation of the child and adult receptors. Residential non-carcinogenic hazards are the maximum value between the child and adult receptors.

Arsenic risks and hazards are based on inorganic forms only and do not include organic arsenic metabolites.

Chromium was assumed to be present in biological species in the nontoxic trivalent (Chromium III) state (DeCarlo 2004, 2005 and Frey 1994). This assessment assumes that the chromium detected in site biota would not contribute to health risks.

TEQ = Toxicity Equivalence Factors.

Table 11. Summary of risks and hazards, high-end consumer.

Sampling Season	Biota	Chemical	Carcinogenic Risk				Noncarcinogenic Hazard Index			
			Child	%	Adult	%	Child	%	Adult	%
Dry	Octopus (he‘e)	Lead	NA	NA	NA	NA	NA	NA	NA	NA
		Dioxins TEQ	2.8E-08	0.1%	5.2E-08	0.1%	NA	NA	NA	NA
		Octopus Total:	2.8E-08		5.2E-08		NA		NA	
	Sea Cucumber (loli)	Arsenic	9.3E-08	0.3%	1.7E-07	0.3%	0.002	0.1%	0.001	0.1%
		Chromium	NA	NA	NA	NA	NA	NA	NA	NA
		Sea Cucumber Total:	9.3E-08		1.7E-07		0.002		0.001	
	Seaweed (Limu kohu)	Cobalt	NA	NA	NA	NA	0.08	2.8%	0.04	2.8%
		Lead	NA	NA	NA	NA	NA	NA	NA	NA
		Thallium	NA	NA	NA	NA	0.2	6.2%	0.09	6.2%
		Heptachlor	**6.7E-06**	23.3%	**1.2E-05**	23.3%	0.03	1.2%	0.02	1.2%
		Heptachlor epoxide	**2.1E-05**	72.1%	**3.9E-05**	72.1%	**2**	67.9%	1.0	67.9%
		Dioxins TEQ	8.3E-07	2.9%	1.6E-06	2.9%	NA	NA	NA	NA
		Seaweed Total:	**2.8E-05**		**5.3E-05**		**2**		1	
Wet	Octopus (he‘e)	Lead	NA	NA	NA	NA	NA	NA	NA	NA
		Dioxins TEQ	1.1E-07	0.4%	2.1E-07	0.4%	NA	NA	NA	NA
		Octopus Total:	1.1E-07		2.1E-07		NA		NA	
	Sea Cucumber (loli)	Arsenic	2.0E-07	0.7%	3.8E-07	0.7%	0.005	0.2%	0.002	0.2%
		Chromium	NA	NA	NA	NA	NA	NA	NA	NA
		Sea Cucumber Total:	2.0E-07		3.8E-07		0.005		0.002	
	Seaweed (limu kohu)	Cobalt	NA	NA	NA	NA	0.4	13.7%	0.2	13.7%
		Lead	NA	NA	NA	NA	NA	NA	NA	NA
		Thallium	NA	NA	NA	NA	0.2	8.0%	0.1	8.0%
		Heptachlor	NA	NA	NA	NA	NA	NA	NA	NA
		Heptachlor epoxide	NA	NA	NA	NA	NA	NA	NA	NA
		Dioxins TEQ	7.1E-08	0.2%	1.3E-07	0.2%	NA	NA	NA	NA
		Seaweed Total:	7.1E-08		1.3E-07		0.7		0.3	
TOTAL			**3E-05**		**5E-05**		**3**		1	
RESIDENTIAL TOTAL			**8E-05**				**3**			

Notes:

ELCR within 1E-06 to 1E-04 and HI greater than 1 are bolded in the table.

Residential Totals for carcinogenic risk are the summation of the child and adult receptors. Residential non-carcinogenic hazards are the maximum value between the child and adult receptors.

Arsenic risks and hazards are based on inorganic forms only and do not include organic arsenic metabolites.

Chromium was assumed to be present in biological species in the nontoxic trivalent (Chromium III) state (DeCarlo 2004, 2005 and Frey 1994). This assessment assumes that the chromium detected in site biota would not contribute to health risks.

TEQ = Toxicity Equivalence Factors.

heptachlor epoxide) collected from Mākua during the dry sampling season. Heptachlor and heptachlor epoxide were not detected above the MDLs and RLs in the background locations during the dry sampling season. Heptachlor and heptachlor epoxide in limu kohu collected in during the dry sampling season accounted for approximately 95% of the calculated carcinogenic risk. Heptachlor and heptachlor epoxide also accounted for approximately 70% of the non-carcinogenic hazards.

Lead was carried forward as a chemical of concern in both he‘e and limu kohu (Table 12). The supplemental HHRA used USEPA's Integrated Exposure Uptake Biokinetic (IEUBK) Model for Lead in Children (USEPA 2010) to assess lead hazards in diet (USEPA 2003 and 2009). The USEPA recommends the use of central tendency (CTE) values as inputs to the IEUBK Model. This assessment evaluated a CTE scenario using average lead in biota concentrations to represent an "average" seafood consumer, as well as a reasonable maximum exposure (RME) scenario using the 95% Upper Confidence Level (UCL) of lead concentrations to represent the "high-end" seafood consumer. The supplemental HHRA compared calculated blood-lead (PbB) concentrations to the State of Hawai‘i, Department of Health PbB concentration goal of 5 micrograms per deciliter (µg/dL). Under both the "average" (CTE) and "high-end" (RME) consumer scenarios, lead hazards to children did not exceed the regulatory level of concern of 5 µg/dL.

The supplemental HHRA evaluated risks and hazards under multiple health-protective current and future land use scenarios. Risks and hazards should be evaluated with consideration of realistic current and future land use scenarios, the conservativeness of the risk assessment assumptions and process, and the economic and cultural importance of MMR to the community. For example, very conservative seafood consumption rates and a fraction ingested from site of 100% were used for both seafood consumer scenarios. These assumptions apply to only a very limited segment of the local population. The risk estimates calculated in this assessment should therefore be considered conservative.

The carcinogenic risk due to the consumption of limu kohu was primarily driven by the organochlorine pesticides heptachlor and heptachlor epoxide. Organochlorine pesticides may have been used in the region in the past, but the use of heptachlor and heptachlor epoxide has been discontinued since the 1980s, they have not been used at MMR in the interim, and

Table 12. Summary of lead hazards.

