Marine Sanctuaries Conservation Series NMSP-07-01

ORDNANCE REEF, WAI'ANAE, HAWAI'I.
Remote Sensing Survey and Sampling at a Discarded Military Munitions Sea Disposal Site
FINAL REPORT

U.S. Department of Commerce
National Oceanic and Atmospheric Administration
National Ocean Service
Office of Ocean and Coastal Resource Management
National Marine Sanctuary Program

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About the Marine Sanctuaries Conservation Series

The National Oceanic and Atmospheric Administration's National Ocean Service (NOS) administers the National Marine Sanctuary Program (NMSP). Its mission is to identify, designate, protect and manage the ecological, recreational, research, educational, historical, and aesthetic resources and qualities of nationally significant coastal and marine areas. The existing marine sanctuaries differ widely in their natural and historical resources and include nearshore and open ocean areas ranging in size from less than one to over 5,000 square miles. Protected habitats include rocky coasts, kelp forests, coral reefs, sea grass beds, estuarine habitats, hard and soft bottom habitats, segments of whale migration routes, and shipwrecks.

Because of considerable differences in settings, resources, and threats, each marine sanctuary has a tailored management plan. Conservation, education, research, monitoring and enforcement programs vary accordingly. The integration of these programs is fundamental to marine protected area management. The Marine Sanctuaries Conservation Series reflects and supports this integration by providing a forum for publication and discussion of the complex issues currently facing the National Marine Sanctuary Program. Topics of published reports vary substantially and may include descriptions of educational programs, discussions on resource management issues, and results of scientific research and monitoring projects. The series facilitates integration of natural sciences, socioeconomic and cultural sciences, education, and policy development to accomplish the diverse needs of NOAA's resource protection mandate.

ORDANANCE REEF, WAI’ANE, HAWAI’I
Remote Sensing Survey and Sampling at a Discarded Military Munitions Sea Disposal Site

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COVER

Wai'anae coast. (NOAA/NMSP)

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ABSTRACT

National Oceanic and Atmospheric Administration (NOAA) National Marine Sanctuary Program (NMSP) entered into a Special Studies Agreement with the United States Army (Office of the Deputy Assistant Secretary of the Army for Environment, Safety and Occupational Health (DASA (ESOH)) and the United States Navy (Office of the Deputy Assistant Secretary of the Navy for the Environment (DASN(E)) to collect screening level data to support a Department of Defense (DoD) evaluation of potential explosive and human health hazards posed by military munitions present at the site. The objective of the Ordnance Reef Project is to independently collect data to define the extent of a discarded military munitions sea disposal site off O'ahu Hawai'i, in an area locally referred to as Ordnance Reef, and determine through biological, sediment and water column sampling whether munitions constituents (e.g., explosives, metals) are potentially impacting human health and the environment. This data will support DoD's evaluation of potential risks posed to human health and the environment from the discarded military munitions at Ordnance Reef.

LIST OF ACRONYMS

C&C	City and county
DASA (ESOH)	Deputy assistant Secretary of the Army for Environment, Safety and Occupational Health
DASN (E)	Office of the Deputy Assistant Secretary of the Navy for the Environment
DGPS	Differential Global Positioning System
DLNR	Department of Land and Natural Resources
DO	Dissolved oxygen
DoD	Department of Defense
DSO	Dive Safety Officer
EA	Environmental assessment
FAD	Fish aggregating devices
FDA	Federal Drug Administration
FSP	Field Sampling Plan
GIS	Graphical information system
GPS	Global positioning system
HASP	Health and Safety Plan
HSTP	Hydrographic System & Technology Program
Kg	Kilograms
MDSU	Military dive support unit
Mg	Milligrams
NASA	National Aeronautics and Space Administration
NOAA	National Oceanic and Atmospheric Administration
NRDC	Natural Resources Defense Council
NMSP	National Marine Sanctuary Program
OCS	Office of Coast Survey

OIC	Ocean Imaging Consultants, Inc.
ppm	Parts per million
ppt	parts per thousand
QA	Quality Analysis
QAPP	Quality Assurance Project Plan
QC	Quality control
ROV	Remotely operated vehicle
SAP	Sampling and Analysis Plan
SOP	Standard operating procedure
TIFF	Tagged Image File
USACE	U.S. Army Corps of Engineers
USEPA	U.S. Environmental Protection Agency
UXO	Unexploded ordnance
WWTP	Wastewater treatment plant
XRF	X-ray fluorescence spectrometry

TABLE OF CONTENTS

Topic Page

APPENDIX

LIST OF FIGURES AND TABLES

Table Page

EXECUTIVE SUMMARY

The main thrust of the Ordnance Reef Project, under the direction of the Office of the Deputy Assistant Secretary of the Army for Environment, Safety and Occupational Health (ODASA (ESOH)) and the Office of the Deputy Assistant Secretary of the Navy for the Environment (DASN (E)) was to independently collect data to define the extent of a discarded military munitions sea disposal site off O'ahu Hawai'i that is locally referred to as Ordnance Reef and determine the presence or absence of munitions constituents (e.g., explosives, metals) through biological, sediment and water sampling. This data will support DoD's evaluation of potential risks posed to human health and the environment from the discarded military munitions at Ordnance Reef.

NOAA conducted a side scan sonar survey was conducted to identify locations of possible military munitions and determine the extent of these munitions within the study area. Once the survey team located the areal extent of likely munitions, it divided the study area into three sub-areas: the munitions area, the control area and the Wai'anae Ocean Outfall area. The munitions area included the area where discarded military munitions were previously discovered. The control area which was up current from the munitions and outfall areas was selected far enough from the other two areas so that biota would be unlikely to be affected by the target munitions constituents and chemicals originating from the other two.

NOAA surveyed an 81.7 linear mile area was surveyed using side scan sonar. In addition, 96 sediment samples and 49 fish were collected and all were analyzed for metals. All of the fish and a portion of the sediment samples were also analyzed for explosives. Water samples were collected and processed for salinity, dissolved oxygen, pH and temperature.

The project was confined to a maximum depth (approximately 300 feet) based on equipment limitations. The extent of the discarded military munitions area extends from depths of 24 feet to the maximum depth of our study area. Clusters (9) of military munitions not previously identified were found near shore. Discarded military munitions present within the study area range from small arms ammunitions to large caliber projectiles and naval gun ammunition. The identification of the specific munitions proved difficult as these munitions had been underwater for some time and had provided habitat for marine life. As a result, most munitions and clusters of munitions were encrusted in coral growth. Because the DoD cautioned the project team not to move or disturb munitions, which prohibited removing coral growth, the identification of munitions by specific type during deeper dives was difficult.

Overall trace metal enrichment in sediments from the study area is very low. This observation suggests that little contamination of the Ordnance Reef area is derived from discarded military munitions. Areas where high metals were detected were located at the outfall from the on-shore Wai'anaeWastewater Treatment Plant (WWTP) and attributed to natural land drainage from adjacent road surfaces and volcanic rock minerals. There were no detections of the explosives cyclonite (RDX), trinitrotoluene (TNT), or tetryl during the sampling effort, however, a related munitions compound, dinitrotoluene (DNT) was detected in four sediment samples (three near munitions, and one not associated with munitions). No explosives or related compounds were detected in the fish.

1. ORDNANCE REEF PROJECT DESCRIPTION

The National Oceanic and Atmospheric Administration (NOAA)'s National Marine Sanctuary Program (NMSP) entered into a Special Studies Agreement with the United States Army (Office of the Deputy Assistant Secretary of the Army for Environment, Safety and Occupational Health (DASA (ESOH)) and the United States Navy (Office of the Deputy Assistant Secretary of the Navy for the Environment (DASN(E)) to collect screening level data to support a Department of Defense (DoD) evaluation of potential explosive and human health hazards posed by military munitions present at the site.

Ordnance Reef Project Objective:

The projects objective of this project is to independently collect data to define the extent of the discarded military munitions sea disposal site off O'ahu Hawai'i, in an area locally known as Ordnance Reef and determine through biological, sediment, and water column sampling, whether munition constituents (e.g., explosives, metals) are potentially impacting human health and the environment. This will support a DoD evaluation of potential risks posed to human health and the environment from discarded military munitions at Ordnance Reef. This objective explicitly includes:

- Determining the boundaries of the site, quantity, type, and distribution of military munitions within the study area.
- Assessing Ordnance Reef to determine if munitions constituents releases have occurred within the study area.

    - If a release has occurred, determine its location and source.
    - Collect data to support an evaluation of whether the release poses a threat to human health and the environment.

Supporting tasks to accomplish the objective include:

- Re-acquiring and imaging key military munitions located during the 2002 survey of Ordnance Reef (2002 survey) that the US Army Corps of Engineers conducted under the Formally Used Defense Site Program and imaging targets of significance not previously identified. Document coordinates.
- Providing data to DoD to allow identification of munitions types
- Verifying and comparing the ecology of the study area, to include a control area to habitat descriptions in the 2004 *Wai'anae Ecological Characterization* through close-in acoustic and optical survey using high resolution side scan sonar remotely operated vehicle (ROV) and self contained breathing apparatus (SCUBA) divers
- Measuring the oceanographic conditions associated with the study area to include current profile, pH, dissolved oxygen (DO), conductivity and salinity
- Conduct a representative amount of sampling and analysis to develop a profile of concentrations for munitions constituents (e.g., explosives, metals) in sediment, water and fish tissue samples across Ordnance Reef and comparing

metals concentrations in sediment and water to relevant local control area conditions.

- Fish collected are species harvested for human consumption.
- Perform primary component analysis of metals to identify contributions from terrigenous input and areas influenced by anthropogenic sources such as the Wai'anae Waste Water Treatment Plant (WWTP) (i.e., sewage treatment plant)

The project's objective was accomplished through remote sensing and the collection and analysis of environmental media and fish tissue. The site is a known munitions disposal area in Pokai Bay off Wai'anae and Maili, O'ahu, HI (Figure 1). An interdisciplinary approach was necessary and included participants from NOAA's NMSP, National Marine Fisheries Service, National Ocean Service, Office of Coast Survey (OCS) Hydrographic System & Technology Program (HSTP), Special Project Office, State of Hawai'i Division of Aquatic Resources, University of Hawai'i, Teledyne Benthos and Oceanic Imaging Consultants, Inc.

Data from the 2002 report of this area was used in planning the project. Military munitions located during the 2002 survey were re-acquired and imaged providing greater detail during this project. Deeper areas not surveyed under USACE's effort were examined to determine the extent (boundaries) of this disposal area to the depth allowed by the survey equipment. The project was confined to depths within optimum survey limits (approximately 300 feet) of the vessel and equipment.

This report presents the purpose, scope of work, strategy, methodology and data acquired from various marine resources, sediment and water in the defined study area. Marine resources were also sampled from reference locations adjacent to O'ahu, up current from the study area, and not expected to have been impacted by Ordnance Reef or the Wai'anae Ocean Outfall (outfall).

The project planning considered other possible environmental impacts to the area such as the outfall located at the southeast corner of the study area. The fieldwork began on May 28, 2006 and was completed on June 8, 2006.

This final report of findings is hereby provided to the Offices of the Secretaries of the Army and Navy.

2. SITE DESCRIPTION

Ordnance Reef, (Unexploded Ordnance as indicated on NOAA's nautical chart 19340), lies on the western, leeward side of O'ahu and covers an area of approximately 1 nautical mile in length by 0.5 nautical miles in width, and lies in approximately 10 - 70 meters of water. The nearest Hawaiian cities are Wai'anae, which is approximately 3 miles to the northeast, and Maili, HI, approximately 5 miles to the east.

Site History

During a benthic survey of the outfall in 1992, City and County (C&C) of Honolulu, Department of Wastewater Management's oceanographic team discovered military munitions between 0.3 and 0.6 miles northwest of the existing sewage outfall's diffuser. Military munitions observed between 60 and 120 feet deep included clipped .50 caliber ammunition, and projectiles (possibly 3 to 5 inch naval projectile) that were 2 to 3 feet long. All military munitions observed were described as discarded military munitions. The C&C's oceanographic team also discovered military munitions south of the sewage outfall and just west of the Hawai'i-designated Fish Haven.

At the request of Army Corps of Engineers, the Explosive Ordnance Disposal Detachment (MIDPAC (UIC-32082) from Pearl Harbor, HI planned to conduct a diver survey to determine the various amounts and types of military munitions in Pokai Bay on the western coast of O'ahu, HI. The survey for military munitions was scheduled to begin September 2001 but put on hold until July 2002 due to the events of September 11, 2001. Diving operations began on July 18 and continued until July 25, 2002. The search method employed was swimming a course heading the length of the study area, with course corrections sent from the surface to ensure accurate runs. Each run was 100 yards apart. This was deemed sufficient to get a general evaluation of the overall search area. Bounce dives were conducted on the deepest section just outside of the third section to try and determine the extent the military munitions disposal site. Contacts were reported and marked using global positioning system (GPS) (Figure 1).

A variety of military munitions were located during the survey, including, but not limited to naval gun ammunition, 105mm and 155mm artillery projectiles, mines, mortars, and small arms ammunition. According to ODASA-ESOH, the munitions appear to be discarded military munitions (DMM[1]), not unexploded ordnance (UXO[2]) (defined below). This is important

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[1] Discarded Military Munitions (DMM). Military munitions that have been abandoned without proper disposal or removed from storage in a military magazine or other storage area for the purpose of disposal. The term does not include unexploded ordnance, military munitions that are being held for future use or planned disposal, or military munitions that have been properly disposed of, consistent with applicable environmental laws and regulations. (10 U.S.C. 2710(e).

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

because discarded military munitions are considered to pose less of a explosives hazard than unexploded ordnance because unlike unexploded ordnance, such munitions have not been through their arming sequence.

Records detailing the disposal of munitions at this location have not been uncovered through extensive research efforts. It is presumed these munitions date from the activities associated with World War II. The geographic boundaries of this project encompassed a search area of approximately 3 by 1.5 nautical miles that was inclusive of the 2002 survey's study area, Fish Haven and the outfall area. Based on the USACE documentation of its 2002 survey, the munitions described are expected to contain one or more of the following compounds as their major explosive contents: TNT, RDX, tetryl. The metal target compounds were: arsenic, copper, and lead.

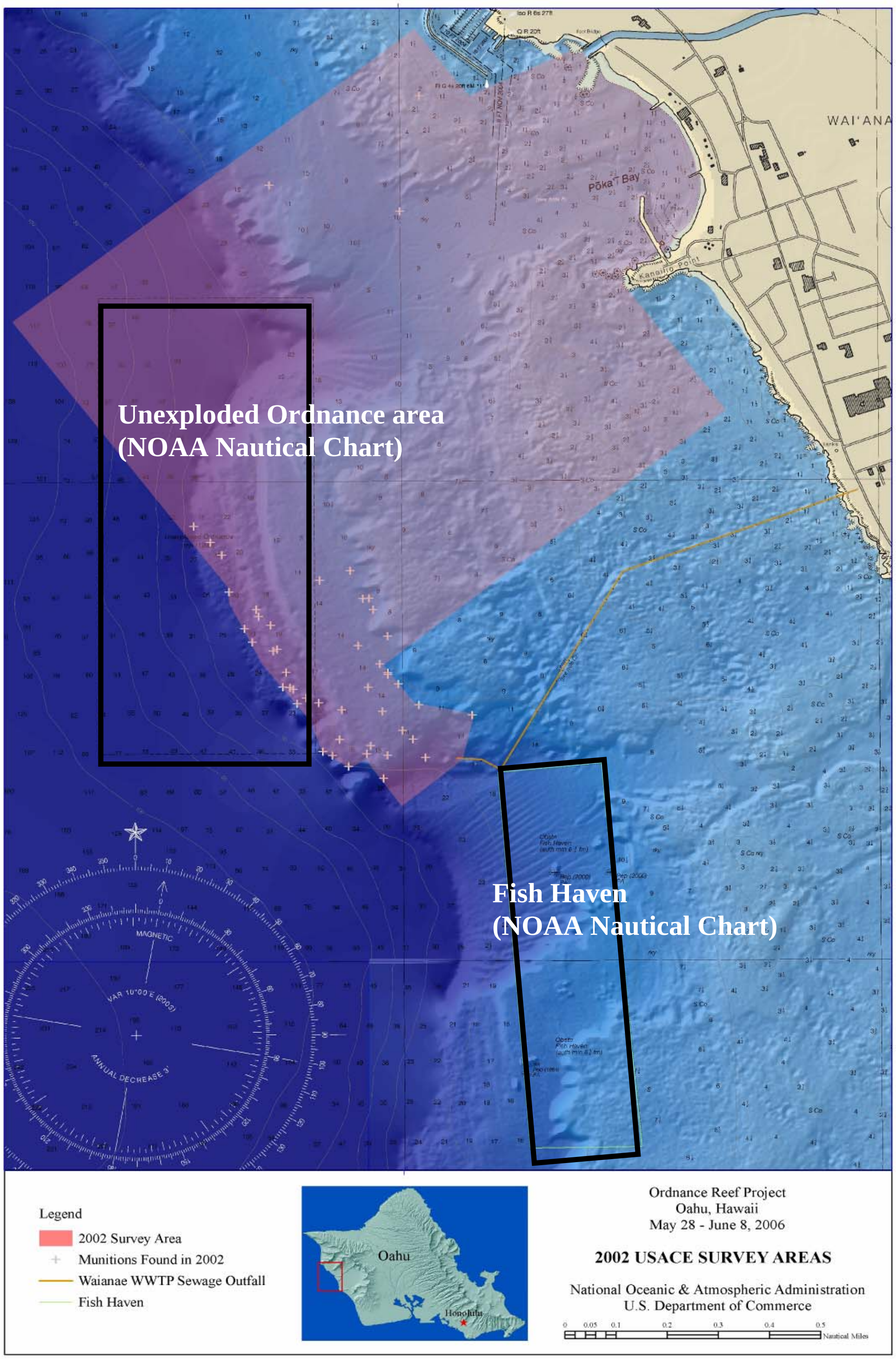

Figure 1. USACE 2002 study area. (Pink shaded area)