Sampling Season	Media	Percent of Consumption	Receptor	Age Group	Average Blood Lead (µg/dL)	High-End Blood Lead (µg/dL)
Dry	Octopus (he'e)	60% of total meat consumption	Child Resident	0.5-1	1.3	1.6
				1-2	1.4	2.1
				2-3	1.4	2.2
	Seaweed (limu kohu)	23% of total vegetable consumption		3-4	1.4	2.1
				4-5	1.3	2
				5-6	1.2	2
				6-7	1.1	2
Wet	Octopus (he'e)	60% of total meat consumption	Child Resident	0.5-1	1.2	1.3
				1-2	1.4	1.6
				2-3	1.4	1.6
	Seaweed (limu kohu)	23% of total vegetable consumption		3-4	1.3	1.5
				4-5	1.2	1.4
				5-6	1.1	1.3
				6-7	1.1	1.3

Note:
- Residential Child blood-lead concentrations were calculated via EPA IEUBK (USEPA, 2010). Maximum blood-lead concentrations calculated were for the 2-3 age group.
- Percent of consumption was based on Pacific-Asian diet as assumed in the HDOH Evaluation of Environmental Hazards at Sites with Contaminated Soil and Groundwater (HDOH 2011a).
- Octopus consumption was assumed to be 100% of the "Fish and Products" of the total "Fish, Meat & Poultry" in the Pacific-Asian diet (consumption of Fish and Products/ total Fish, Meat and Poultry consumption).
- Limu kohu consumption was assumed to be 100% of the "other vegetables" of the total "Vegetable" consumption in the Pacific-Asian diet (consumption of Other Vegetables/total Vegetable consumption).
- µg/dL = micrograms per deciliter.

they will not be used at MMR in the future. If organochlorine pesticides were excluded from this assessment, estimated carcinogenic risk and noncarcinogenic hazards would be below all applicable regulatory levels of concern.

5.1.2 2009 HHRA

The Army conducted a marine resources study, addressing fish, shellfish (Kona Crab and urchins), other invertebrates, and limu near Mākua Beach and in the Mākua muliwai (temporary brackish water pond) to determine if they bioaccumulate constituents at levels that could pose a health risk to area residents who rely on marine resources for subsistence (USARHAW and 25th ID (L) 2009).

The study concluded that a potential incremental carcinogenic risk (risk greater at Mākua Beach than background location) for subsistence fishermen potentially exposed to the mean concentrations of COPCs in fish is approximately 3×10^{-5}. This risk estimate is within the USEPA (1990)

target risk range of 10^{-6} to 10^{-4}. The incremental risk over background is largely due to assumed exposures to alpha-BHC, bis(2-ethylhexyl) phthalate, and heptachlor epoxide. The study concluded that there is no potential incremental carcinogenic risk (risk greater at Mākua Beach than background location) for subsistence fishermen potentially exposed to the mean concentrations of COPCs in shellfish harvested at Mākua Beach because the risk estimated for background is higher than that estimated for shellfish harvested at Mākua Beach.

A potential carcinogenic and noncarcinogenic hazard from consuming limu in the nearshore waters of Mākua was reported and was attributed largely to arsenic. Arsenic was detected in limu in concentrations ranging from 4.56 to 109 mg/kg. Limu samples from Mākua beach were composites of various species and did not include limu kohu. Limu was not collected from the background location and therefore it was not possible to determine whether the arsenic levels detected in limu at Mākua Beach are elevated over background. The arsenic was not speciated and was conservatively assumed to be entirely inorganic. The assessment of risk from consuming limu was determined to be deficient by the court ruling (U.S. District Court 2012) and as a result that assessment was conducted as part of the current study.

Based on the general similarity of carcinogenic and noncarcinogenic health risks between the Mākua Beach and the background location, it was apparent that the Army's past activities at MMR were not independently responsible for human health risks from the constituents detected in marine resources. Considering the concentrations of constituents found in the Mākua area, the numerous possible sources of these constituents, the mobility of these constituents and the fact that they can originate from multiple sources, the report concluded that it was unlikely that future military activities at MMR alone would cause unacceptable risk to human health.

Tables 13 and 14 provide a summary comparison of the 2009 Marine Resources Study risk assessment results and this 2015 Marine Resources Supplemental risk assessment results.

For the 2009 human health risk assessment, the potential risks and hazards identified in the human health risk assessment were largely due to

Table 13. Summary of the incremental carcinogenic risk for Mākua.

Environment	Environmental Media	Fisherman	Risk/Location		Incremental Risk	Contaminant of Potential Concern (COPC) for Incremental Risk
			Mākua	*Background*		
Muliwai	Fish	Subsistence				
		Recreational				
	Shellfish	Subsistence	E	E	U	
		Recreational				
Nearshore	Fish	Subsistence	E	E	E	Alpha-BHC, bis(2-ethylhexyl) phthalate, Heptachlor Epoxide
		Recreational	E	E	U	
	Shellfish	Subsistence		E		
		Recreational		E		
	Limu (2009)	Subsistence	E		E	Arsenic
		Recreational	E		E	
	Octopus (2014)	Subsistence				
		Recreational				
	Sea Cucumber (2014)	Subsistence				
		Recreational				
	Limu (2014)	Subsistence			E	Heptachlor Epoxide
		Recreational				

Notes:

E = Exceeds the US EPA risk level for fish consumption (1E-05).

U = Unlikely potential risk; chemical concentrations at both sites are elevated, but the incremental risk is below the US EPA risk level for fish consumption.

In the 2014 assessment, background locations were evaluated by calculating their respective background threshold values, to which concentrations at Mākua were compared. Chemicals below the background threshold value were eliminated from evaluation. As such, only the incremental risks were evaluated.

The 2014 assessment calculated incremental risks during two seasons (wet and dry). The incremental risks presented are a cumulative total of the two seasons.

The limu samples collected in 2009 were composite samples that included many species of limu, but excluded the most commonly eaten species: limu kohu.

Table 14. Summary of the noncarcinogenic hazard for Mākua.

Environment	Environmental Media	Fisherman	Hazard		Incremental Hazard	Contaminant of Potential Concern (COPC) for Incremental Hazard
			Mākua	*Background*		
Muliwai	Fish	Subsistence	20	47	--	
		Recreational	7	16	--	
	Shellfish	Subsistence	14	9	5	Manganese, cobalt
		Recreational	5	3	2	
Nearshore	Fish	Subsistence	7	5	2	Nitroglycerin
		Recreational	2	2	--	
	Shellfish	Subsistence	12	3	9	Cadmium, perchlorate
		Recreational	4	1	3	
	Limu (2009)	Subsistence	58	--	--	Arsenic
		Recreational	17	--	--	
	Octopus (2014)	Subsistence	--	--	--	
		Recreational	--	--	--	
	Sea Cucumber (2014)	Subsistence	--	--	--	
		Recreational	--	--	--	
	Limu (2014)	Subsistence	--	--	2	Heptachlor Epoxide
		Recreational	--	--	--	

Notes:

Shaded = Noncarcinogenic hazard at Mākua is greater than background.

"--" = Below the noncarcinogenic hazard regulatory level of concern of 1.

In the 2014 assessment, background locations were evaluated by calculating their respective background threshold values, to which concentrations at Mākua were compared. Chemicals below the background threshold value were eliminated from evaluation. As such, only the incremental hazards were evaluated.

The 2014 assessment calculated noncarcinogenic hazards during two seasons (wet and dry). The noncarcinogenic hazards presented are the maximum value calculated between the two seasons.

The limu samples collected in 2009 were composite samples that included many species of limu, but excluded the most commonly eaten species: limu kohu.

eight compounds, including four metals (arsenic, cadmium, cobalt, and manganese), two organochlorine pesticides (alpha-BHC and heptachlor epoxide), and two explosives (nitroglycerin and perchlorate). Using data from this study and previous studies (described in Section 1.2 of this report), demonstrates that some of the same substances found at elevated levels in the marine resources at Mākua are also found in other environmental media and are a component of military munitions; however, there are a range of other possible natural and anthropogenic sources of these compounds.

6 Discussion and Conclusions

6.1 Discussion

6.1.1 Nature and extent of contamination

Volatile organic compounds and semivolatile organic compounds were not detected above MDLs and RLs in any he‘e, loli, or limu kohu samples from either the dry and wet season from Mākua and are therefore considered to be of no further concern in this study.

Organochlorine pesticides were detected at concentrations above the RLs in seven limu kohu samples collected from Mākua during the dry season, four limu kohu samples collected from Mokulē‘ia during the dry season, and two limu kohu samples collected from Ka‘ena Point during the wet season. No other organisms analyzed showed any evidence of organochlorine pesticides above the MDLs and RLs.

The energetic compounds, 2,4-DNT, RDX, and nitroglycerine, were not detected at or above the MDLs in any he‘e, loli, or limu kohu sample collected from the three study areas either during the dry or wet sampling seasons. Perchlorate was detected in a single he‘e sample collected from Mākua during the dry season, and in one he‘e (dry season) and 14 limu kohu samples (seven dry season and seven wet season) collected from Mokulē‘ia, and five loli (one dry season and four wet season) and 10 limu kohu samples (five dry season and five wet season) collected from Ka‘ena Point. All of the detections were estimates below the RLs (except for one sample), and were at least three orders of magnitudes below the SV of 2,800 μg/kg, therefore are considered to be of no further concern.

Dioxins/dibenzofurans were detected above the RLs in all samples except for three he‘e and one loli samples collected from the three study areas; total TCDD dioxin isomers and PeCDD dioxin isomers were the only constituents that were detected at concentrations above the SVs. Total TCDD dioxin isomers were detected at concentrations above the SV in six he‘e, five loli, and seven limu kohu samples collected during the dry season from Mākua; one he‘e, seven loli, and eight limu kohu samples collected during the dry season from Mokulē‘ia; and five he‘e, seven loli, and eight limu kohu samples collected during the dry season and one he‘e sample

collected during the wet season from Ka‘ena Point. PeCDD dioxin isomers were detected at concentration above the SV in a single he‘e sample collected from Mākua during the wet season.

Metals/metalloids were detected in the biota samples collected during both dry and wet seasons at all three study sites, which is common as some of these elements are present in the biota owing to biological requirements. Chromium is the only metal with detected concentrations above the SV in biota samples collected from Mākua, Mokulē‘ia, and Ka‘ena Point. Except for the chromium concentration that exceeded the SV in a single loli sample collected during the dry season from Mākua, none of the chromium concentrations that exceeded the SV in samples collected from Mākua were significantly higher than their respective counterpart samples collected from Mokulē‘ia and Ka‘ena Point. The two-sample comparison test results do not show any significantly greater mean concentrations of chromium between biota from Mākua and Mokulē‘ia, or between biota from Mākua and Ka‘ena Point. The concentrations observed in this study are comparable to what was found at the control site of the Ordnance Reef (HI-06) study (USACE 2014). The lower concentrations in limu kohu samples collected from Ka‘ena Point likely reflect the fact that this area gets the lowest runoff of the three areas studied (from soil/volcanic rock fragments from which chromium in Hawai‘i is commonly derived). Chromium (VI) is readily reduced to chromium (III) by marine organisms (Nakayama et al. 1981). Any chromium detected in biota tissues is thus highly likely to be the non-carcinogenic chromium (III) as opposed to chromium (VI).

Inorganic arsenic was not detected above the MDL in he‘e samples collected from any of the three sites. Loli samples, however, did generally contain some inorganic arsenic as well as organic arsenic, but there were no significant differences between Mākua and the two background locations. That limu kohu had the highest concentrations of inorganic arsenic and highest ratio of inorganic to total arsenic was anticipated as seaweed and other plants take up inorganic arsenic because of its structural similarity with the essential plant nutrient phosphate. Thus, the proportion of inorganic arsenic to organic arsenic is often higher in (marine) plants than in animals, in which most of the arsenic tends to occur in the organic form(s) (e.g., see Ordnance Reef [HI-06] Final Report [USACE 2014]). While all samples of limu kohu collected from Mākua, Mokulē‘ia, and Ka‘ena Point contained concentrations of inorganic arsenic that exceeded the SV of 0.0267 mg/kg, there were no statistically significant differences

between Mākua and the two background locations. This indicates that military activities at MMR are anticipated to have little influence on arsenic levels within marine resources in the Mākua nearshore or muliwai areas.

6.1.2 Fate and transport

6.1.2.1 Exposure pathway analysis

An exposure pathway describes the course that a chemical takes from a source to an exposed individual. A complete exposure pathway consists of the following four factors:

- A source of potentially toxic chemicals;
- A contaminated medium, such as loli, he‘e, or limu kohu;
- An exposure or contact point with the contaminated medium, such as consumption of loli, he‘e, and/or limu kohu; and
- An exposure route for chemical intake by a receptor, such as uptake through the gastro-intestinal tract.

Designation of an exposure pathway as complete indicates that human exposure was possible but does not necessarily mean that exposure will occur or that exposure occurs at the levels estimated in this report. When any one of the factors is missing in a pathway, it is considered to be incomplete. Incomplete exposure pathways do not pose health hazards and were not evaluated in this risk assessment.