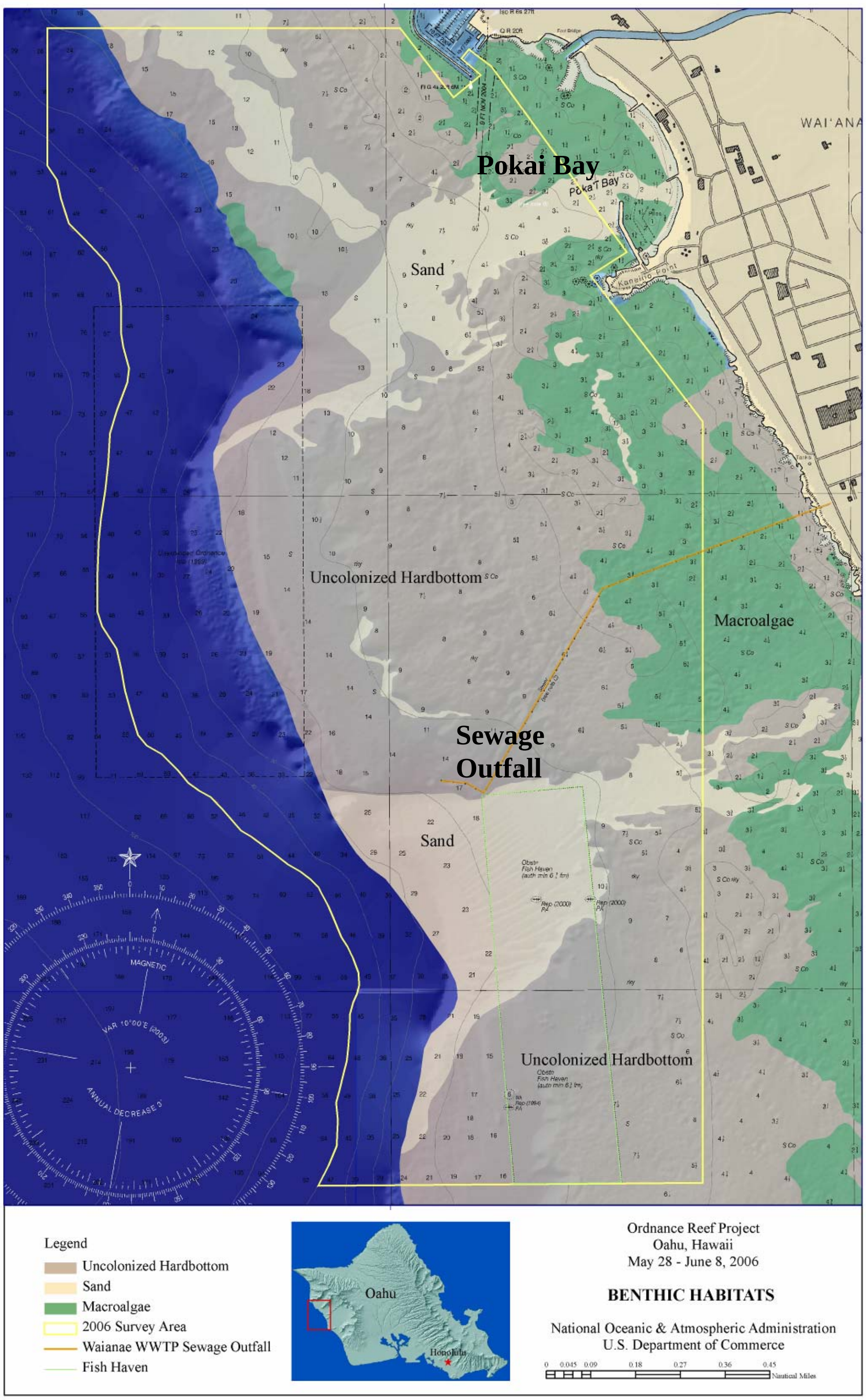

Figure 2. Benthic habitat map in study area.

3. ENVIRONMENTAL CONDITIONS

The following section describes the various environmental influences affecting both the survey operations and samples recovered in the study area. A consideration of environmental conditions is fundamental for the science team to determine the proper equipment and techniques to be used in collecting data, along with the potential effect the natural processes may have on the condition of the disposed munitions. Environmental factors may also contribute to the post depositional alterations of munitions within the study area. The data presented was used by researchers and is intended to familiarize the reader with the general conditions in the study area and the Island of O'ahu. The data contained in this section has been extracted from the *Wai'anae Ecological Characterization, a State, Federal, and Community Partnership* project.

Climate

Waiʻanae Rainfall

Due to the impact of the rain shadow on storms driven by the trade winds, Waiʻanae is usually one of the driest areas on the island. The average annual rainfall in Waiʻanae is 21.3 inches (55 centimeters), less than half of the average for Oʻahu as a whole.

During the wet season, or hoʻoilo, the trade winds weaken and are periodically replaced by Kona winds. The storms carried by the Kona winds approach the island from the southwest. Because the majority of Oʻahu's land mass is southwest of the Koʻolau Mountains, precipitation generated from the Kona wind storms is evenly distributed across the island, with the exception of the area east of the Koʻolau Mountains

Kona storms are an important source of water supply in the Waiʻanae area. About 65 percent of the annual recorded precipitation for the area comes from these wet season storms. It is expected that the rainfall has washed minerals from the mountain region north of the study area through the agricultural valleys into the ocean. The southeast current could carry the minerals into the study area.

The back to back storms during February and March 2006 had set records on the Island of O'ahu. These storms carried sediment into the study area. Sediment derived from mafic volcanic rocks can have a relatively high proportion of ferromagnetic materials and consequently a high magnetic susceptibility that could complicate interpretation of magnetometer data in predominantly marine carbonate sediments of the study area. These sediments, being carried into the study area were thought by the science team to cause a large number of magnetic anomalies providing researchers with what is known as false positives. Based on the heavy rains and the magnetic signatures associated with volcanic rock, the use of a magnetometer was omitted from the survey plan.

Geology and Geomorphology

The Hawai'ian Islands stretch about 1,600 miles from the island of Hawaiʻi to Kure Atoll in the Northwestern Hawai'ian Islands. These islands are part of a volcanic chain that runs nearly 4,000 miles from the Aleutian Islands to the central Pacific Ocean, formed from a combination of tectonic plate movement and a volcanic hotspot that now lies beneath the Island of Hawaiʻi. These islands range in age from nearly 30 million years old—Midway Atoll in the northwest—to land currently being formed by volcanic eruptions on Hawaiʻi (Juvik and Juvik 1998).

Like all regions of the Hawai'ian Islands, the geology and geomorphology of Waiʻanae are based on its individual volcanic origins and history. The island of Oʻahu was formed by two volcanoes, the Waiʻanae and Koʻolau, beginning approximately four million years ago (Stearns and Vaksvik 1935). Soils in the Waiʻanae moku[3] are a result of its volcanic history, as well as recent erosion processes. Volcanic eruption deposited lava flows and pyroclastics that built the main mass of the Waiʻanae volcano, which has since gradually eroded to its current physical characteristics.

Soils

Soils in the Waiʻanae moku have a volcanic origin. Eruptions of the main shield-building stages of the Waiʻanae volcano began at the ocean floor between 3 and 4 million years ago, depositing lava flows and pyroclastics that built the main mass of the Waiʻanae volcano, which eventually rose to more than 10,000 feet above the ocean surface. Additional volcanic activity occurred between 2.5 and 3 million years ago, with the last activity occurring a half-million years ago, before the volcanos became inactive.

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

1. Lualualei Series, Fill Land, and ʻEwa Series Association
2. Tropohumults-Dystrandepts Association
3. Rock Land and Stony Steep Land Association

Other soil types and associations exist within Waiʻanae, including the Kemoʻo, Mahana, Mokulēʻia, and Pulehu series. In addition, rock outcrops are present at various locations throughout the moku (Figure 3).

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[3] **moku**: district, island, islet, section, forest, grove.

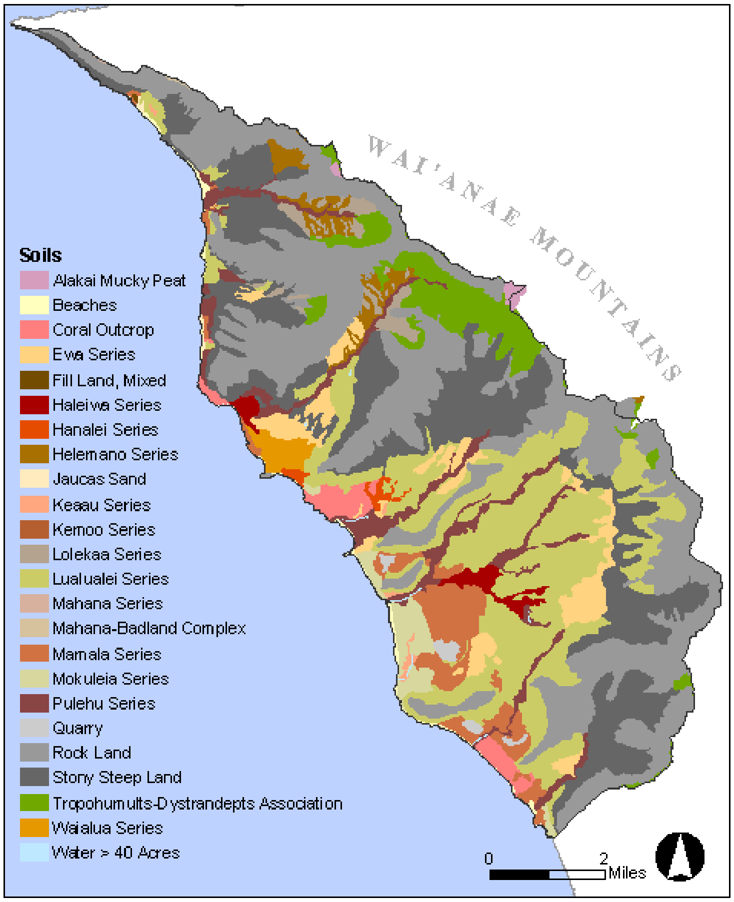

Figure 3. Soil types of the Wai‘anae moku, 2003.Source: CZM Hawai‘i

Coastal Waters

All Hawai‘i State waters are classified as Class A or Class AA. Class A waters have strict pollution discharge regulations to protect them for recreational and aesthetic enjoyment. Class AA waters have regulations against discharge to maintain the waters in a natural pristine state. The Wai‘anae coast is designated Class A waters from Barbers Point at the southern end to Mākua Beach near the northern end.

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

Nutrients

Nutrients are taken up by marine plants, phytoplankton, and marine algae for primary production. Nutrients commonly measured in seawater include silica and inorganic and organic forms of nitrogen (nitrate and nitrite, and dissolved organic nitrogen) and phosphorus (phosphate, dissolved organic phosphorus). Nutrient concentrations in seawater off the Wai‘anae coast are likely to vary with the time of year and location as observed in other coastal waters of Hawai’i (e.g., Ringuet and Mackenzie, 2006, De Carlo et al., 2006).

Land-based sources of nutrients from streams and surface water runoff cause localized increases in nutrient concentrations in coastal waters. The uptake of nutrients by marine plants and decomposition of marine life in the sea also contribute to variation in nutrient concentrations found in the water column. In general, open ocean surface waters near the Hawai’ian Islands are oligotrophic; this is particularly true off dry leeward sides of the islands such as Wai‘anae, where nutrient concentrations are extremely low. Primary production is generally considered to be limited by the availability of nitrogen and micronutrients such as iron (Ringuet and Mackenzie, 2006).

Coastal Water Quality

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

Stream Discharge

Many of the streams of the Wai‘anae moku have been channeled through the urban areas. This causes water to reach the ocean much more quickly, potentially increasing levels of trash, nutrients and other pollutants entering the coastal water. In spite of this, only one stream, Kaupuni Stream, was on the 2004 list of impaired waters in Hawai‘i (Koch and others 2004). Of the 70 streams in the report, Kaupuni Stream is considered a medium priority listing with nutrients, turbidity and trash as the primary pollutants. Ulehawa Stream was the focus of a community-based trash monitoring and clean-up in 2001-2002.

Figure 4. The Wai‘anae Wastewater Treatment Plant (WWTP) , Source: CZM Hawai‘i

Wai‘anae Wastewater Treatment Plant (WWTP)

The City and County of Honolulu’s conservation district use permit for installation of the outfall pipe at Wai’anae (Figure 4), was approved in November, 1983. The WWTP (Figure 4) outfall pipeline which was installed in 1986 extends 1.1 miles (1.8 kilometers) offshore into 108 feet (33 meters) of water. In 1996, the WWTP was converted from a primary to a secondary WWTP, which discharges 3.4 million gallons per day of mainly domestic wastewater through the outfall offshore. The long-term monitoring program at the diffuser reported an immediate drop in levels of suspended particles and nutrients. The diffuser is 531 feet (161.8m) long and discharges at approximately 1.5 feet (0.5m) above the seafloor through vertical risers.

Stream Flow

The term "stream flow" refers to the rate at which water flows through the natural stream channel. Stream flow directly reflects climatic variation, such as rainfall, and is very important variable to virtually all environmental monitoring of surface water. Stream systems play a key role in the regulation and maintenance of biodiversity. Stream flow can be described as a combination of several factors (Oki 2003) (Figure 5):

- Direct runoff from land to a stream
- Base flow (water that the stream receives from the groundwater table)
- Rainfall directly on streams
- Water stored within the stream bank
- Any water added to the stream by human activity

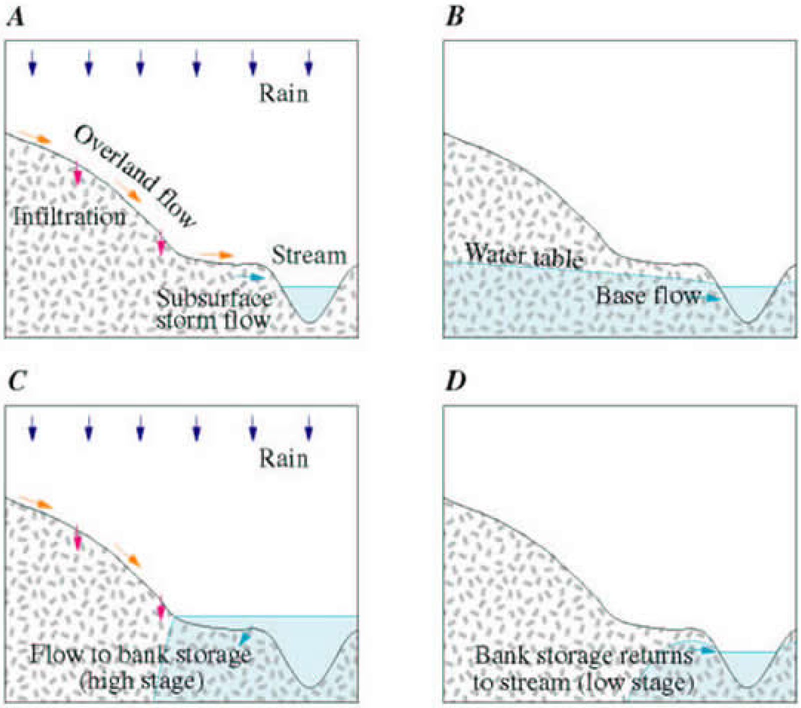

Figure 5. Components of stream flow include (A) direct runoff of rainfall (overland flow and subsurface storm flow), (B) ground-water discharge (base flow), and (C, D) flow related to bank storage. Source: Oki 2003.

Human intervention such as diversions, dams, channelization, and changes in land use can have a significant effect on stream flow. Recently, the makai portions of many streams are being "modernized" with the construction of concrete drainage channels. This removes the ability of the stream to interact naturally with the land. Unlike a natural streambed, which traps debris and sediment and filters out contaminants, concrete channels create impervious surfaces that increase the velocity of surface water, conveying sediments and other potential contaminants to the sea. Other human impacts on stream flow include the effects of road and house lot construction, which sometimes includes moving natural stream channels; siltation from agricultural and suburban development; and the dumping and accumulation of trash and debris in streams.

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

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

Ocean Processes

This section describes the coastal and ocean process that shape the Waiʻanae's shoreline and nearshore waters, including the currents and tides, water column profile, waves and erosion, and water quality.

Currents and Tides

Near-shore currents along the Waiʻanae coast are influenced by local and regional oceanographic and climatic conditions. Tides, trade winds, and large-scale ocean currents, together with island mass effects, create distinct oceanographic conditions along the leeward sides of the Hawai’ian Islands, including the Waiʻanae coast.

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

Water Column Profile

The water column profile for the area off Kahe Point was studied extensively in the 1980s as part of the proposed (but never built) 40 megawatt Ocean Thermal-Energy Conversion plant. Although Kahe Point is just outside the southern extent of the Waiʻanae moku, information and data collected at Kahe Point can be considered relevant to the Waiʻanae coast. Changes in temperature, salinity, oxygen, and nutrients with depth were measured from surface water to depths of 2,950 feet (900 meters) (Noda and others 1981).

Temperature and Salinity

The temperature and salinity (salt content) of seawater are important attributes of the water column profile. Temperature and salinity gradients define different layers in the water column and indicate the boundaries of different water masses off the Waiʻanae coast.

The mixed layer of the ocean off the Waiʻanae coast extends from the surface to depths of about 100 to 200 feet (30 to 60 meters). In the mixed layer, temperature is nearly uniform with depth. Below the mixed layer is the thermocline, the layer in which seawater temperature declines rapidly with depth. In the thermocline, seawater temperature decreases from about 24 degrees centigrade at a depth of 200 feet (60 meters) to 15 degrees centigrade at over 650 feet (200 meters). Below this depth, temperature decreases gradually. At 2,950 feet (900 meters) depth, seawater temperature off Kahe Point is about 4 degrees centigrade.

Surface water salinity off Kahe Point is about 34.8 parts per thousand (ppt), typical of the Pacific central water mass. This low-salinity warm surface layer grades into the underlying Pacific intermediate water mass, which is characterized by a maximum salinity of 35.1 parts per thousand (ppt) at 600 feet (180 meters) and minimum of 34.2 ppt at 1,500 feet (460 meters). At 2,950 feet (900 meters) depth, seawater salinity off Kahe Point is about 34.4 ppt.

Dissolved Oxygen

There is about 100 times less oxygen in the entire ocean than in the earth's atmosphere, yet this is a vital resource for animals in the ocean. Higher concentrations of dissolved oxygen correspond to higher levels of photosynthesis in the ocean. Colder water can also dissolve higher levels of oxygen. These are the primary reasons why there is a lower concentration of oxygen in Hawai’ian waters than much of the world's oceans. An oxygen minimum of one milliliter per liter of seawater occurs at a depth of 2,240 feet (680 meters). The oxygen minimum zone is caused by the settling and decomposition of plankton and other organic matter from the surface mixed layer. Off Kahe Point, the dissolved oxygen content of the surface water is around 4.8 milliliters per liter of seawater (Noda, 1981).

Marine Ecosystems

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

This section discusses Wai‘anae's marine ecosystems including intertidal communities, coral reefs, and offshore pelagic and deep sea communities. Special focus is also given to the marine mammals and sea turtles that commonly inhabit the waters off of the Wai‘anae moku.

Critical Marine Habitats and Resources

<u>Coral Reefs.</u> Coastal areas with high wave exposure generally have the lowest coral cover in O‘ahu, while bays and wave-protected coastal areas have the highest coral cover. Not surprisingly, coral cover is low along much of the Wai‘anae coast, due to the shallow, flat, and low-relief bottoms in this area. However, corals thrive on the artificial reefs off the Wai‘anae coastline, off of Mākaha Beach, and on the thermal outfall pipe at Kahe Point, just south of the Wai‘anae moku.

These areas are dominated by two coral species, *Pocillopora meandrina* and *Porites lobata*, and the reefs provide food and shelter for many fish and invertebrates. The reef at the Kahe power plant outfall is the subject of the longest running coral reef study in the world, with monitoring occurring continuously since 1971.

<u>Humpback Whales.</u> Humpback whales appear in Hawai’ian waters between November and April, when they socialize, mate, and give birth. When engaged in singing, nursing, or competition for mates, whales can become very vulnerable to human hazards because their attention is focused on these reproductive activities. Humpback whales are an endangered species protected under the Marine Mammal Protection Act (MMPA) and both the state and

federal Endangered Species Acts. In addition, they are a valuable source of tourist revenue to the state. By law, steps must be taken to minimize potential human threats.

The Hawai’ian Islands Humpback Whale National Marine Sanctuary, which includes near shore waters along parts of all the main Hawai’ian Islands, was established to protect the largest breeding grounds for the humpback whale. Humpback whales migrate annually from Alaska to Hawai’ian waters, covering nearly 3,000 miles of open ocean in less than two months' time. Approximately 2,000 to 5,000 individuals come here each year, constituting a significant portion of the total North Pacific population of 6,000 to 10,000 whales.

Hawai’ian Monk Seal. The Hawai’ian monk seal (*Monachus schauinslandi*), a federally listed endangered species, most commonly inhabits the Northwestern Hawai’ian Islands. However, monk seals are occasionally sighted around the main Hawai’ian Islands, including off Mākua Beach on the Wai‘anae coast. Prominent threats to monk seal populations include entanglement in fishing gear; disturbance by humans, which can cause seals to abandon haul-out areas and their pups; and predation by sharks.

Green Sea Turtle. The green sea turtle *(Chelonia mydas*), considered the most abundant sea turtle in Hawai’ian waters, and is listed as a threatened species under the federal Endangered Species Act. These turtles can be seen off the waters of Wai‘anae.

Threats to sea turtles occur from land-based and sea-based activities, such as loss of nesting habitat due to development, nest predation, boat collisions, entanglement in fishing gear, and ingestion of marine pollution.

Hawksbill Turtles. Hawksbill turtles are distributed throughout the tropics, generally occurring at latitudes from 30 degrees north to 30 degrees south within the Atlantic, Pacific, and Indian Oceans and associated bodies of water. The hawksbill turtle is listed as endangered throughout its range. In the Pacific, this species is rapidly approaching extinction due to a number of factors, but the intentional harvest of the species for meat, eggs, shell, and stuffed curio trade is of greatest impact (NMFS and USFWS 1998b).

In Hawai‘i, hawksbills nest only on main Hawai’ian Island beaches, primarily along the east coast of the island of Hawai‘i. Two of these sites (Halape and Apua Point) are in the Hawai‘i Volcanoes National Park. Other beaches on Hawai‘i with recorded hawksbill nesting include Kamehame, Punaluu, Horseshoe, Ninoole, Kawa and Pohue. Not all of the presently known hawksbill beaches have nesting each year. Kamehame Point on Hawai‘i and a black sand beach at the river mouth of Halawa Valley at the east end of Moloka‘i are the most consistently used beaches. In surveys from 1989 to 1993, eighteen hawksbills were tagged and 98 nests documented. Nesting occurred from late May, with hatching completed by early December. Peak nesting activity occurs from late July to early September (NMFS and USFWS 1998b).

Loggerhead Turtle. The loggerhead turtle is listed as a threatened species throughout its range. Its threatened status is consistent with population levels and trends observed in the Pacific. The stocks found in U.S. jurisdiction most likely originate from Japanese nesting areas, so activities in Japan that have an impact on nesting success or on foraging in coastal waters are of concern. The U.S. and Mexico (primarily Baja California South) provide important developmental habitats for juvenile loggerheads. A primary threat to the species in the Pacific is incidental mortalities associated with commercial fisheries, particularly long-line and net fisheries (NMFS and USFWS 1998d).

Coral Species and Cover

Coastal sites with high wave exposure have the lowest coral cover (less than 10 percent), while bays and wave-protected coastal areas have the highest coral cover (70 to 80 percent) (Brainard and others 2002). Coral cover is low along the Wai‘anae coast (one to two percent of bottom area), a condition typical of shallow, flat, low-relief bottoms in this area (Russo 1997). Most of the seafloor is uncolonized pavement, a flat hardbottom of volcanic or limestone rock, interspersed with sand channels. However, corals thrive on the artificial reefs and on the armor rock at the inshore wastewater effluent pipeline, probably because of artificial topographical relief (Harrison 1987).

The Wai‘anae moku is dominated by two coral species, *P. meandrina* and *P. lobata* (Russo 1997). *P. lobata*, a massive and encrusting species, is the most common coral in the main Hawai’ian Islands (Figure 6). It is surge-tolerant and can be found in a variety of habitats, from tide pools to depths of approximately 145 feet (45 meters). It is most common on wave-exposed reef slopes between three and approximately 10 to 45 feet (14 meters), in a zone below the cauliflower coral. *P. meandrina* is one of the four most abundant species of Hawai’ian reef-building corals. It is a surge-tolerant species that inhabits exposed shorelines and the surge zone of reef slopes. Its dense skeleton, sturdy branches, and symmetrical head formation suit it to the moderate wave action encountered close to the surface. It is the dominant coral species on reef slopes at depths of less than three meters (10 feet), but can also be found to greater than 85 feet (27 meters) or more in depth. The thin encrusting species *L. purpurea* is also found in Wai‘anae.

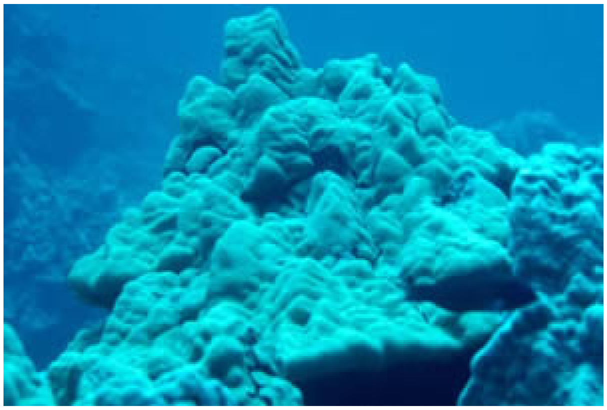

Figure 6. Lobe coral (*Porites lobata*). Source: National Oceanic and Atmospheric Administration (NOAA).

The value of Hawai‘i's coral reefs cannot be overstated. They provide shoreline protection from waves and storm surge. They have provided a continuous supply of fresh fish and other basic food for the people of Hawai‘i for the past thousand years. They are the source of the sand on Hawai‘i's beaches. They are an integral aspect of Hawai‘i's multi-billion dollar tourist industry, providing countless snorkeling, diving, surfing, and fishing opportunities. Coral reefs and hard bottom habitats are found along the length of the Wai‘anae coast and provide food and shelter for reef fish and invertebrates.

Reef Structure

Most reefs on the inhabited islands of Hawaiʻi are known as fringing reefs, growing near the shoreline. Fringing reefs are the first type of reef to form around young volcanic islands, such as Hawaiʻi, Maui, Oʻahu, and Kauaʻi. These reefs form in areas of low rainfall runoff, primarily along the leeward shores such as the Waiʻanae coast of Oʻahu. Typical reef zonation consists of (1) reef flat zone (0 to 2 meters or 0 to 6.5 feet), (2) reef bench zone (2 to 10 meters or 6.5 to 32.8 feet), (3) reef slope zone (10 to 30 meters or 32.8 to 98.4 feet) and (4) rubble zone (30 to 40 meters or 98.4 to 131 feet) (AECOS, Inc. 2002) (Figure 7).

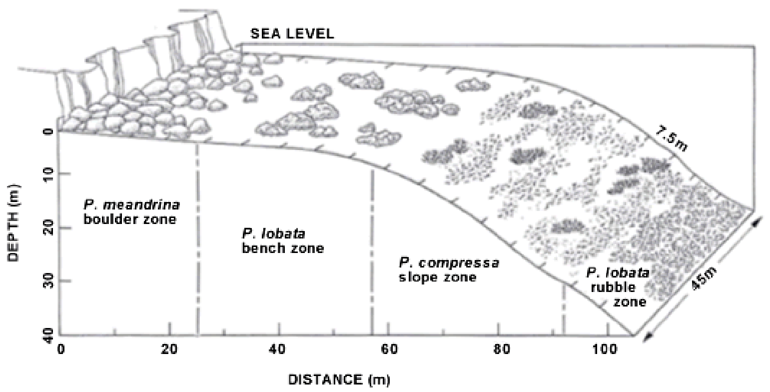

Figure 7. Schematic diagram of reef showing depth profile, approximate zone boundaries, and transect orientation. Source: Dr. S. Dollar

<u>Reef Flat Zone.</u> On the Waiʻanae coast, sand occurs along the shore and is affected by substantial wave energy, especially through the winter due to the wrap-around effect from North Pacific storms. Below the waterline, sand is replaced by a limestone platform, or reef flat, that extends several meters offshore. This platform is virtually barren of macro invertebrates and macroalgae, although covered with short turf algae. Corals, represented by the compact and sturdy cauliflower coral (*Pocillopora meandrina*) (Figure 8), are distributed in patches on the reef flat. Animals living in this zone need to contend with strong surge and crashing waves by either boring into the rock (urchins), or by darting out between waves from a protective hole to feed on turf algae (AECOS, Inc. 2002).

Figure 8. *Pocillopora meandrina* off the Wai‘anae coast. Source: Ranjeet Bhagooli

Reef Bench Zone. The limestone platform drops off vertically within 10 to 20 meters (approximately 30 to 65 feet) from shore, and the deeper vertical portions, known as the reef bench, contain the corals *P. meandrina*, *Porites lobata*, and *Lepastrea purpurea*. In areas of boulders, the common brown algae (*Padina* spp.) and red algae (*Liagora* spp.) are present. Unattached benthic invertebrates, such as sea urchins, are rare. Reef fish are moderately abundant around the boulders, and in the deeper areas of the shoreline bench (AECOS, Inc. 2002).

Reef Slope Zone. Wave energy subsides at the depth of the reef slope zone, and the more delicate finger coral becomes common. The greatest concentration of living material is here, at the reef's seaward edge, where plankton and clear water of normal salinity are dependably available. The characteristics of the seafloor are of great importance in structuring fish communities and in determining the number of fishes living in the area. In areas of high relief, where fish can seek refuge, a high abundance and diversity of fishes are present. Large schools of taape (bluelined snapper; *Lutjanus kasmira*), kole (goldring surgeonfish; *Ctenochaetus strigosus*), aloiloi (black damselfish; *Dascyllus albisella*), and other common fish species are present swimming over these rocks (Russo 1997). Sandy bottoms or pavement rock generally attract very few fish to the area (AECOS, Inc. 2002).

Rubble Zone. Coral cover diminishes in the rubble zone, and coral rubble and sand dominate the seascape. Fish concentrations drop off considerably, as the habitat provides little refuge in this zone (AECOS, Inc. 2002).

Off the Wai‘anae coast, the seafloor beyond the reef begins at approximately 100 meters depth, and continues to a depth of 5,000 meters. Sand and sediment cover limestone and volcanic rock where currents do not scrub the seafloor bare. Ledges and slopes off Ka‘ena Point are prime habitats for a number of bottomfish species. Numerous pinnacles rising from the seafloor attract fish and other species as well. A massive and ancient landslide of the Wai‘anae mountain range exists 100 miles offshore (approximately 160 kilometers from the coast) in approximately 2.5 miles deep (4,000 meters) of water (Coombs and others 2004).

Description of Habitats

The study areas incorporate four major benthic habitats that will be considered during both survey and sampling (Figure 2).

Sand (16.7% of the study area): Course sediment typically found in areas exposed to currents or wave energy (Figure 9).

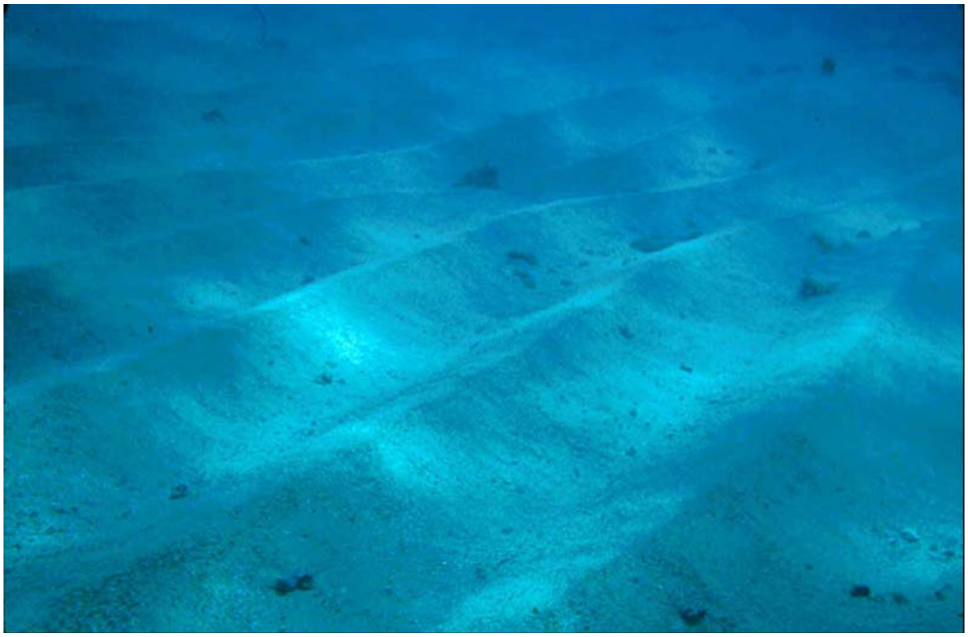

Figure 9. Sand.