The conceptual site model (CSM) provides the basis for identifying and evaluating the potentially complete exposure pathways at Mākua Beach and the Mākua muliwai. As shown in the CSM diagram (Appendix I, Figure 8), potential sources of COPCs include surface water, sediments, and biota (e.g., loli, he‘e, and limu kohu). The CSM shown also illustrates the potential chemical migration pathways, exposure points, and exposure routes evaluated at Mākua Nearshore area and the Mākua muliwai. Chemical fate and transport processes were used to define the potential migration pathway, and included transfer of COPCs between environmental media, such as surface water and fish tissue, and transport of COPCs through movement of an environmental medium by natural dispersive processes, such as surface water flow.

An exposure pathway is complete when there is a point at which chemical uptake by a human receptor may occur. Exposure routes considered in this

supplemental human health risk assessment are limited to loli, he‘e and limu kohu consumption.

6.1.2.2 Organochlorine pesticides

Organochlorine pesticides have had widespread use in Hawai‘i since the 1940s in support of large-scale agriculture (i.e., pineapple and sugarcane cultivation). Organochlorine pesticides adhere strongly to soil particles and can persist in the soil environment long after initial application. These chemicals can enter the aquatic environment from a variety of sources, including direct aquatic release from industrial and municipal effluents or as a result of agricultural and urban nonpoint-source runoff. When associated with soil particulates, these chemicals can be transported via erosion of agricultural soils and can enter the ocean as a component of suspended sediment loads of streams discharging into the ocean. These chemicals can also be transported to the ocean environment by wind-blown dust, and removed from the atmosphere by natural deposition, incorporation within sea mist, or by rain.

Upon entering the coastal seawater environment, organochlorine pesticides will strongly bind to marine sediments and suspended particulate matter. Incorporation of organochlorine pesticides within marine sediments acts as an environmental sink resulting in the removal of this contaminant from the water column. However, re-suspension and redistribution of these sediment-bound contaminants, as a common feature of coastal hydraulics, can result in a continued pathway of exposure to aquatic organisms. Some solubilization and volatilization (e.g., air-water exchange at sea surface) will occur, but association with particulate matter is the most significant fate mechanisms for these chemicals in the marine environment. Organochlorine pesticides bound to suspended particulate matter remain in the water column and can transport great distances within ocean currents (Ilyina et al. 2006) with marine turbulence providing a means of dilution. Organochlorine pesticides are extremely hydrophobic. As such these chemicals can bioaccumulate in lipid tissues of marine organisms as a result of exposure via ingestion or respiration. Abiotic and microbial transformation of these pesticides may be important but dependent on the specific pesticide in question.

In the present case, the occurrence of organochlorine pesticides in biota samples were limited to limu kohu samples. Alpha-BHC was identified in excess of the project SV in limu kohu samples collected during the dry

season sampling event at Mākua and Mokulēʻia, and during the wet season sampling event at Kaʻena Point. The presence of heptachlor epoxide in the limu kohu samples collected from the Mākua site may suggest transformation of heptachlor is occurring at this location. As listed in Table 15 organochlorine pesticides of the pesticides aldrin, aldrin-BHC, heptachlor, and heptachlor epoxide above threshold values were found as part of the Hydrogeologic Assessment (U.S. Army 2009b, Appendix G-1) in both surface water and a few groundwater samples. So as listed in Table 15 there is a potential pathway for these pesticides from Mākua to the Ocean. However, the mechanism of this transformation could not be determined from the existing data, since there are so many other agricultural sources of pesticides from other portions of Oahu. These pesticides may have been transported by trade winds across the Waianae Mountains, or may have been introduced by wood treated for termite control in the training area. For example, wooden pallets, often treated with pesticides for termite control, may have been brought into the training areas. Several samples contained low levels of herbicides (dalapon, 2,4-D, MCPP), which could have been introduced by weed controlling operations. There have been herbicides sprayed at Mākua to control weeds along the road.

As discussed in Section 4, heptachlor and heptachlor epoxide may have been used in the region in the past, but their use has been banned since 1988, they have not been used in the interim, and they will not be used at MMR in the future. Proposed training activities at MMR will employ Best Management Practices to control potential soil runoff or fugitive dust releases from the range. The Army will also conduct a long-term water quality monitoring program to assess current and future water quality. A monitoring program will provide the Army with another tool to evaluate potential pathways for substances to migrate beyond the boundaries of MMR. Compliance with the sustainable range program at MMR and adherence to the long-term water quality monitoring program will minimize or prevent the introduction of trace amounts of organochlorine pesticides that may be present in soils at MMR to marine resources at Mākua Beach. Because the source of organochlorine pesticides at MMR has been eliminated and because implementation of Best Management Practices will control the potential pathway for the introduction of residual organochlorine pesticides from MMR to the marine resources at Mākua Beach, the proposed training activities are not anticipated to pose an increased risk to human health to area residents who rely on marine resources for subsistence.

Further, on authorization to resume live-fire training at MMR, the Army would evaluate the potential impacts from the proposed training by conducting a long-term monitoring program to detect if there is a potential for substances to migrate off the installation and into the Mākua nearshore and muliwai areas. If a substance were identified during monitoring, the Army would conduct further analysis to verify the detection. If the identified substance were detected above the USEPA acceptable risk level, then the Army would take appropriate action to correct the situation and prevent or minimize the potential for the substance to be released into the muliwai or nearshore areas of Mākua. In accordance with the requirements of the 2001 SA, before finalizing a long-term program to monitor detected contaminants, the Army would provide a 60-day public comment period on the scope of and protocol for such monitoring.

6.1.2.3 Energetic compounds

The only energetic compounds-related contaminant detected in this study, below project SVs in all cases, was perchlorate. Perchlorate is both a naturally occurring and man-made chemical that is used to produce rocket fuels, fireworks, flares, and energetic compounds. Perchlorate can be present in bleach and in some agricultural fertilizers. Perchlorate can persist for decades in the aquatic environment because of its kinetic stability.

Upon entering the marine environment, perchlorate salts will rapidly dissolve and dissociate into perchlorate anion and a corresponding cation. Perchlorate anion (hereafter referred to as perchlorate) does not typically form insoluble metal compounds in solution (Cotton and Wilkinson 1980) and is only weakly adsorbed to mineral surfaces (Logan 2001; Urbansky and Brown 2003; Urbansky and Collette 2001). As a result, perchlorate is not efficiently removed from the water column via aqueous precipitation or adsorption to marine sediments. Concentrations are typically reduced via physical dilution and mixing or by uptake of marine organisms, including seaweeds (Martinelango et al. 2006). As a dissociated anion, perchlorate bioaccumulation is not expected to be the result of hydrophobic partitioning to lipids. Microbial transformation of perchlorate occurs under anaerobic conditions and in the presence of nitrate and sulfate (Logan 1998). Marine microbial transformation of perchlorate in coastal waters would be limited by the slow diffusion of perchlorate into deeper anaerobic sediments.