Macroalgae (8.2% of the study area): An area with 10 percent or greater coverage of any combination of numerous species of red, green, or brown macroalgae. Usually occurs in shallow back reef and deeper waters on the bank/shelf zone. High relief (hard bottom) habitats take precedence over macroalgae cover (Figure 10).

Continuous Macroalgae: Macroalgae covers 90 percent or greater of the substrate. May include blowouts of less than 10 percent of the total area that are too small to be mapped independently (less than the MMU). This includes continuous beds of any density (may be a continuous, sparse or dense bed).

Patchy Macroalgae: Discontinuous macroalgae with breaks in coverage that are too diffuse or irregular, or result in isolated patches of macroalgae that are too small (smaller than the MMU) to be mapped as continuous macroalgae.

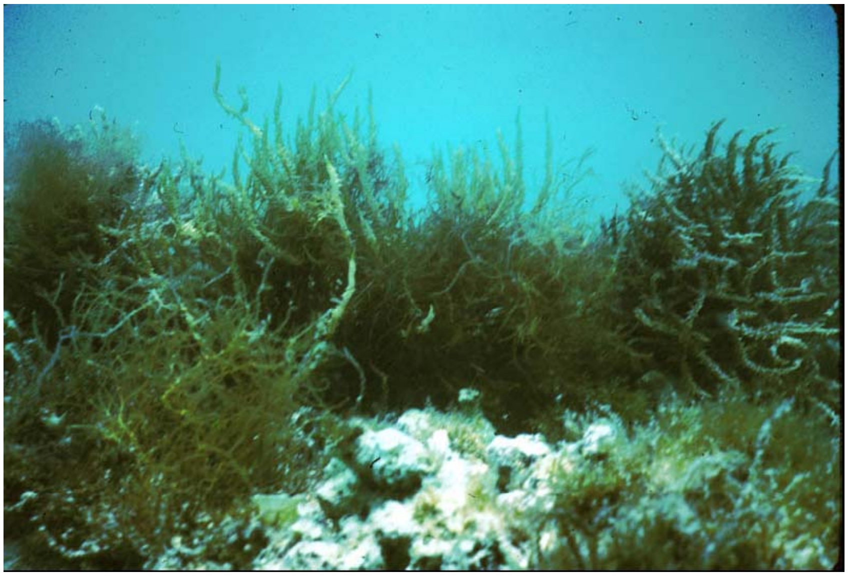

Figure 10. Microalgae.

Uncolonized Hardbottom (50.2% of the study area): Hard substrate composed of relict deposits of calcium carbonate or exposed volcanic rock (Figure 11).

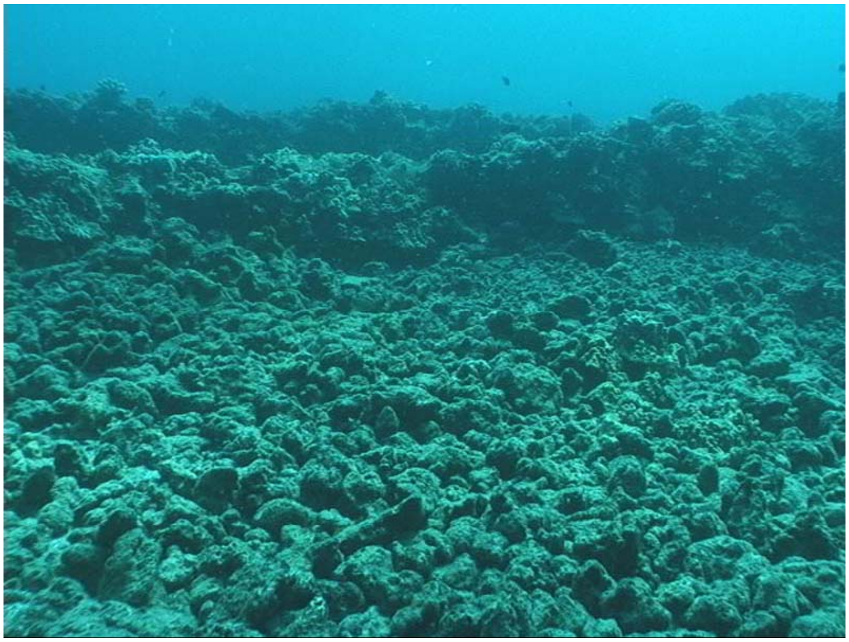

Figure 11. Uncolonized hard bottom

Unknown (24.9% of the study area): Areas outside of 20 fathom line not identified.

Fish and Other Species

There are 557 documented species of reef and shore fish in Hawaiʻi, of which 135 are endemic. Surgeonfish are the dominant fish group, and herbivores generally account for over 70 percent of the total reef fish biomass, followed by invertebrate feeders (13 percent) and plankton feeders

(9.7 percent). Predators are rare, accounting for 3.8 percent of reef fish biomass (Brainard and others 2002).

The highest numbers and species of fish are found in locations of moderate wave exposure. The lowest biomass is found in areas exposed to north and south swells. Increasingly complex habitats have more fish and a greater variety of species, which illustrates the importance of shelter as a refuge for some fish to avoid predation (Jokiel and others 2001). Exceptions do occur in a few places around the islands where high fish biomass occurs in sites with low habitat complexity, but these sites are protected from fishing. The Waiʻanae coast has few locations with complex habitat and has no no-fishing areas. Thus, most of the reef along the coast has low species diversity and biomass.

Although the Waiʻanae coast in general offers relatively few fish species and low numbers of fish, there are exceptions where large schools of reef fish have been documented. They include the three artificial reefs: Pōkaʻī Bay Artificial Shoal (created with old cars, concrete pipes and a steel barge in 1963), the *Mahi* shipwreck (sunk in 1982) and the seaplane wreck (sunk in 1986), the outfall pipe of the wastewater treatment plant in Waiʻanae town; and the thermal outfall of the Kahe power plant just south of the Waiʻanae moku (Kanenaka 1991; Russo 2001a, b; Harrison 1987).

The weke (yellowstripe goatfish; *Mulloidichthys flavolineatus*), naʻenaʻe (surgeonfish; *Acanthurus dussumieri*), u u (menpachi; *Myripristis berndti*), and the saddleback wrasse (*Thalassoma duperrey*) occur in large schools at these sites (Hobson 1984). Also common are the brown surgeonfish (*Acanthurus nigrofuscus*), Pacific Gregory (*Stegastes fasciolatus*), goldring surgeonfish (*Ctenochaetus strigosus*) and the blackfin chromis (*Chromis vanderbilti*). Moray eels in the family Muraenidae species in the genus *Gymnothorax.* These eels are common apex predators with 38 species of morays found on Hawai'ian reefs. Individuals are resident to specific reef areas, and feed on a wide range of reef associated fish and invertebrates.

Armor rock surrounding pipes and artificial reefs provide ample habitat space for hiding and mating, ample surface for the colonization of food sources, and a reference point above the seafloor for aggregation and maintenance of schools. Artificial structures placed in areas normally devoid of bottom relief can attract large numbers of fish and provide surfaces for coral and other sessile organism attachment. Macroalgae represent over 50 percent of the benthic cover in the Hawai'ian coral reef ecosystem. Red algae are the most commonly occurring algae in Hawaiʻi, representing four of the five most common species. Green and brown algal species are found in most reefs in smaller numbers (Brainard and others 2002).

Research and Monitoring

The WWTP outfall pipe was installed in 1986 and extends 1.8 kilometers offshore into 33 meters of water. Benthic community structure and fish community structure have been monitored quantitatively at sampling stations every year since 1990 for possible effects of treated sewage effluent inshore of the outfall diffuser discharge (Russo 2001a, b). In 1996, the WWTP was converted from a primary to a secondary WWTP, reducing the concentration of the effluent entering the ocean. A noticeable decline in fish abundance around the diffuser in subsequent years was attributed to this conversion.

The State's artificial reef program has monitored numbers of fish, estimated total biomass, and species richness or diversity at the major sites along the Waiʻanae coast. Regular surveys have been conducted at the Pōkaʻī Bay Artificial Shoal since 1962, and fish abundance has been monitored at the sunken vessel *Mahi* since 1986 (Kanenaka 1991).

The Hawaiʻi Coral Reef Assessment and Monitoring Program was created during 1997-1998 by coral reef researchers, managers, and educators in Hawaiʻi. The program developed a statewide network of over 30 long-term coral reef monitoring sites, with three on the Waiʻanae coast. All of these are in the vicinity of the Kahe power plant, to build on the 30-year data set from that location. Rapid quantitative assessments of the benthic and fish species were conducted and compared among sites. The three Kahe sites were among the sites displaying the least abundance and diversity of species across the islands. These data will be used in conjunction with the National Oceanic and Atmospheric Administration's shallow water habitat maps to understand their ecology in relation to other geographic areas.

Ocean Recreation and Tourism

Waiʻanae's location on the leeward side of the Waiʻanae Mountain Range, from Kaʻena Point in the north to Kahe Point in the south, provides beautiful coastal landscapes, natural white sand beaches, and majestic mountain ridges. On the coast and at sea, Waiʻanae offers diverse ocean water sports, including off-shore fishing, surfing, snorkeling, spear fishing, canoe paddling, and ocean swimming at numerous public beach parks.

Swimming and Beach Recreation

About 18 miles of the Waiʻanae Coast is made up of beach parks and community recreation areas. These beach parks enable public access for swimming, snorkeling, or surfing. Some of the notable beach parks known for excellent swimming and beach conditions in the summer include Mākaha Beach Park, Nānākuli Beach Park, and Māʻili Beach Park. In the winter season, however, riptide or undertow conditions can exist at these parks, and the surf can be extremely dangerous. Pōkaʻī Bay offers excellent swimming year round since it is well protected from the surf, even during the winter surf season. Unlike other reefs along the Waiʻanae Coast, Pōkaʻī Bay's coral reef slopes gradually away from shore, thereby reducing riptide effects.

Surfing

Heʻe nalu (wave sliding, aka surfing) was practiced by kings and queens and the men and women of Hawaiʻi long before 1500 AD (SurfArt.com 2000). Waiʻanae's coast has played a significant role in the contemporary sport and business of surfing. Waiʻanae was home to the first international surfing contest, held in 1953 at Mākaha Beach.

Most surf in Hawaiʻi is generated from ocean swells that come from the north, south, and west directions. Oʻahu's North Shore, or "Country," is famous for its waves that originate from the north and northwest in the late fall and winter. The South Shore, or "Town," is famous for its southern waves, which normally occur during the late spring, summer, and early fall. The Waiʻanae Coast generates beautiful surf conditions from a westerly swell, but it also has the perfect orientation to pick up waves from the north and south as well, making it one of the ultimate year-round surf locations.

Ocean Tours, Sightseeing, Snorkeling, and Fishing

Several commercial companies operate out of the Wai‘anae Boat Harbor to provide access to ocean sports along the Wai‘anae coast. Through specialty tours, visitors can fish, snorkel, sail, kayak, and watch spinner dolphins and humpback whales in their natural habitat. Spinner dolphins are frequent visitors to bays and beaches along the northwest coastline toward Ka‘ena Point. Humpback whales are often seen one-half to three miles offshore, primarily from January through April. The waters around the main Hawai’ian Islands of Kaua‘i, O‘ahu, Hawai‘i, Maui, Moloka‘i, Lanai, and Kahoolawe constitute one of the world's most important North Pacific humpback whale habitats and the only place in the United States where humpbacks reproduce.

Fishing

People from all over the island of O‘ahu come to Wai‘anae to fish off its coast. Participants are primarily part of the small vessel pelagic troll fishery. These are vessels between 16 and 30 feet long, fishing for species that feed in the upper layers of the water column and dragging or drifting bait or artificial lures behind the boat (Glazier 1999). The state-owned Wai‘anae boat harbor is the island's primary small vessel harbor and ramp access point, affording quick access to the ocean via a sometimes very busy seven ramp launch area. The harbor facility was constructed in 1972. The harbor has berthing spaces for 146 vessels. It is the center of fishing activity along the Wai‘anae coast

The annual Ahi Fever Fishing Tournament has occurred every June since 1997. It is the largest fishing tournament in Hawai‘i, based on total number of anglers and boats registered

Pelagic Fisheries

Commercial fisheries data from the State Division of Aquatic Resources ranks the waters off the Wai‘anae coast first or second for total pounds of all species landed. In 2001, landings off the Wai‘anae coast totaled 982,734 pounds, or just over 12 percent of the total landings in Main Hawai’ian Island waters (Figure 12).

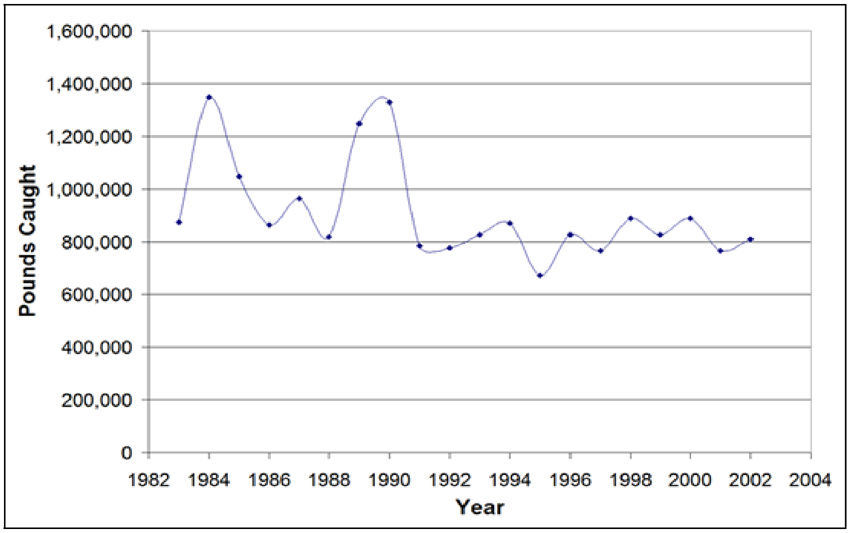

Figure 12. Total pounds of fish caught off Wai‘anae, 1983 to 2002. Source: Hawai‘i DLNR, Division of Aquatic Resources

Skipjack tuna or aku (*Katsuwonus pelamis*) is the top species landed in this district, and the small fleet of aku pole and line fishery (currently three vessels) lands more than one million pounds of fish from Hawai'ian waters. Yellowfin (*Thunnus albacares*) and bigeye ahi (*Thunnus obesus*), akule (*Selar crumenophthalmus*) and blue marlin (*Makaira mazara*) are also caught in greater numbers than at most places in the state (State of Hawai'i Department of Land and Natural Resources [DLNR] 2001). This is due mostly to the comfort of fishing in the calm lee of the island and the convenience of deep waters close to shore.

Inshore Fisheries

Although far fewer inshore reef fish are caught in Wai‘anae than in other sites around the islands, goatfish or weke (*Mulloidichthys* spp.) and the introduced blue-lined snapper or taape (*Lutjanus kasmira*) are taken in fairly large numbers (State of Hawai'i DLNR 2001). Shore casting and spear fishing on the reef are common activities up and down the coast. Most of these anglers will keep their catch, either for dinner or to distribute to friends and family.

Fishing Regulations

Pōka‘ī Bay Fishery Management Area. The only Wai‘anae-specific fishing regulations occur in the Pōka‘ī Bay Fishery Management Area (Figure 13). Numerous regulations are intended to reduce the amount of take of fish, crabs, shrimp, and baitfish in this area. Anglers may use only one fishing line with no more than two hooks to catch fish. They may use a maximum of ten nets with a two-foot diameter to take crabs, and may use only hand nets for shrimp. They must have a bait license or be a licensed pond owner to take baitfish or young mullet (pua), respectively. All other net fishing is illegal in this area (State of Hawai'i DLNR 2003b). No biological, sediment or water column sampling will be conducted within the Fishery Management area.

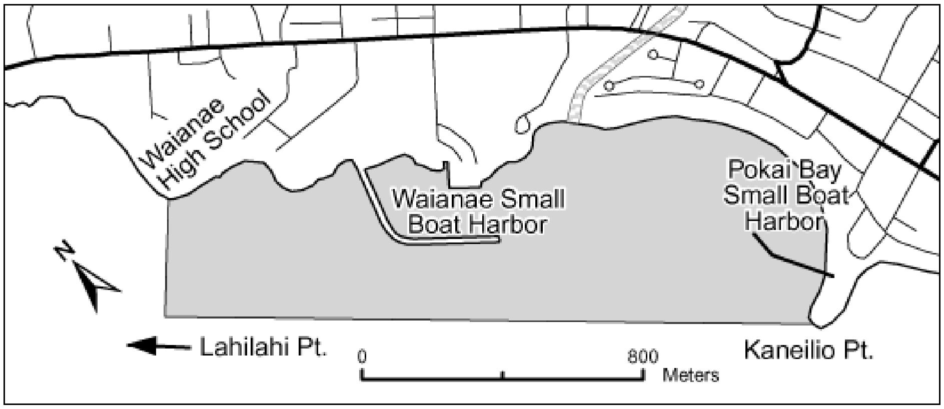

Figure 13. Fishery Management Area in the Wai‘anae moku. *Source: Hawai‘i DLNR, Division of Aquatic Resources*

Ka‘ena Point to Mākua Bottomfish Restricted Fishing Area. The bottomfish restricted fishing area off the Wai‘anae coast was identified to promote recruitment and minimize over fishing of bottomfish species in the area. The shallow side of this restricted fishing area follows the 100 fathom isobath, the contour of the seafloor at 100 fathoms. It is illegal to catch bottomfish in the restricted fishing area using a trap, trawl, bottomfish longline, or net (State of Hawai’i DLNR 2003b).

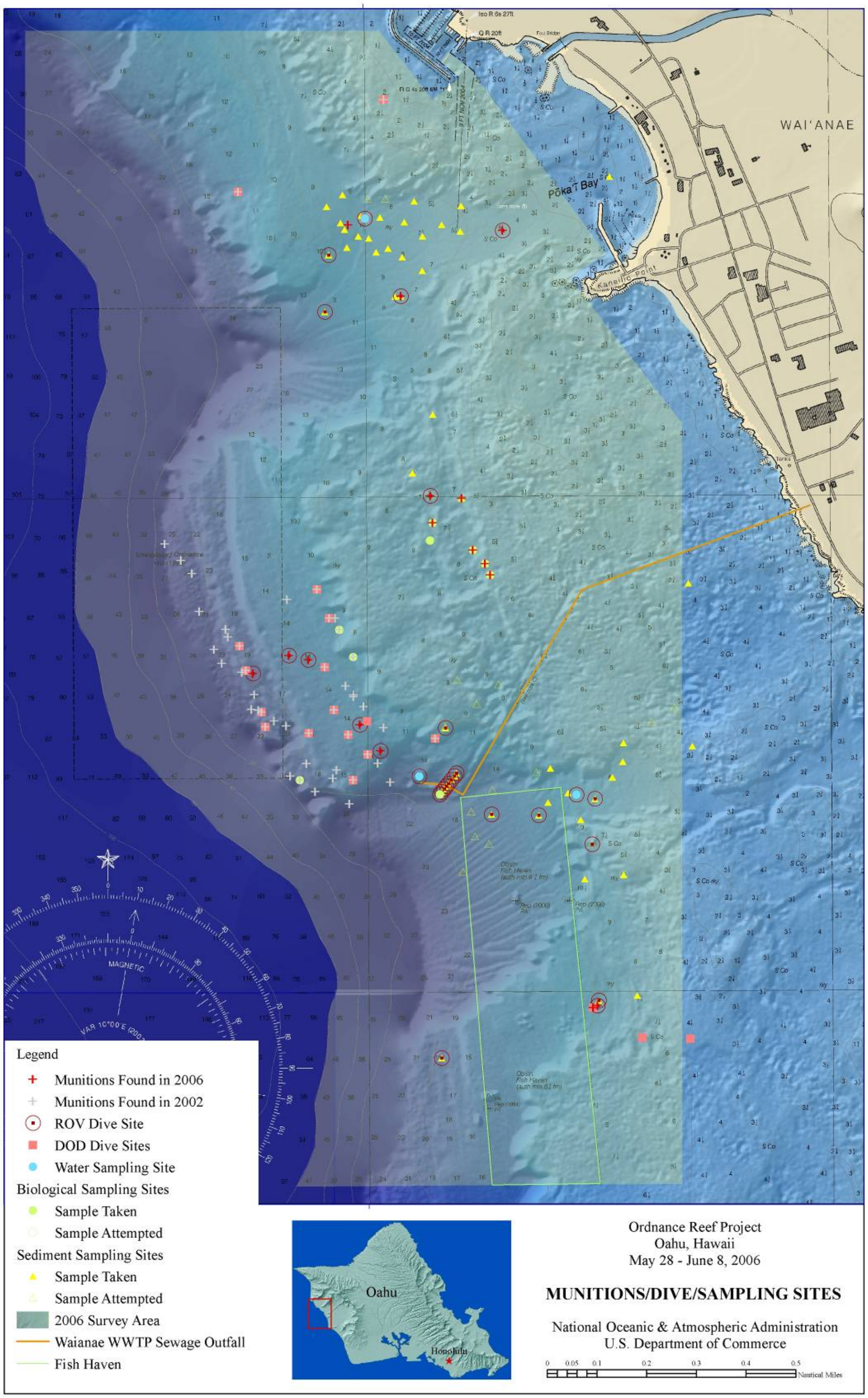

Figure 14. GIS all data collection sites.

4. Field Activities

The following section describes the methods and procedures used in planning and implementing the field activities. The fieldwork was conducted from May 28 through June 9, 2006, the following activities were conducted:

- Planning (GIS data);
- Remote Sensing;
- Sample Locations and Rationale;
- Sample Collection;
- Sediment Sample Analysis;
- Water Sampling;
- Fish Tissue Analysis.

Planning

One of the major planning elements incorporated into this project was a Geographic Information System (GIS) which was used throughout the project for planning, to capture and display the data collected during the survey to support decision making in the field, and for evaluating the data following the field work. Pre-survey planning within the GIS project allowed researchers to become familiar with the bottom topography and habitats within the study area, depths, currents and document previous work conducted. Large format maps of the study area where developed to use during briefings in the field pre-survey base data layers incorporated into the project included the following:

- NOAA raster nautical charts numbers 19361 (Port Wai’anae), 19357 (Island of O’ahu), 19004 (Hawai’ian Islands)
- bathymetry
- benthic habitats
- 2002 survey study area and munitions sites
- 2006 proposed study area
- O’ahu coastal aerial photos
- USGS topographic maps of O’ahu
- 10m hill shaded digital elevation model for O’ahu
- Towns, beaches, fish ponds, roads, charted wrecks, aids to navigation, wetlands, boating facilities, submerged cables, and other background layers
- Used proposed study area, benthic habitat, and bathymetry layers to determine the type of survey equipment to utilize
- Used size of study area and water current/tide information to determine length and orientation of survey lines and subsequent duration of sonar survey

During field operations, benthic habitat information was confirmed by both divers and ROV operations and additional data was added. The locations of all shallow water targets from sonar data collected in the field was captured, and the locations of shallow water targets in study area were correlated with the 2002 survey's munitions locations on bathymetry layer to determine depth to targets. Throughout the survey, the GIS provided the dive teams with locations and depths of 2002 munitions sites and locations and depths of military munitions located during the 2002 survey and the locations and depths of shallow water targets from the current survey. This was used to plan daily operations and identify appropriate locations for sampling.

Following survey operations all sampling and DOD/ROV dive site locations were input into a master spatial table reconciling location and attribute data for the researchers. The locations of all sites where some form of activity took place were plotted and maps depicting these activities were generated for inclusion in this report. Additionally, all deep water target locations were extracted from sonar data, plotted and overlaid on shallow and deepwater 2002 survey's munitions locations and locations not previously identified, but discovered during the project to quantify the nature of sonar targets. A final map showing all activity associated with this project is included as Figure 14.

Remote Sensing

Equipment for the survey was selected based on the following criteria: Depth of areas to be surveyed, bottom topography of the area, environmental condition anticipated, and resolution required for identification of munitions. A Benthos C3D High Resolution 200 kHz Side Scan Imaging System (C3D) with bathymetry and Benthos 1624 dual-frequency 123 kHz and 383 kHz side scan sonar were used to determine the extent of munitions within the study area. The C3D system was towed along side the survey vessel R/V *Manacat* (Figure 15*)* and continuously collected acoustic images of the shallow water study area. Line spacing for the C3D side scan sonar was set at 50 meters to ensure a minimum of 200% coverage of the study area. R/V *Manacat* maintained an average speed at 3 knots. A close-in survey with minimal line spacing (i.e., ≤ 50m) was set to examine areas west and east of the primary target area to determine the extent of the site. A minimum of five equidistance cross lines was incorporated in the survey for quality assurance purposes. Minimum height above the sea floor for C3D was between 5 to 10 meters (10 to 20 percent of sonar range).

Figure 15. R/V *Manacat.*

Survey Planning

Researchers created and conducted the survey using Hypack Max hydrographic survey software. This software allows the researcher to design the survey by setting up planned survey lines with a digital chart as a background. Using the navigation package in the software, a boat operator can follow the planned lines and collect data. During the Ordnance Reef survey, Hypack was used to collect positioning data from a Seres Differential Global Positioning System (DGPS). A notebook computer, operating on a Microsoft Windows XP platform, powered Hypack. Researchers configured the DGPS to update its position two times a second and supply navigation data to Hypack and the Benthos C3D side scan sonar. The DGPS unit exported positioning through a data port to Hypack and sonar computers using a NMEA 0183 data stream through a 9-pin RS232 serial cable. Using the same navigation source for both devices reduced positioning errors during post processing and target relocation.

One NOAA raster chart (19321 *Port Wai'anae, Island of O'ahu*) was imported into Hypack and served as the background file throughout the survey. The digital chart has a Hypack compatible BSB vector format, which allows for its direct importation as a background file. Once the background file was imported, researchers set up survey lines using the coordinates and line spacing discussed in the FINDINGS section of this report. The computer running Hypack provided navigation and survey data to the helm. The video feed allowed the captain to navigate and monitor the survey vessel's progress along the planned survey lines.

Side Scan Sonar

Side scan sonar detects objects projecting above the ocean floor using an acoustic (sound) pulse that produces a detailed graphic image of the surface of the seafloor, similar to an aerial photograph. Detectable objects include manmade structures such as pilings and shipwrecks and geological features like rock and sand. If a site has some visible trace on or above the seafloor, the side-scan sonar can locate it. Side scan sonar cannot detect or produce images of objects completely buried beneath the seafloor. Extremely rocky or irregular bottoms can make it difficult to interpret sonar returns.

Two side scan sonar systems were employed during the project. A Teledyne Benthos C3D sonar imaging system was used to collect sonar data from the shallow water depths (<60 feet) within the study area. The C3D system combines high resolution imagery and wide swath bathymetry for bottom mapping, image interpretation, and a 3-dimensional look at the seafloor.

Teledyne Benthos 1624 dual frequency (100 kHz/400 kHz) side scan sonar was used in depths >60 feet. The dual frequency side scan allowed for better imaging at depth. The systems consist of a hydrodynamic sensor, called a towfish, which transmits acoustical pulses into the water and receives a return when the pulse is reflected by objects on the bottom. The sensor transfers data through a tow cable to a computer that collects acoustical data and processes it into digital images of the seafloor.

During the survey a portable generator supplied the sonar system and navigation / Oceanic Imaging Consultants, Inc (OIC) laptops with power. The OIC computer runs the sonar's operating system, GeoDAS. The monitor displays a waterfall display of incoming data in real time. The sonar sensor sends out an acoustic pulse that strikes the bottom and returns to the sensor as an echo. Each echo is recorded and displayed as a single line and successive lines accumulate to build the entire image

The DGPS provided positioning information for the sonar. The sonar computer combined the incoming image with the DGPS signal allowing the sonar operator to determine the position of potential targets on the display. Layback, the distance the sensor was towed along side the R/V *Manacat,* had to be determined and entered into the sonar computer in order to record exact target locations. A reasonable estimate of layback was made by measuring the distance from the DGPS antennae to the towfish.

Post Processing - Side Scan Sonar

OIC GeoDAS software was used to process the C3D sonar data. Several program features within the GeoDAS software suite aided in the analysis. Filters eliminated noise in the signal and enhance image detail. Feature length, height, and area were measured to aid in determining potential significance. A zoom feature enlarged a target image and exported the image as a TIFF file (Appendix 2 and Appendix 4). These files contain a file format description that specifies the content and structure for the management of geo-referenced imagery.

Researchers reviewed each file for anomalous features using GeoDAS review software. An image file was created for every feature selected for closer examination to determine a possible source. Features considered for closer examination were straight lines, large protruding objects, regular geometric shapes, light patches that could indicate scour areas, and isolated features in areas of smooth ocean floor. Such features could represent man-made debris and would warrant further investigation.

Using the GeoDAS software, researchers measured features and recorded its length, width, and height where possible (L x W x H). Each feature was then evaluated using four criteria: appearance, size, location and environment to determine whether its origin was geologic, man-made, or potential munitions.

Evaluation by appearance considers the general shape of the feature, whether it is made up of geometric shapes or straight lines, and whether it is hard or soft. A relatively dark and distinct image in the sonar record indicates that a hard surface returned the sonar pulse, while a target made of softer material exhibits a lighter and less distinct sonar image. Evaluation by size compares a feature's length, width, and height to its surroundings. Evaluation by location compares the sonar feature's location to known munitions disposal areas, man-made structures deposited for the Fish Haven, or areas of known geologic features. Evaluation by environment asks the question: Does the feature look out of place compared to its surrounding environment or does it match the environment?

Geologic / Biologic features generally appear as rounded objects among readily identifiable rock formations or coral heads and are often large in size. The features exhibit well-defined edges indicating a hard surface. Geologic features match their surrounding environment.

A man-made designation indicates that there is sufficient evidence to determine that a feature is possible man-made debris or an object. The features often display characteristics indicative of man-made debris. Man-made features may be debris or man-made material deposited for the Fish Haven

Criteria	Description
Possible Geologic / Biologic Feature	
Appearance	Hard, well defined return; irregular shape
Size	Large area
Location	Not located within a known disposal area
Environment	Looks similar to surrounding area
Man-made	
Appearance	Well defined appearance

Size	Variable
Location	May be located within a known disposal area
Environment	Does not appear to be part of surrounding area
Possible Munitions	
Appearance	Straight lines, right angles, geometric shapes
Size	Larger or smaller than surrounding features
Location	Within a known disposal area
Environment	Does not appear to be part of surrounding area

Table 1. Criteria used to determine side scan sonar feature designation (Cantelas, 2001).

Features categorized as possible military munitions must meet several criteria (Table 1). Their appearance must indicate a non-natural origin. A feature’s shape is important in determining its origin. If the shape contains straight lines, right angles, or geometric shapes such as rectangles there is high probability that it is not part of the natural environment. Feature location is also important in determining if an object is possible man-made debris. A feature isolated on the seafloor or dissimilar to the local environment suggests a debris origin. Factors such as survey vessel motion, biological organisms in the water column or power surges in the data cable also account for an object appearing to have a non-natural shape. Features that exhibit several of the criteria for munitions were selected as targets.

A total of 81.7 linear nautical miles was surveyed (Figure 16) during the remote sensing portion of the project. The first two days of survey covered the shallow water portion of the study area. 93 sonar contacts were identified during the first day of survey. 53 targets were identified on the second survey day for a total of 146 sonar contacts throughout this area. As the survey team was acquiring 200% coverage, a little more than half the targets appears on adjacent survey lines. Many of these targets had signatures that appear to be geologic in nature. Once the targets were recorded, planned dives to these areas evaluated similar sonar returns to determine if the returns came from man-made objects or were geologic.

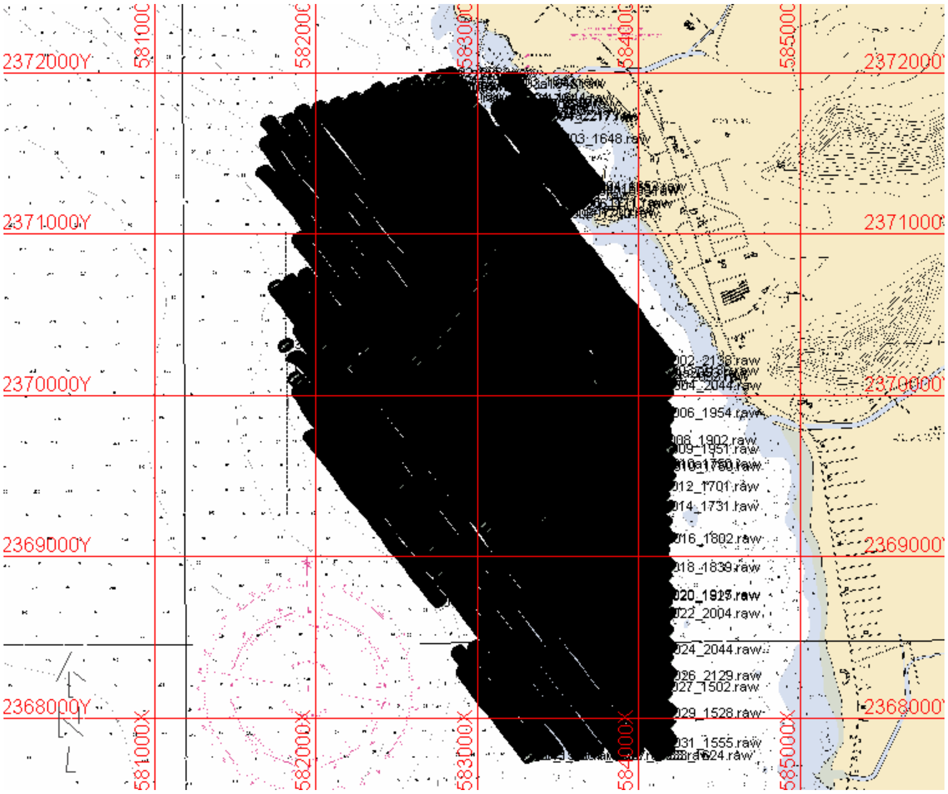

Figure 16. Completed survey areas.