The presence of perchlorate in samples collected from all three sites may have resulted from the wide-spread use of recreational fireworks on the July 4th and New Year's holidays. Although recreational fireworks have been greatly restricted in Hawai'i since January 2011, the large plumes of smoke and fine particulate matter produced by recreational fireworks during these holidays in the recent past may have contributed to perchlorate accumulation in the near-shore environment.

As listed in Table 15, perchlorate was found at low levels in surface water samples collected as part of the Hydrogeologic Assessment (U.S. Army 2009b, Appendix G-1) so there is a potential chemical migration pathway; however, the mechanism of this transformation could not be determined from the existing data, since there are so many other agricultural sources of pesticides from other portions of Oahu. Perchlorate was found in only one biota sample collected from near Mākua Beach but was found in fifteen biota samples collected from Mokulē'ia and in fifteen biota samples collected from Ka'ena Point. This indicates a source, or sources, of perchlorate other than activities at MMR.

6.1.2.4 Dioxins/dibenzofurans

Chlorinated dioxins (CDDs) and chlorinated dibenzofurans (CDFs) are almost ubiquitous in the environment because of the numerous pathways of their formation (Ramamoorthy and Ramamoorthy, 1997). They are formed as an unintentional by-product of incomplete combustion. Industrial sources include industrial incinerators (e.g., municipal and industrial waste incinerators), cement kilns, industrial manufacture of chlorinated chemicals, and as a component of emissions from coal and oil-fired power plants. Non-industrial sources can include residential wood burning, backyard burning of household trash, oil heating, backyard barbecuing, emissions from diesel-fueled vehicles, and the burning of nearly any woody item. Low concentrations of these chemicals existed in the environment prior to industrialization as a result of natural combustion (e.g., forest and grassland fires) and volcanic activity. Transportation by wind-blown dust, deposition by atmospheric precipitation, and stream discharge of contaminated sediments are all possible modes of exposure to the near-shore environment.

Similar to the organochlorine pesticides, CDDs and CDFs are very hydrophobic and will be strongly associated with the organic fraction of marine sediments and suspended particulate matter. Therefore, the marine fate

and transport description made in the previous section will generally apply for CDDs and CDFs; however, volatilization (i.e., air-water exchange) and photolysis reactions may play a larger role in CDD and CDF removal.

TCDD dioxin isomers (i.e., Total TCDD dioxin isomers) were detected at concentrations in excess of the project SV in he‘e, loli, and limu kohu samples collected during the dry season sampling event at all sampling locations. PeCDD dioxin isomer was identified in a single he‘e sample collected from Mākua during the dry season. A single TCDD dioxin isomer detection occurred from an additional he‘e sample collected during the wet season sampling event at Ka‘ena Point. Given the widespread nature and persistence of these chemicals in the environment, their presence at low levels in these samples at both Mākua and the background locations is reasonable. In addition, as listed in Table 15 concentration of dioxin and furan compounds were present in soil, surface water, streambed sediments, and muliwai sediments as reported in the Hydrogeologic Assessment (U.S. Army 2009b, Appendix G-1) so there is a potential chemical migration pathway; however, the mechanism of this transformation could not be determined from the existing data, since there are so many other sources of dioxin and furan compounds from other portions of Oahu, including the background samples from the Waianae Coast as reported in the Hydrogeologic Assessment (U.S. Army 2009b, Appendix G-1). Their presence at low levels at both Mākua and the background locations indicates a source, or sources, other than activities at MMR.

6.1.2.5 Metals

All detections of target metal species were below project SVs (where defined) with the exception of chromium. Chromium concentrations were within the range of published values observed world-wide in a variety of marine plant and animal tissues (Neff 2002). Atmospheric pollution is a major source of chromium contamination in aquatic environments and is removed from the air by atmospheric fallout or precipitation. Other sources include water discharged from electroplating and metal finishing industries and runoff from urban areas. In the aquatic environment chromium (Cr) is typically found as trivalent (chromium [III]) or hexavalent (chromium [VI]) forms. Chromium (III) is naturally occurring, non-carcinogenic, and is an essential micronutrient for marine organisms and humans. Chromium (VI) is man-made and carcinogenic (Sadiq 1992).

Upon entering the marine environment, chromium (III) will complex with organic suspended particulate matter and adsorb to organic, oxide, hydroxide, carbonate, and clay sediment surfaces (Sadiq 1992). Incorporation of chromium within marine sediments acts as a primary environmental sink to remove chromium (III) from the water column and reducing its bioavailability; however, re-suspension and re-distribution of these sediment-bound contaminants, as a result of coastal hydraulic actions, can result in a continued pathway of exposure to aquatic organisms. Chromium (III) bound to suspended particulate matter will remain in the water column and can transport great distances within ocean currents (Ilyina et al. 2006); marine turbulence providing a means of dilution. Chromium (VI) does not form strong complexes and will typically remain in solution (Eisler 1986; Daugherty 1992).

Chromium is known to bioaccumulate in marine organisms. However, the toxicological impact of bioaccumulated chromium, and its biomagnification potential to humans, is complicated by the initial form and reactivity of chromium upon entering the organism. Chromium (VI) is readily reduced to chromium (III) by marine organisms (Nakayama et al. 1981). Any chromium detected in biota tissues is thus highly likely to be chromium (III) as opposed to chromium (VI). Chromium (III) is itself not carcinogenic, and no mechanisms are known for transforming chromium (III) to the carcinogenic form, chromium (VI) within the human digestive system (De Flora et al. 1990). Therefore it is unlikely that small amounts of chromium (III) and chromium (VI) found in seafood pose a significant cancer hazard to human consumers of seafood (Neff 2002).

Chromium concentrations were present in soil and surface water, above threshold values (Preliminary Remediation Goals) as reported in the Hydrogeologic Assessment (U.S. Army 2009b, Appendix G-1) so there is a potential chemical migration pathway for chromium; however, the mechanism of this transformation could not be determined from the existing data, since there are so many other sources of chromium including the volcanic rocks of the Waianae Mountain Range. The presence of metals, including chromium, at similar levels at Mākua and the background locations indicates a source, or sources, other than activities at MMR.

6.1.3 Risk assessment

The supplemental HHRA concluded that the total cumulative risks and hazards from the consumption of a combination of all three biota types

(i.e., loli, he‘e, and limu kohu) were within acceptable risk and hazard levels of concern for “average” consumers.