At the conclusion of each day, the data was processed and a GIS map of the area was made and reviewed to determine the optimum areas for sampling and dive operations. The project leads reviewed the results to determine if the project objectives were met and to plan activities for the following day. The edge of the disposal area was determined based on the optimum survey limitations of the C3D, 1624 and ROV. The data from the sonar was used to determine the boundary of the munitions area. Although in some instances the 3CD images were sufficient to determine the size of the items, inspection and photography by divers or the ROV was necessary.

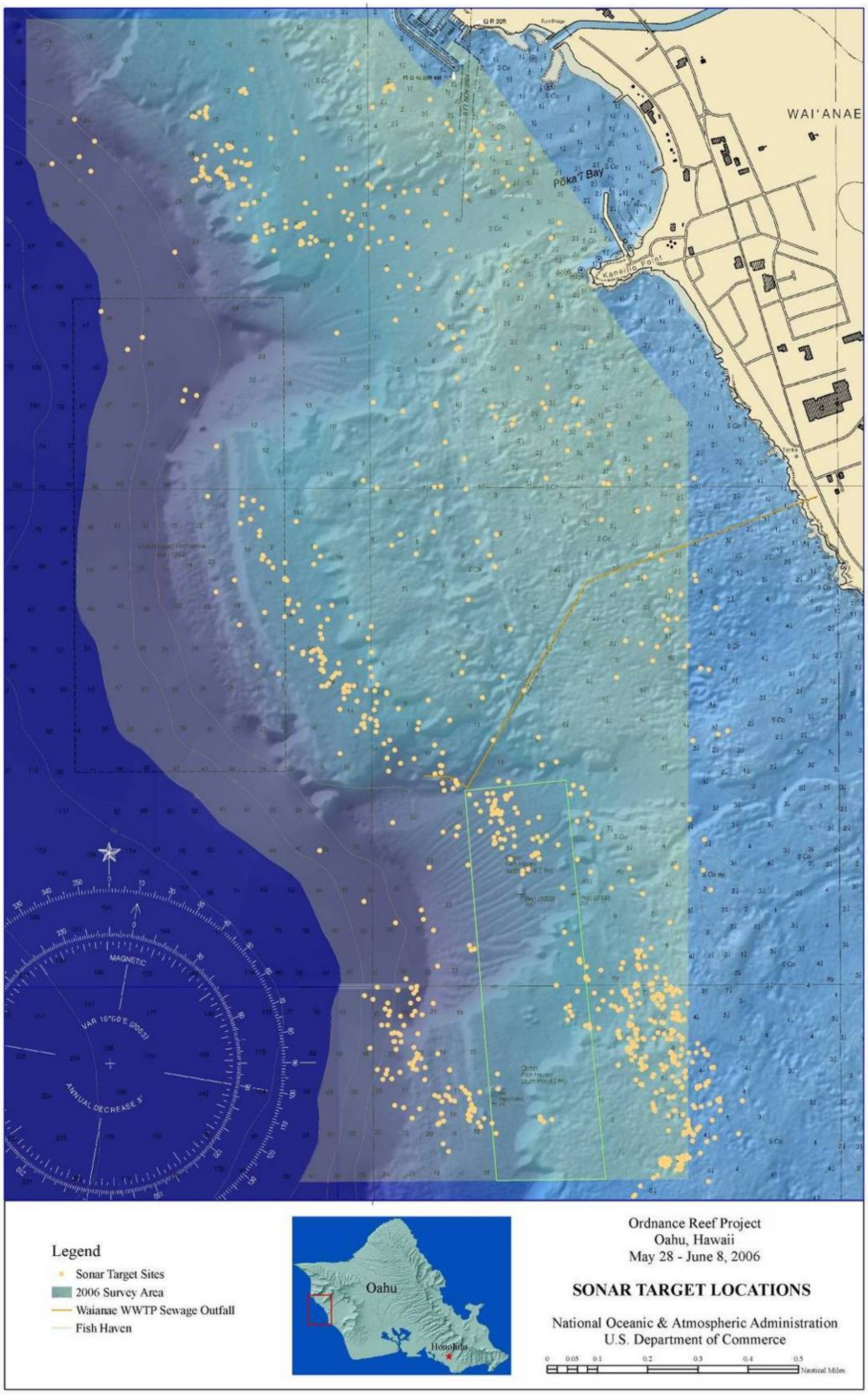

Figure 17. Sonar target locations.

Figure 18. Researchers reviewing side scan sonar data.

Data from the C3D survey was used to divide the study area in several ways. First, the area containing munitions from the area that does not, then by geologic features and finally by habitat types. The project leads examined the overlays to determine the most appropriate ways to subdivide the study area for the remainder of the study (establishing site grids for sampling). The survey program began in the shallowest portion of the study area (Pokai Bay) to allow divers to confirm the presence of suspect munitions identified with the C3D system.

Remotely Operated Vehicle (ROV)

At depth inaccessible to divers, ROV operations in the study area involved running radial survey lines over areas of interest within Ordnance Reef. The Teledyne Benthos Stingray ROV (Figure 20) is equipped with a video camera and lights to facilitate small or large object identification. Images of the habitat in and around the area were also captured during the ROV operations. Target areas were identified for ROV inspection based on the abundance of suspect munitions present and/or any unusual sonar returns. Close examination and imaging of individual munitions helped facilitate identification and assisted in determining the quantity of munitions within the disposal area.

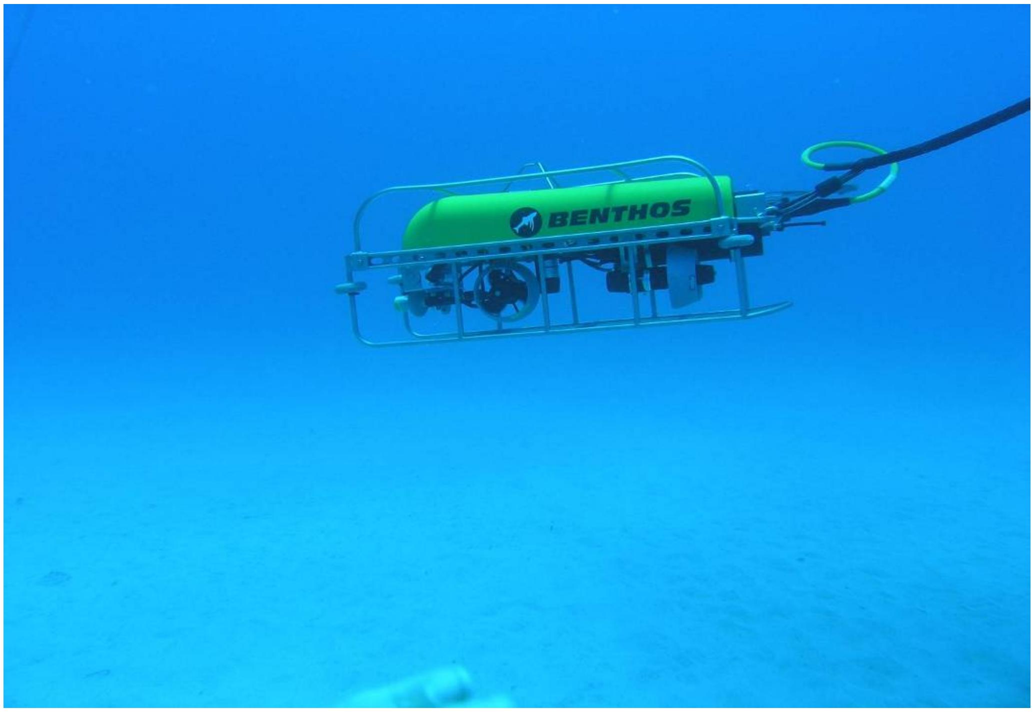

Figure 19. Teledyne Benthos Stingray ROV.

The ROV made 17 dives during the project's survey (Figure 19). The ROV was deployed from the R/V *Manacats*' stern and driven down to the suspected sites by the ROV operator. The ROV traveled in a star pattern from the pre-determined DGPS location out to 100m and then return on the same line. Positioning for the ROV was based upon the vessels known DGPS location.

Dive Operations

NOAA

NOAA divers were used during the project to take still images of key features within the study area. Maximum depth of divers was $\leq$ 120 feet. Diving operations took place in conjunction with sediment and biological sampling.

During the daily Plan of the Day briefing, NOAA divers were presented with a list of dive site target areas from the previous day's side scan work or from USACE 2002 study area. Depending upon depth, the divers examined the daily targets and assisted in both biological and sediment sampling.

Without touching or disturbing the suspect munitions in any way, divers placed a ruler for scale nearby and photographed each item from several angles to aid in identification (Figure 20). Divers recorded observations including habitat types, predominant coral species, and described the habitat in the vicinity of each munitions. Areas of interest were targeted by the ROV. In addition, images acquired by the ROV, sampling areas and targets of interest were also evaluated for potential dive opportunities.

Figure 20. Diver measurement tools (black and white PVC scale used in photos in 10cm sections).

All diving operations complied with the NOAA Diving Regulations (NOAA Administrative Order 209-123), current policies of the NOAA Diving Center, and applicable reciprocity agreements. All dives were conducted within the no-compression limits of the U.S. Navy Dive Tables. NOAA divers participated in:

- Collecting sediment samples
- Spear-fishing for biological sampling;
- Capturing images with scale bar of targets of interest ;
- Conducting site characterization;
- Assisting with fish trap recovery

Military Unit Dive Support (MDSU)

Figure 21. MDSU dive briefing.

DoD provided the project team with a MDSU to photograph and assess any military munitions encountered during the project. A daily briefing was held with MDSU dive supervisor to review the daily dive plan as prepared by the PI. Depth of dives, site priorities, currents and visibility were taken into consideration during the briefing. All dives were kept within DoD dive limitations.

The primary areas for MDSU dives were to image key munitions discovered during the 2002 survey within the study area. MDSU examined 16 of the 2002 survey areas were examined during the 5 days they were on site. (The 2002 survey sites are identified in this report's Findings Section of this report as Site XX). With the exception of two MDSU dives, the munitions identified during the 2002 survey were reacquired and imaged by the team.

Sample Locations and Rationale

Sediment, water column and biological samples were collected from the survey area following the remote sensing survey. Samples were collected at or near military munitions, the WWTP Outfall and a control area up current of the study area.

Control area samples were collected distant enough from the main study area that biota would be unlikely to be affected by target munitions constituents originating from the study area. These areas were identified from a review of nautical charts and 2002 survey report. The analytical parameters selected for each sample location were based on a review of the sonar and ROV data collected, USACE historical records and past environmental studies performed at the sewage outfall. The location of each sample was documented by using a DGPS receiver to meter to sub-meter accuracy. This will allow the sampling point to be reacquired in the future if necessary.

Because traditional sampling and analysis methods for marine ecosystems do not always provide the information needed for decision making in a timely and cost-effective manner, rapid characterization methods were used to speed up site characterization. These advanced screening methods can detect contaminants in many different environmental media, including air, water, soil, and sediment. This section provides information on X-ray fluorescence spectrometry (XRF) – used to determine concentrations of metals analytical method for quick and cost-effective characterization of sediments at marine sites:

Sample Collection

Sediment and water column sampling in the study area was guided by preliminary results of the remote sensing survey. Overall, sample collection was targeted at the area immediately offshore of Pokai Bay, the Wai'anae WWTP outfall pipe, a documented Fish Haven (FH) area to the south of the outfall as well as near documented military munitions (Figure 35).

Sediment Sampling

A two dimensional grid of target sites was established to cover the control, the outfall, and munitions areas. Operational difficulties were immediately encountered using this approach to sample sediments owing to a combination of the physical characteristics of the bottom (substrate type and topography) and physical forcing within the water column (currents). Sediment sampling with a PONAR grab was only marginally successful on reefs, reef flats and other hard substrate where sediment tends to only accumulate in depressions. Hence, the majority of the sediment sampling by PONAR targeted sandy areas. Divers were deployed to manually collect additional sediment samples from areas with hard substrates. In deeper water, the PONAR grab was guided to the sample location by the ROV but this was often unsuccessful in waters deeper than 80 feet due to currents. In total, 96 individual sediment samples were recovered (105 attempts were made) within the study area, leading to the recovery of 96 individual samples. Sampling locations were individually documented using a differential global positioning system (DGPS) receiver with meter to sub-meter accuracy.

On recovery of the PONAR, the sediments were released into a decontaminated plastic tray and the sediment characteristics were recorded. The sediments were then transferred into sample containers using a clean plastic spoon. Divers used clean plastic spoons and collected the sediments directly into the sample container while at depth.

Water Column Sampling

Water column sampling was carried out using Niskin bottles modified for trace element work. Previous oceanographic research has shown that samples can be collected without contamination using Niskin bottles on a conventional rosette and cable (e.g., Sanderson et al., 1995; Measures and Vink, 1999, 2000; Measures et al., 2001). The 10-L modified Niskin bottles used in the current study were equipped with epoxy-coated springs and silicone O-rings and hung on a nylon line. A two-person team carried out shipboard sub-sampling of water from the Niskin bottles after recovery. One person, dubbed “clean hands” handled all trace-element clean materials (e.g., Nalgene bottles) while gloved. The other, dubbed “dirty hands” assisted by manipulating contamination prone surfaces and equipment.

Filtering and pre-analysis processing of water samples was subsequently carried out in a Class 100 laminar flow hood at the University of Hawaii. Samples were filtered through acid-rinsed 0.45 µm Gelman Sciences Acro 50A filters. All plasticware used for sample storage, handling, and processing was scrupulously cleaned by a series of acid washing steps that exceed EPA recommendations, as previously described by Spencer et al. (1995) and De Carlo and Spencer (1997). These cleaning procedures were originally developed to minimize contamination for analysis of lead by thermal ionization mass spectrometry (TIMS) and are modifications of earlier methods (Mahoney et al., 1991). All processed water samples were double bagged in clean zip-lock bags and stored chilled at 4^{o}C until analysis. Bottles of filtered and unfiltered water were acidified to pH<2 with quartz distilled HCl (e.g., see Moody and Beary, 1982) in a laminar flow hood in the SOEST ICP-MS clean laboratory one day prior to analysis. Because offshore Hawaiian marine waters are known to contain very little suspended material (unless during/after storms), it is not practical to weigh filters with a sufficient level of accuracy to determine suspended solids concentrations without undue risk of contamination. Filtered and unfiltered seawater samples were analyzed by FIA-ICPMS as described by De Carlo and Resing (1998). The difference between the two analyses is considered to represent the contribution from particles. Replicate filtered seawater samples were processed for QA/QC purposes.

Profiles of water column properties were obtained through hydrocasts with a YSI 6600 multi-parameter probe system. Because of ship operational time constraints and because water currents can integrate signals over a relatively wide area, only three target water column locations were sampled (see Table 4; Appendix J). Samples were recovered from 55 feet of water depth at Site 33, to the south east of the outfall, at 53 feet near a known munitions target to the east of Site 77, and near the bottom (88 feet) at Site WO, located immediately to the north of the end of the outfall pipe (see Figure 38).

Biological Sampling

Biological specimens were collected during the later portion of the project's cruise off Pokai Bay, Oahu. The goal of the study was to provide an indication of potential impacts to the human food chain and the potential for significant adverse impacts on the local ecosystem from the discarded munitions. The marine resource study focused on a target species list developed by NOAA Fisheries and DLNR/DAR. The species were selected to represent a range of trophic levels and fishing niches and focused on popular food fishes, and higher end predators.

A total of 49 individual representative reef fish from various trophic levels were collected throughout the designated survey area. Fish species were selected based on foraging levels in the ecosystem, long term residence time within the survey area, and importance as local food fish to the resident population of the Wai'anae Coast of Oahu.

In addition to fishes, an attempt was made to collect certain Hawaiian invertebrates in sand or sediment habitats. Targeted invertebrates included polychaete worms, crustaceans, echinoderms, and mollusks. Fish traps were baited and deployed on June 7 with negative results.

The fish were collected using standard collection techniques with equipment provided by NOAA Fisheries (spears or hook and line). Of the 49 samples; 13 came from the Fish Haven south of the known military munitions disposal area (Control Area), 8 were collected at 2 locations adjacent to the Wai'anae WWTP Outfall (Outfall Area), and 28 came from 11 locations within the military munitions disposal area where military munitions were known or suspected present (Munitions Area).

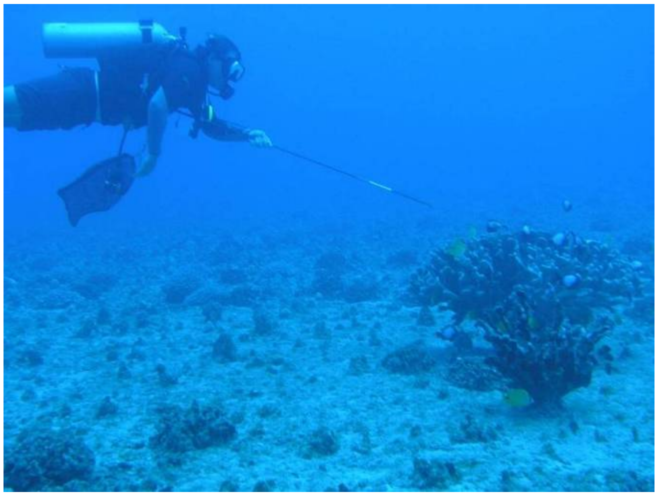

Figure 22. Sample collection.

Figure 23. Recording biological data.

Each biological sample was recorded in the field, packaged in Teflon coated bags, and stored for shipment to the lab. The samples were shipped on dry ice frozen.

Sediment Sample Analysis

Rapid Shipboard Screening of Sediments by XRF

A rapid sediment characterization/screening for metals (As, Co, Cu, Fe, Mn, Mo, Pb, Rb, Se, Sr, Zn, Zr) was carried out using a field X-ray fluorescence spectrometry (XRF) to provide near real time semi-quantitative data and was originally designed to generate a metals distribution map that could be used during the field operations. Samples that were rapidly screened on board were subsequently returned to the NOAA Office of Environmental Response and Restoration laboratory in Seattle, WA for further XRF analysis under optimized conditions. None of the samples screened on ship displayed preliminary concentrations of elements of potential concern.

Laboratory Analysis

All sediment samples for which recovery exceeded the minimum size needed for rapid shipboard screening by XRF were also subsequently processed for wet chemical analysis in the laboratory. Sediment samples were dried in an induction oven at 60^{o}C to a constant weight and homogenized with a tungsten-carbide ball and mill. Splits (~200 mg) of the sample powders were digested in closed Teflon containers using concentrated minerals acids and subsequently analyzed by atomic spectrometry for their elemental composition using methods previously employed in our laboratory (e.g., Wen et al., 1997; De Carlo et al., 2004, 2005). Our digestion procedures and analysis are comparable to those described in EPA SW846 (e.g., Method 3050, 3051 or 3052 followed by ICPOES Method 6010 and ICPMS analysis Method 6020). Standard quality assurance and quality control (QA/QC) procedures were undertaken during the course of sample preparation and analysis. These include the preparation and analysis of reagent and procedural blanks, replicate sample analyses, and analysis of certified reference materials (CRM).

The analytical parameters selected for examination in sediment samples were based on USACE historical records and previous environmental studies performed at the WWTP and other locations on Oahu (e.g., De Carlo et al., 2004, 2005). Samples were analyzed for a suite of major, minor and trace elements that were selected based on their potential to help identify individual contributions to the overall sediment composition from munitions, terrigenous (volcanic) materials and marine carbonates. The elements analyzed included As, Ca, Cd, Co, Cu, Cr, Fe, Mg, Ni, Pb, Sr, U, V, and Zn.

A subset 47 of the 96 sediment samples was sent to Calscience Environmental Laboratories (CEL, Garden Grove, California), which is CEL accredited for analysis of explosives by USEPA Method 8330 under the National Environmental Laboratory Accreditation Program (NELAP) issued by State of California, Department of Health Services, No. 03220CA, Expiration Date: 09/30/2007.

Fish Tissue Analysis

To preserve sample integrity and preparation consistency, the laboratory was responsible for preparation and analysis of the fish tissue. All testing and analyses was conducted at Test America Laboratory (formerly Sequoia Analytical Laboratory), Morgan Hill Laboratory for except mercury was analyzed at both Test America Laboratory, Morgan Hill and Portland, Oregon. Based on input from DLNR on fish consumption in Hawai'i, whole fish were homogenized, and tissue samples were analyzed for heavy metals using EPA Methods 6010B and 7471A and explosives using EPA method 8330. The laboratory analytical reports are provided in Appendix G.

Data Evaluation

The exposure point concentration (EPC) refers to the concentration of a compound specific medium to which a receptor may be exposed. EPCs are based on either the 95% upper confidence limit (UCL) of the mean, or the maximum detected concentration, whichever is lower. The use of the 95% UCL is a conservative estimate of the mean. The method that was followed to calculate the 95% UCL is dependent upon the shape of the data distribution. The 95% UCL concentrations were calculated using the appropriate equation for the data distribution recommended by EPA (EPA, 1992).

The data were evaluated initially by the Shapiro-Wilk *W*-test to determine whether data were normally or lognormally distributed, after which the appropriate summary statistics were calculated. The arithmetic mean concentrations and standard deviations are based on the positive identifications (i.e., detects) plus the nondetects at the lesser of one-half the sample quantitation limit or the maximum detected value. The 95% UCL of the mean for a compound was calculated per EPA guidelines presented in *Supplemental Guidance to RAGS: Calculating the Concentration Term* (EPA, 1992). The appropriate formula (dependent on the type of distribution) was used to estimate the 95% UCL of the mean. Shown below are the formulas:

Lognormal Distribution

$$UCL = e^{\left(\bar{x}+0.5s^2+sH/\sqrt{n-1}\right)}$$

Where:

UCL = 95% upper confidence limit of the mean
e = constant (base of the natural log, equal to 2.718)
$\bar{x}$ = arithmetic mean of the log-transformed data
s = standard deviation of the log-transformed data
H = H-statistic, determined by the standard deviation and sample size
n = sample size for the contaminant in the designated media set

Normal Distribution

$$UCL = \bar{x} + t\left(s / \sqrt{n}\right)$$

Where:

UCL = 95% upper confidence limit of the mean
$\bar{x}$ = arithmetic mean of the untransformed data
t = Student-*t* statistic
s = standard deviation of the untransformed data
n = sample size for the contaminant in the designated media set

If the results of the Shapiro-Wilk *W*-test did not indicate normality or lognormality, it was assumed that the data were lognormally distributed and the lognormal equation was used to calculate the 95% UCL. Tables 3 and 4 present the EPCs.

The fish tissue arsenic data displayed acceptably normal distribution while the zinc data displayed either log normal or no discernable distribution. The standard, off-the-shelf statistical software program Statistica® was used to calculate the UCLs in the case of arsenic where the data were normally distributed. In the case of zinc data, however, the UCLs were calculated using an Excel® spreadsheet to incorporate the special provisions for log-normal data. All other data display too few positive detections for a reasonably confident estimate of the UCL to be made using standard methods.

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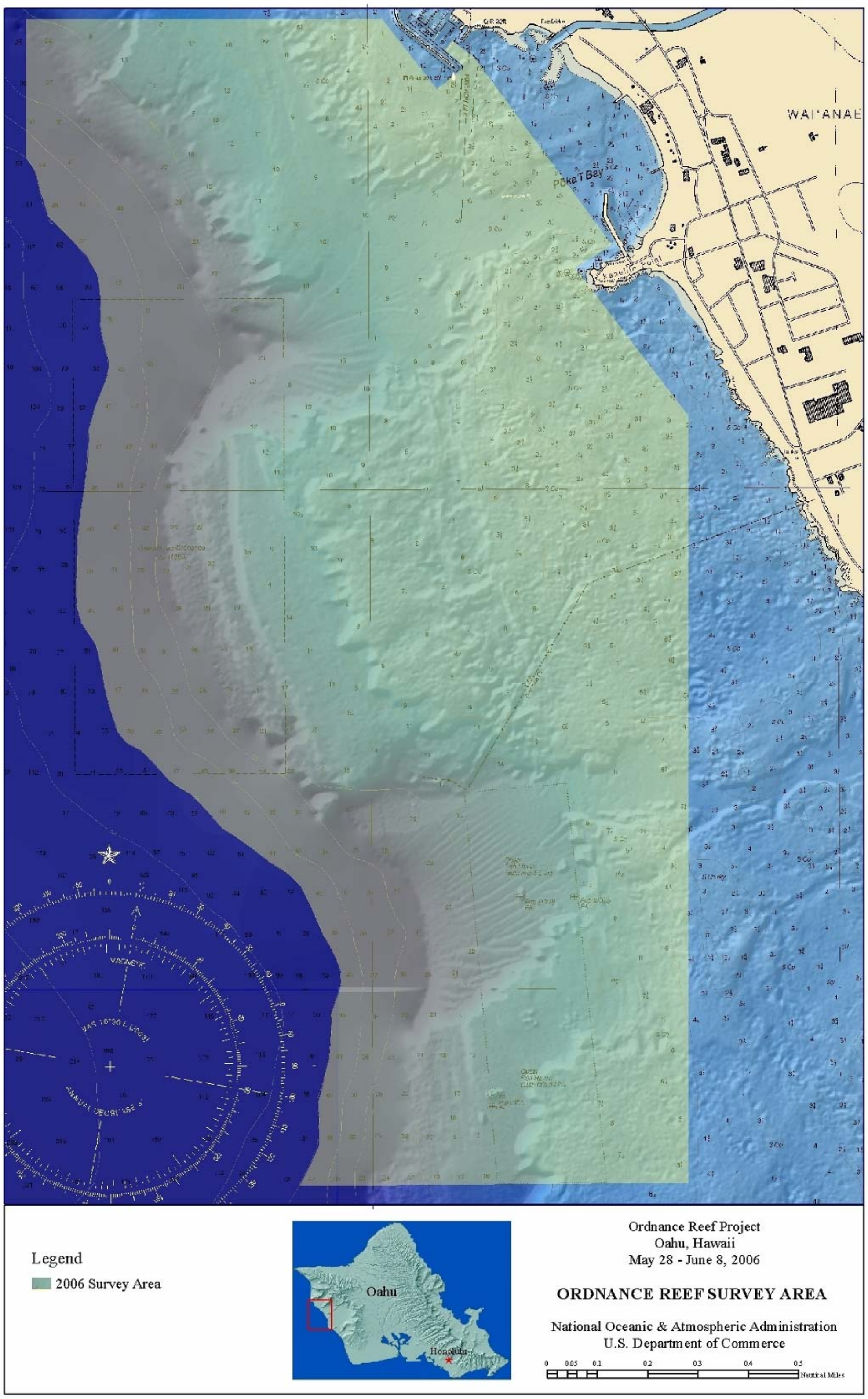


Figure 24. Ordnance Reef survey area. (highlighted in green).

5. REMOTE SENSING SURVEY

The following section describes the survey methods, field procedures implemented and results of the remote sensing survey field component of the Ordnance Reef Project. A remote sensing survey was conducted to determine the boundaries of sea disposed military munitions at Ordnance Reef. The preliminary boundaries of the study area were established based on the data available from the 2002 USACE study of the site, likely depths for recreational divers and limitations of the survey equipment. The entire area where munitions were found during the 2002 survey is encompassed by the study area (Figure 24).

Findings

Shallow water survey

The first two days of survey of the project included the shallow water areas of the Ordnance Reef project. On the first day, 93 sonar contacts were identified during the first day of survey. 53 targets were identified on the second survey day for a total of 146 sonar contacts throughout this area. As the survey team was acquiring 200 % coverage, a little more than half the targets appeared on adjacent survey lines and were dismissed as duplicative contacts. Shallow water target evaluation can be found in Appendix C and side scan images of each target can be found in Appendix D of this report.

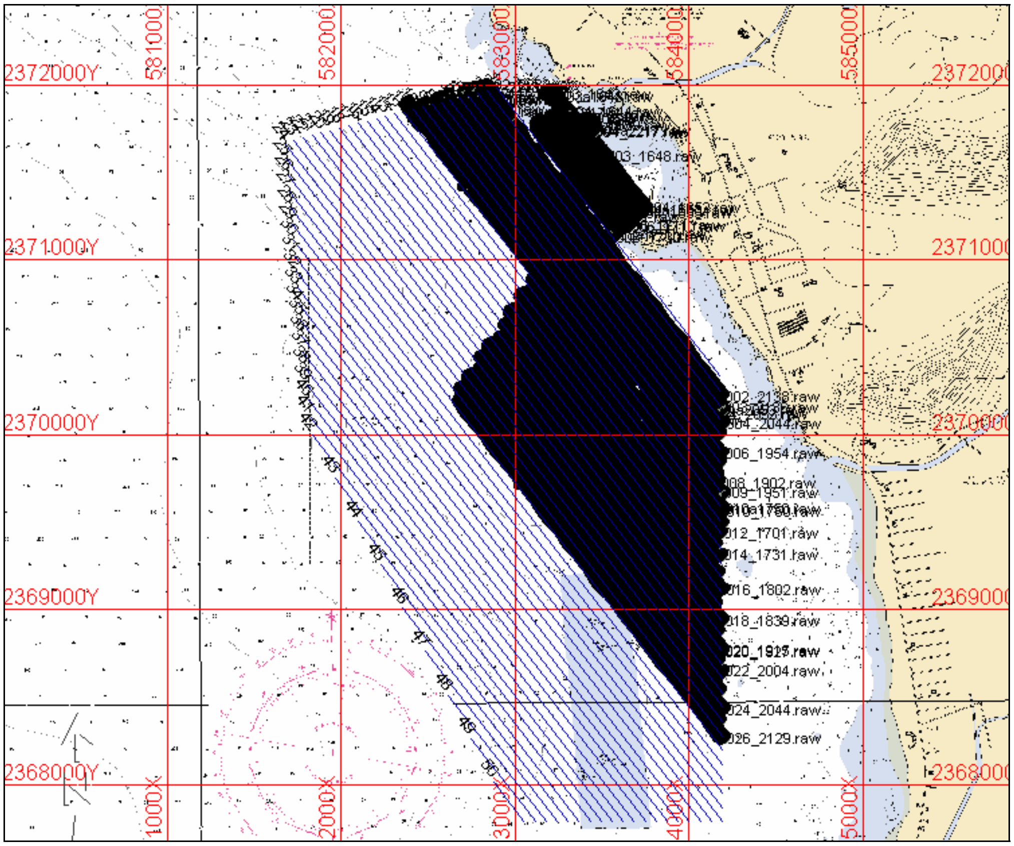


Figure 25. Planned survey lines and area completed (in black) for May 30 & June 1.

During the survey, researchers set the sonar's range to 50m (100m total range) for the shallow areas and 100m (200m total range) for the deeper areas. These range scales were decided upon based on depth of water and resolution of image capture while acquiring 200% coverage within the shallow water study area.

The researchers deployed the side scan sonar fish from the R/V *Manacats*' davit arm located on the port side of the vessel. The sensor operates best at an altitude equal to approximately 10% of the range scale. Using a 50m range the optimal altitude was 5m above the bottom. Altitude was generally controlled by the length of cable paid out combined with boat speed. To ensure maximum clarity of the sonar image towing speed of the R/V *Manacat* was 2.5 to 3.5 knots.

Figure 26. Teledyne Benthos C3D side scan sonar.

The shallow water study area is a very active geologic area. The area is a mixture of hard bottom and coral heads producing the multiple targets acquired by the side scan sonar. Divers and the ROV were sent to targets that had similar sonar returns. The purpose of this was to be able to distinguish between geologic and biologic features from possible munitions. The ROV and divers were able to rule out many of the targets acquired during the shallow water survey as either geologic or biologic (coral heads). Of the 146 targets, only 9 proved to contain munitions not previously identified new munitions' sites (Figure 27) with one area were reacquired from the 2002 USACE survey (Appendix I).

The survey evaluated six areas were evaluated using the Teledyne Benthos ROV within the shallow water study area. ROV operations within the shallow water areas included a thorough examination with Pokai Bay. In addition, no military munitions were located at two sites located outside the northeast corner of the Fish Haven also produced negative findings of munitions.

Based on sonar returns, two additional sites were examined with no munitions found. The ROV was used to investigate one of the near shore munitions identified during the 2002 survey. The site was described as having a 105mm round. Images of the site reveal two objects associated with this report.

MDSU participated in dives within the shallow water study area. Their purpose was to reacquire and video tape munitions identified by the 2002 survey and to investigate side scan sonar targets. Of the 5 targets examined, 3 targets to the east of the Fish Haven contained no munitions.