In evaluation of individual species, there were no unacceptable levels of risk calculated for consumption of either loli or he‘e at either the “average” or “high-end” consumption rate. Carcinogenic risk due to the consumption of limu kohu for both the current and future “average” or “high-end” seafood consumers exceeded the point of departure regulatory level of concern of 1×10^{-06} but was within the regulatory risk range of 1×10^{-06} to 1×10^{-04}. The regulatory risk range corresponds to the added cancer risk from exposure to site chemicals above normal background cancer rates. For example, if excess risk is 1×10^{-06} then it is estimated that an additional 1 person in 1 million individuals (roughly the population of O‘ahu island) *may* experience cancer. This risk was primarily driven by organochlorine pesticides. Organochlorine pesticides may have been used in the region in the past, but their use has been banned since 1988, they have not been used at MMR in the interim, and they will not be used at MMR in the future. If organochlorine pesticides were excluded from this assessment, estimated carcinogenic risk and noncarcinogenic hazards would be below all applicable regulatory levels of concern.

6.2 Summary of HHRA from the 2009 study

The Army conducted a marine resources study, addressing fish, shellfish (Kona Crab and urchins), other invertebrates, and limu, near Mākua Beach and in the Mākua muliwai (temporary brackish water pond) to determine if they bioaccumulate constituents at levels that could pose a health risk to area residents who rely on marine resources for subsistence (USARHAW and 25th ID (L) 2009).

The study concluded that a potential incremental carcinogenic risk (risk greater at Mākua Beach than background location) for subsistence fishermen potentially exposed to the mean concentrations of COPCs in fish is approximately 3×10^{-5}. This risk estimate is within the USEPA (1990) target risk range of 10^{-6} to 10^{-4}. The incremental risk over background is largely due to assumed exposures to alpha-BHC, bis(2-ethylhexyl)phthalate, and heptachlor epoxide. The study concluded that there is no potential incremental carcinogenic risk (risk greater at Mākua Beach than background location) for subsistence fishermen potentially exposed to the mean concentrations of COPCs in shellfish harvested at Mākua Beach

because the risk estimated for background is higher than that estimated for shellfish harvested at Mākua Beach.

A potential carcinogenic and noncarcinogenic hazard from consuming limu in the nearshore waters of Mākua was reported and was attributed largely to arsenic. Arsenic was detected in limu in concentrations ranging from 4.56 to 109 mg/kg. Limu samples from Mākua beach were composites of various species and did not include limu kohu. Limu was not collected from the background location and therefore it was not possible to determine whether the arsenic levels detected in limu at Mākua Beach are elevated over background. The arsenic was not speciated and was conservatively assumed to be entirely inorganic. The assessment of risk from consuming limu was determined to be deficient by the court ruling (U.S. District Court 2012) and as a result that assessment was conducted as part of the current study.

Based on the general similarity of carcinogenic and noncarcinogenic health risks between the Mākua Beach and the background location, it was apparent that the Army's past activities at MMR were not independently responsible for human health risks from the constituents detected in marine resources. Considering the concentrations of constituents found in the Mākua area, the numerous possible sources of these constituents, the mobility of these constituents and the fact that they can originate from multiple sources, the report concluded that it was unlikely that future military activities at MMR alone would cause unacceptable risk to human health.

6.3 Conclusions

This supplemental marine resources study was conducted as a supplemental assessment to the 2009 Marine Resources Study to investigate whether constituents potentially associated with military training at MMR are present at levels that pose an unacceptable human health risk in samples of selected species of limu kohu, he'e, and loli found near Mākua Beach and relied on for subsistence by area residents. The study was not designed to assess cumulative risk from all species and exposure pathways; neither was it designed to perform a comprehensive epidemiological study that evaluates cancer or hazard rates across different population demographics. Rather, the study was specifically designed to assess risks and hazards from the consumption of seafood items selected in accordance with the SA (i.e., he'e, loli, and limu kohu).

Table 15. Summary of potential chemical sources and migration pathways.

Chemical of Potential Concern (COPC)	Potential Source									Pathways Monitored						Marine Resources Sampled				
	Military Munitions	Other Military Training Related Activities	Regional Agriculture [1]	Termite Control [1]	Commercial Fireworks, Bleach, and Fertilizers	Wildfires, Incinerators, Cement Kilns, and Power Plants	Urban Runoff [2]	Hawai'i Background Soil [1]	Wai'anae Volcanic Soil [3]	Air [4]	Soil [4]	Groundwater[4]	Surface Water [4]	Streambed Sediments[4]	Muliwai Sediments[4]	Fish[4] (2009)	Shellfish[4] (2009)	Octopus (2014)	Sea Cucumber (2014)	Limu (2014)
Aldrin		✓	✓	✓			✓							E		E	E			
Alpha-BHC		✓	✓	✓			✓					E		E		E				
Arsenic	✓		✓			✓	✓	+	+			E								
bis(2-ethylhexyl)phthalate												E				E				
Cadmium	✓					✓	✓	✓	✓								E			
Chromium	✓					✓	✓	+	✓	D										
Cobalt	✓					✓	✓	✓	✓								E			
Dioxins/dibenzofurans		✓	✓	✓		✓	✓				E		E	E	E					
Heptachlor/Heptachlor epoxide		✓	✓	✓			✓									E				E
Manganese	✓					✓	✓		✓								E			
Nitroglycerin	✓				✓											E				
Perchlorate	✓				✓								E				E			

Notes:

✓ = Potential Source.

+ = Potential Source, background concentration exceeds Preliminary Remediation Goal for soil.

D = Present at detectable concentrations.

E (water and sediments) = Exceeds Preliminary Remediation Goal (PRG) for groundwater or soil (Now called Regional Screening Levels by the EPA).

E (fish, shellfish, limu) = Incremental risk exceeds US EPA risk level for fish consumption (1E-05) or hazard index of 1.

In the 2014 assessment, background locations were evaluated by calculating their respective background threshold values, to which concentrations at Mākua were compared. Chemicals below the background threshold value were eliminated from evaluation. As such, only the incremental hazards were evaluated. The 2009 risk assessment evaluated risk in a different manner than was used for the 2014 risk assessment, calculating the potential risk at Mākua as well as at the background sites and then subtracting to determine the incremental risk. The overall conclusion of the 2009 risk assessment was that: "based on the general similarity of carcinogenic and noncarcinogenic health risks between the Mākua area and the background sites, it is apparent that the Army's past activities at MMR are not independently responsible for any human health risks from the substances detected in marine resources." For a more detailed description of the 2009 risk assessment methodology, results, and conclusions, please refer to the 2009 study.

The limu samples collected in 2009 were composite samples that included many species of limu, but excluded the most commonly eaten species: limu kohu. Limu samples collected in 2009 were analyzed for total arsenic, but not for inorganic arsenic. The 2014 limu kohu data are considered much more accurate and appropriate for this study, and thus only the 2014 data are summarized in Table 15.

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[1]State of Hawai'i Department of Health (HDOH), 2014. Technical Guidance Manual for the Implementation of the Hawai'i State Contingency Plan.

[2]U.S. Geological Survey (USGS), 1998. Occurrence of Organochlorine Pesticides in Stream Bed Sediment and Fish from Selected Streams on the Island of O'ahu, Hawai'i.

[3]Department of the Navy (DON), 2006. Environmental Background Analysis of Metals in Soil at Navy O'ahu Facilities.

[4]USARHAW and 25th ID (L), 2009. Marine Resources Study, Field Sampling Results and Risk Assessment, Mākua Military Reservation, O'ahu, Hawai'i

This study was conducted in a transparent manner and achieved the sampling goal of collecting eight samples each of limu kohu, he‘e, and loli during two sampling seasons (dry and wet) at Mākua and the two background locations (Mokulē‘ia and Ka‘ena Point). Samples were analyzed for the COPCs (including speciation of arsenic into the organic and inorganic fractions) and evaluated to determine the potential risks to human health.

Based on the results of the supplemental HHRA, the total cumulative risks and hazards from the consumption of a combination of all three biota types (i.e., loli, he‘e, and limu kohu) collected from Mākua were within acceptable risk and hazard levels of concern for “average” consumers. In evaluation of individual species, there were no unacceptable levels of risk calculated for consumption of loli or he‘e at either the “average” or “high-end” consumption rate. Carcinogenic risk due to the consumption of limu kohu for both the current and future “average” or “high-end” seafood consumers exceeded the point of departure regulatory level of concern of 1×10^{-06} but was within the regulatory risk range of 1×10^{-06} to 1×10^{-04}. The regulatory risk range corresponds to the added cancer risk from exposure to site chemicals above normal background cancer rates. For example, if excess risk is 1×10^{-06} then it is estimated that an additional 1 person in 1 million individuals (roughly the population of O‘ahu island) *may* experience cancer. The carcinogenic risk due to the consumption of limu kohu was primarily driven by organochlorine pesticides, which are not a component of military munitions and are present due to onshore anthropogenic sources and urban/agricultural runoff. If organochlorine pesticides were excluded from this assessment, estimated carcinogenic risk and noncarcinogenic hazards would be below all applicable regulatory levels of concern.

The risk assessment was based on some extremely conservative assumptions that are unlikely to be met; including an assumption that 100% of the hypothetical consumer’s seafood was from Mākua alone, whereas surveys of area residents indicate that a significant portion of their seafood intake comes from markets and nonlocal sources. This scenario was chosen to assess the worst-case scenario for seafood consumption along the Wai‘anae coast. The U.S. Food and Drug Administration has routinely recommended moderate seafood consumption to limit ingestion of mercury that is associated with certain high-end predatory fish found throughout the world’s oceans. A similar recommendation is likely warranted here.

This supplemental marine resource study provides the data and analysis necessary to answer the objectives established in the 2007 SA and the 20 June 2012 ruling:

Determine whether fish, shellfish, limu (marine algae), and other marine resources near Mākua Beach or muliwai (estuaries or stream mouths), which area residents rely on for subsistence are contaminated by substances associated with proposed military training at Mākua.

Objective #1 was adequately addressed in the 2009 study, except for the failure of the study to evaluate other relevant marine resources consumed by area residents. This 2015 study evaluated the presence or absence of COPCs in three additional marine resources, limu kohu, he‘e, and loli, collected from near Mākua Beach as well as in those same samples collected from two background locations. The marine resources to be sampled were selected based on interviews with local community members and consultation with local cultural practitioners.

Concentrations of COPCs in fish and shellfish were evaluated during the 2009 study; please refer to that study for detailed results.

This 2015 study determined that several compounds associated with proposed military training activities at Mākua were present in limu kohu, he‘e, and loli collected from near Mākua Beach. These compounds included semivolatile organic compounds, organochlorine pesticides, perchlorate, dioxins/dibenzofurans, metals, and arsenic (inorganic and organic). Of these compounds, only zinc, dimethyl arsenic, and organochlorine pesticides were present in biota collected from near Mākua Beach at concentrations significantly higher than in samples collected from the two background locations.

Evaluate whether there is a potential that activities at MMR have contributed or will contribute to contamination in fish, shellfish, limu, and other marine resources;

This study measured concentrations of COPCs in biota collected from near Mākua Beach and compared them to concentrations of COPCs in biota collected from two background locations to evaluate the potential contribution of those COPCs in marine resources that could have resulted from military training activities at MMR. This study also examined planned

future training activities at MMR to assess whether they could contribute an increased level of COPCs to marine resources at Mākua Beach.

All the analytes (the suite of substances that the laboratory analyzed) have a wide range of natural and anthropogenic (man-made) sources. Examples include volatile organic compounds (fuels and gasoline), semivolatile organic compounds (plastics, such as toys), energetics (military munitions and commercial fireworks) organochlorine pesticides (commercial agriculture such as pineapple and sugarcane), perchlorate (commercial fireworks), dioxins/dibenzofurans (byproducts of burning any wood or woody material), metals (volcanic rocks, cars/trucks, fenceposts), and arsenic (natural geologic origin).

In this study, the majority of the COPCs were detected at similar levels in biota collected from near Mākua Beach compared to biota collected from the two background locations. Compounds detected in biota during this study are not unique to military training and are found at both Mākua and background locations; therefore, proposed military activities are anticipated to have little influence, either currently or in the future, on contaminant levels within marine resources in the Mākua nearshore or muliwai areas.

Three COPCs were present at significantly higher concentrations in biota collected from near Mākua Beach than in biota samples collected from the two background locations: zinc in he‘e, dimethyl arsenic in limu kohu, and organochlorine pesticides in limu kohu. The concentrations of zinc in he‘e did not exceed the screening value and dimethyl arsenic has no screening value, thus neither compound advanced to risk assessment and neither is of further concern in this study. Organochlorine pesticides may have been used in the region in the past, but most of these organochlorine pesticides have been banned since 1988. They have not been used at MMR in the interim, and they will not be used at MMR in the future.

There is some potential for past and future release of substances from military training activities at MMR. However, the low levels of most substances detected during this investigation supports the position that if 60 years of live-fire training has not resulted in significant detectable levels of most substances in the area, then future live-fire activities at MMR would be expected to be likewise insignificant. For those substances detected at higher levels, their occurrence in the area cannot uniquely be

attributed to military activities because there are and have been many natural and anthropogenic sources that contribute substances to the Mākua area. The proposed training activities at MMR aren't anticipated to use additional types or quantities of munitions or equipment compared to what has been used historically, thus there is no increase in the potential sources of COPCs from MMR. Proposed training activities at MMR will be closely managed under a sustainable range program that will ensure that training activities do not introduce significant levels of energetics into the soil and will also employ Best Management Practices to control potential soil runoff or fugitive dust releases from the range. The Army will also conduct a long-term water quality monitoring program to assess current and future water quality. A monitoring program will provide the Army with another tool to evaluate potential pathways for substances to migrate beyond the boundaries of MMR. Compliance with the sustainable range program at MMR and adherence to the long-term water quality monitoring program will minimize or prevent the introduction of trace amounts of COPCs from MMR to marine resources at Mākua Beach. By limiting the sources of potential COPCs to be used at MMR and by controlling the potential pathway for the introduction of potential COPCs from MMR to the marine resources at Mākua Beach, the proposed training activities are not anticipated to pose an increased risk to human health for residents who consume marine resources.

Evaluate whether the proposed training activities pose a human health risk to area residents who rely on marine resources for subsistence.

The Army conducted a human health risk assessment in 2009 to evaluate potential risks to area residents who consume fish, shellfish, other invertebrates, and limu from Mākua Beach. The 2009 human HHRA concluded that: “based on the general similarity of carcinogenic and noncarcinogenic health risks between the Mākua area and the background sites, it is apparent that the Army’s past activities at MMR are not independently responsible for any human health risks from the substances detected in marine resources. Considering the level of substances found within the Mākua area, the numerous sources with which these substances are associated, and the ability of these substances from multiple sources to be transported by rain flow and ocean currents, it is not likely that future activities at MMR alone would contribute substances to the marine environment at a level sufficient to cause a human health risk.” Refer to the 2009 study for additional details.

This 2015 study further evaluated potential human health risks to area residents who consume limu kohu, he‘e, and loli from Mākua Beach. The supplemental HHRA concluded that the total cumulative risks and hazards from the consumption of a combination of all three biota types (i.e., loli, he‘e, and limu kohu) were within acceptable risk and hazard levels of concern for “average” consumers. In evaluation of individual species, there were no unacceptable levels of risk calculated for consumption of either loli or he‘e at either the “average” or “high-end” consumption rate. The HHRA found that carcinogenic risk due to the consumption of limu kohu for both the “average” and “high-end” consumer exceeded regulatory levels of concern. However, these risks assumed that one consume quantities of limu kohu that are highly unlikely, given that limu kohu at the study area is extremely scarce. This was corroborated during the sampling events and confirmed by a local fisherman at the public meeting (Appendix J)

The risk was primarily driven by organochlorine pesticides, which are not proposed for use during future training activities at MMR. As discussed above, organochlorine pesticides may have been used in the region in the past, but their use has been banned since 1988, they have not been used in the interim, and they will not be used at MMR in the future. Proposed training activities at MMR will also employ Best Management Practices to control potential soil runoff or fugitive dust releases from the range. The Army will also conduct a long-term water quality monitoring program to assess current and future water quality. A monitoring program will provide the Army with another tool to evaluate potential pathways for substances to migrate beyond the boundaries of MMR. Compliance with the sustainable range program at MMR and adherence to the long-term water quality monitoring program will minimize or prevent the introduction of trace amounts of organochlorine pesticides that may be present in soils at MMR to marine resources at Mākua Beach. Because the source of organochlorine pesticides at MMR has been eliminated and because implementation of Best Management Practices will control the potential pathway for the introduction of residual organochlorine pesticides from MMR to the marine resources at Mākua Beach, the proposed training activities are not anticipated to pose an increased risk to human health to area residents who rely on marine resources for subsistence.

Further, on authorization to resume live-fire training at MMR, the Army would evaluate the potential impacts from the proposed training by conducting a long-term monitoring program to detect if there is a potential for

substances to migrate off the installation and into the Mākua nearshore and muliwai areas. If a substance were identified during monitoring, the Army would conduct further analysis to verify the detection. If the identified substance were detected above the USEPA acceptable risk level, then the Army would take appropriate action to correct the situation and prevent or minimize the potential for the substance to be released into the muliwai or nearshore areas of Mākua. In accordance with the requirements of the 2001 SA, before finalizing a long-term program to monitor detected contaminants, the Army would provide a 60-day public comment period on the scope of and protocol for such monitoring.

Complete one or more studies of limu and other marine resources (e.g., octopus and sea cucumber) near Mākua Beach on which Waiʻanae Coast residents rely for subsistence (obtaining food as a means of maintaining life), in accordance with the terms and conditions set forth in paragraphs 6, 7, and 10 of the 2007 SA (U.S. District Court 2007).

This supplemental marine resource study included the collection of two rounds of samples from the ocean area adjacent to Mākua Beach, as well as from two background locations established in the SAP. This objective has thus been satisfied.

Specify in the study whether arsenic, if present in limu or other marine resources, is organic or inorganic and determine background contamination by testing limu and other marine resources at locations in Hawaiʻi other than Mākua Beach.

This study included the speciation of arsenic into inorganic and organic forms and established background concentrations by testing limu and other marine resources at locations on Oʻahu other than Mākua Beach. There were no statistically significant differences in concentrations of total arsenic or total inorganic arsenic (the more toxic form of arsenic) in biota samples collected from near Mākua Beach when compared to the two background locations. There was a statistically significant difference in the average concentration of dimethyl arsenic in limu kohu collected from Mākua compared to the background locations. Dimethyl arsenic is an organic form of arsenic that is not considered to be toxic, thus this compound has no screening value, and its elevated concentration in limu kohu samples collected from near Mākua Beach compared to the two background locations is considered to be of no concern in this study.

In summary, this supplemental marine resource study has provided the data and analysis necessary to satisfactorily answer the objectives established in the 2007 SA and the 2012 court ruling. In this study, the majority of the COPCs were detected at similar levels in biota collected from near Mākua Beach compared to biota collected from the two background locations. Compounds detected in biota during this study are not unique to military training and are found at both Mākua and background locations; therefore, proposed military activities are anticipated to have little influence, either currently or in the future, on contaminant levels within marine resources in the Mākua nearshore or muliwai areas. While the HHRA found that carcinogenic risk due to the consumption of limu kohu for both the "average" and "high-end" consumer exceeded regulatory levels of concern, the primary risk driver was from two components of organochlorine pesticides (now banned from use) that are not known to have been used at MMR and will not be used in the future. Because there is not a current or future source of organochlorine pesticides at MMR and because implementation of Best Management Practices will control the potential pathway for the introduction of residual organochlorine pesticides from MMR to the marine resources at Mākua Beach, the proposed training activities are not anticipated to pose an increased risk to human health to area residents who rely on marine resources for subsistence.

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