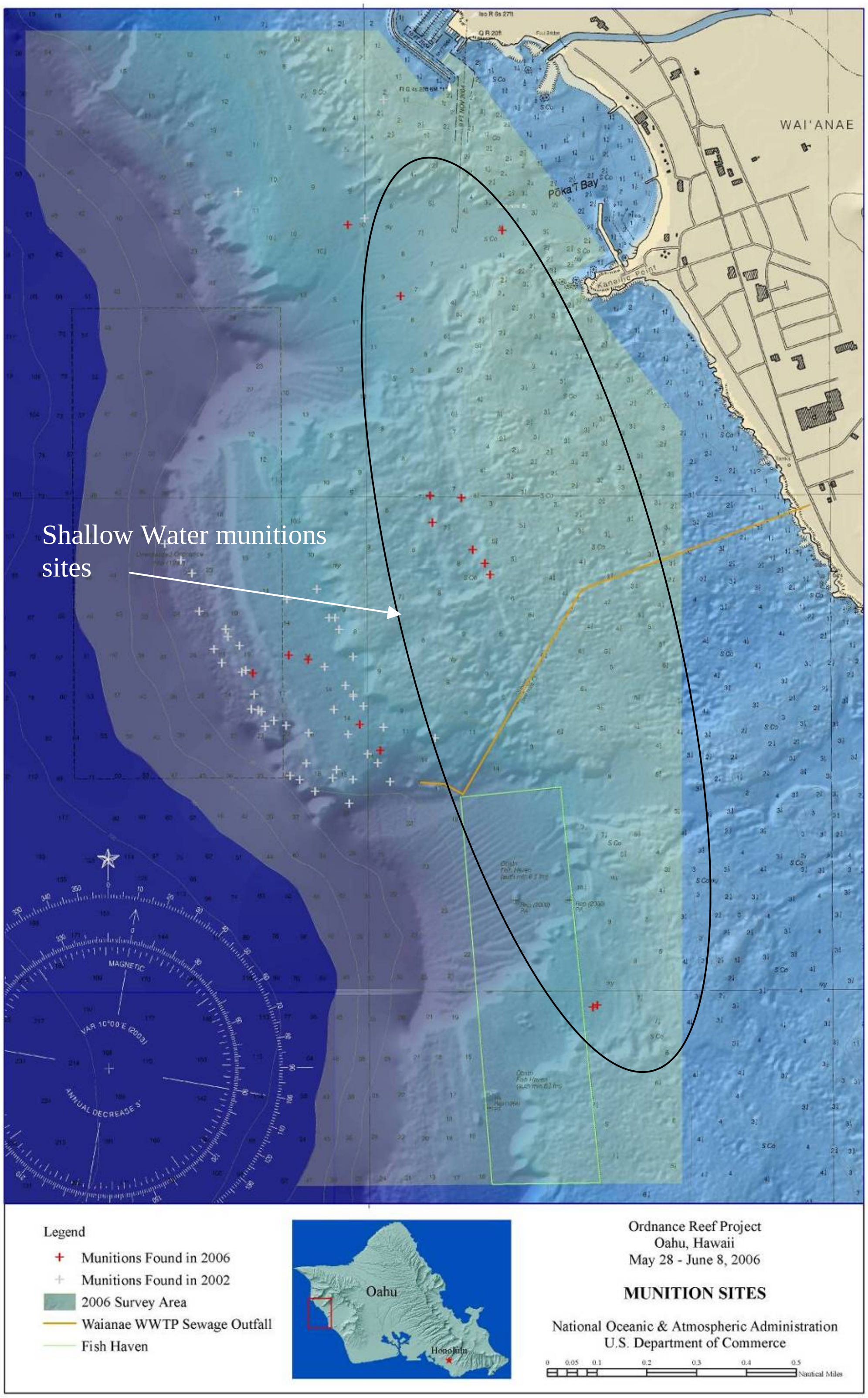


Figure 27. Shallow water 2006 munitions sites.

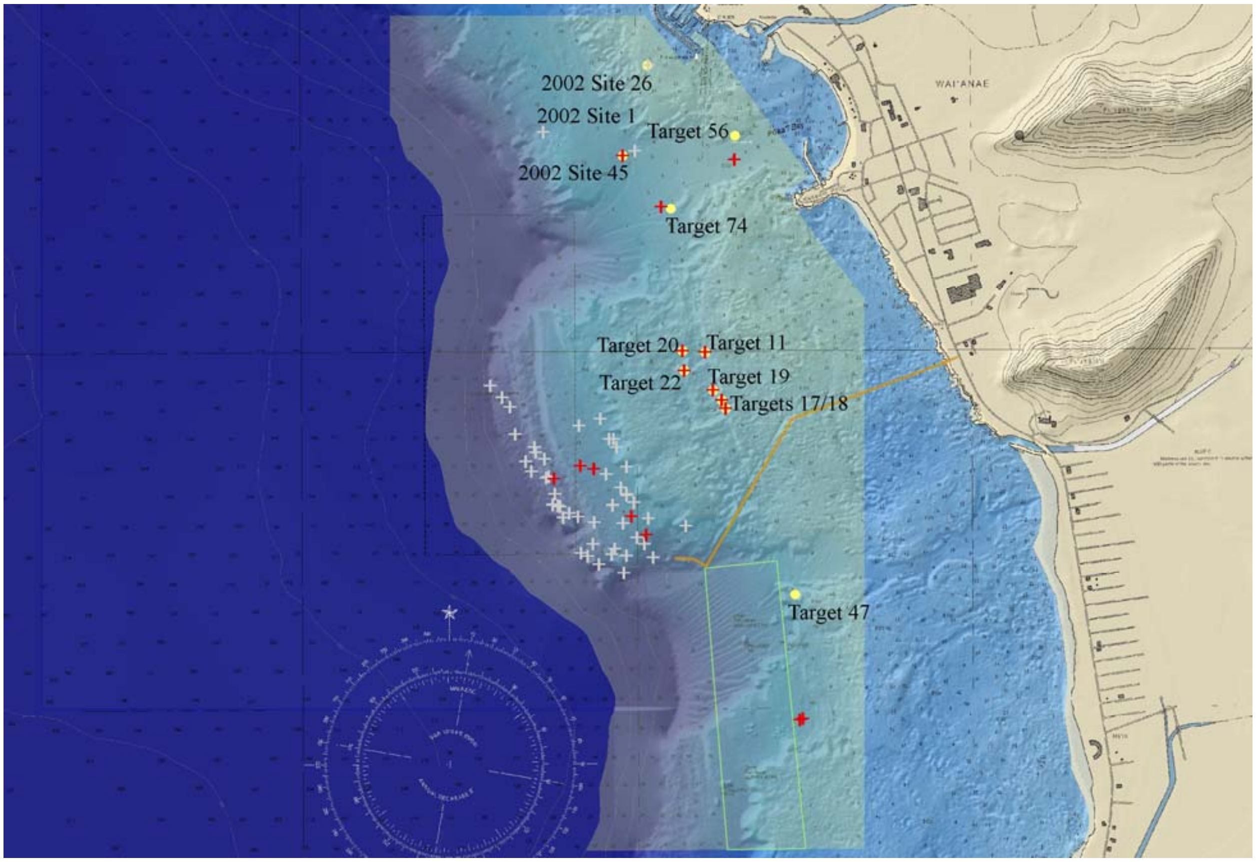
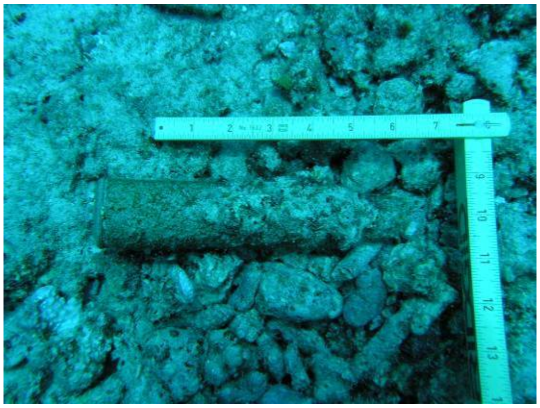
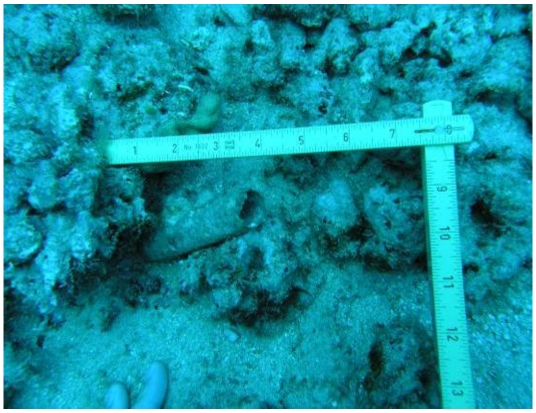


Figure 28. Shallow water target sites.

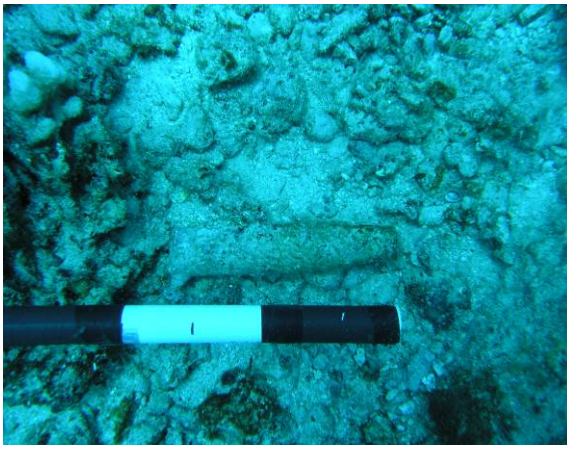
Target 11
Described by divers as having a single 30 caliber round and 37 mm casing. Sediment samples were collected from scattered holes in the reef at this site (images below).



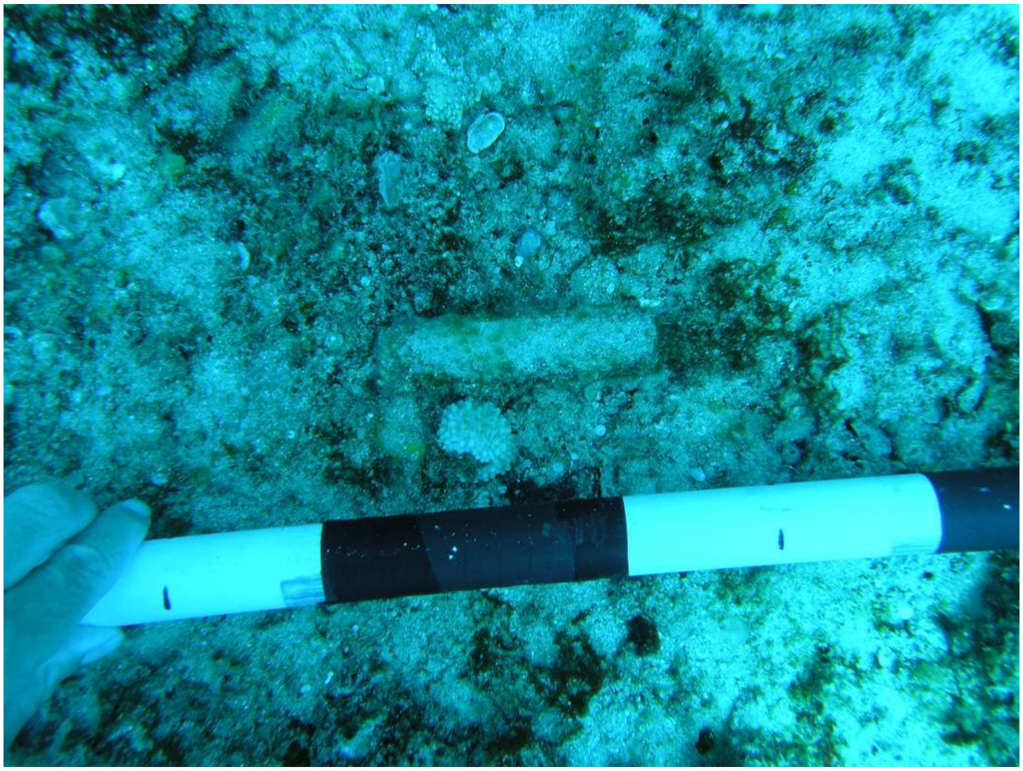


Target 17 / 18
Located by divers on 6/8/06 and described as one .50 caliber round. Fish and sediment samples were taken from this area (No image).

Target 19
Located by divers on 6/6/06 in the afternoon. The area was described as having two .50 caliber rounds and two 37mm casings. Five fish were also collected from this area for analysis (Images below).

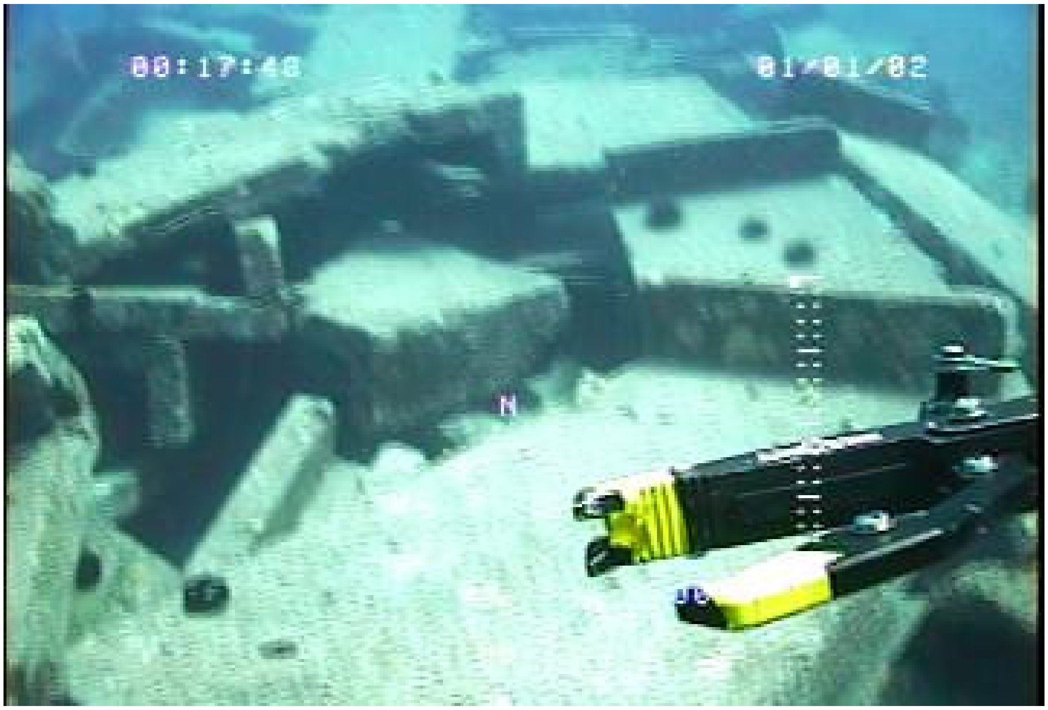


Target 20
In an area south east of target coordinates, MDSU divers on 6/7/06 located dozens of 20mm shells. A fish trap was placed at this location and produced no results. Two fish were captured by NOAA divers in this area for analysis (Image below).

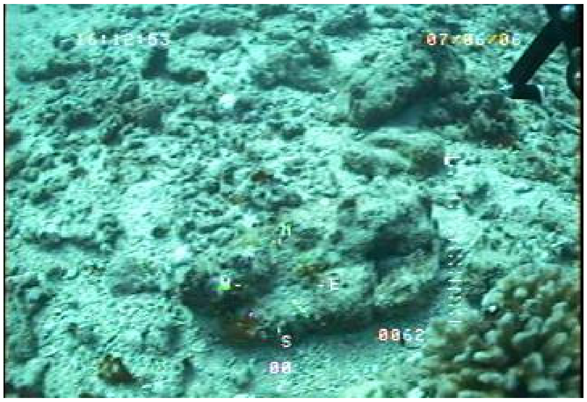


Target 22
Located by divers on 6/7/06 and was described by divers as having scattered .50 caliber ammunitions. Project team members collected four fish were collected for sampling (No image).

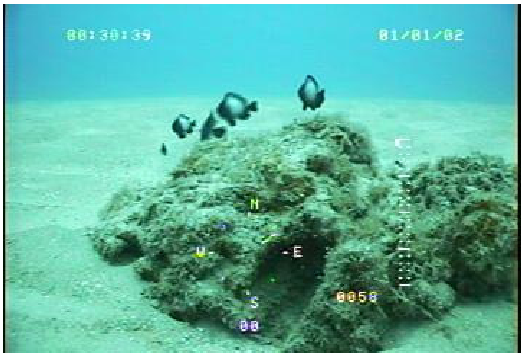
Target 47
Area is located on northeast side of fish haven. ROV imaged concrete slabs dropped as part of the fish haven, confirmed by DLNR personnel (Image below).



Target 56
Just west of Pokai Bay, the ROV imaged an ammunition box and two larger concreted pieces of munitions. The munitions appeared to be .50 caliber rounds. This area included multiple sonar contact including targets 57 and 103 (Image below).



Target 74
The ROV located two concreted boxes west of Pokai Bay. An additional anomaly appeared to have once contained a cylindrical object, possibly a projectile. This area included multiple sonar contact including targets 75, 76 and 100. Sediment sampling of the tan fine grain sand was recovered from this location (Image below).

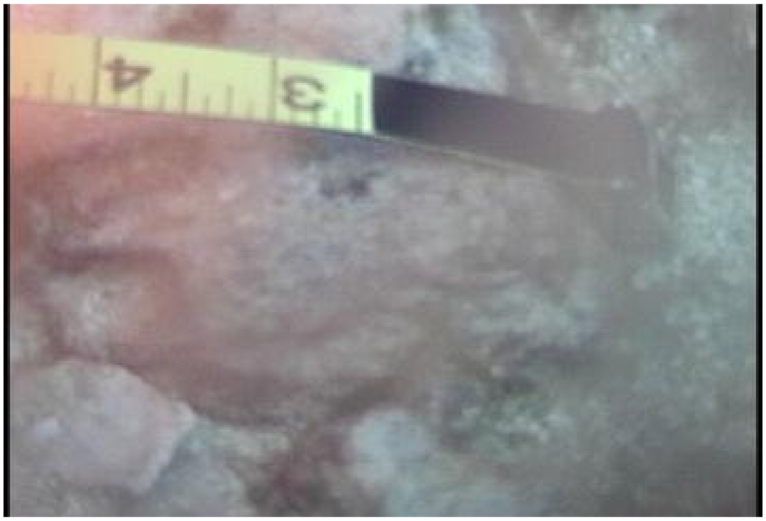


Sonar targets along the northeast edge of the Fish Haven were also investigated. The targets were identified as an extension of the Fish Haven with no munitions seen in the area. (Image below)

Concrete pipes located within Fish Haven.

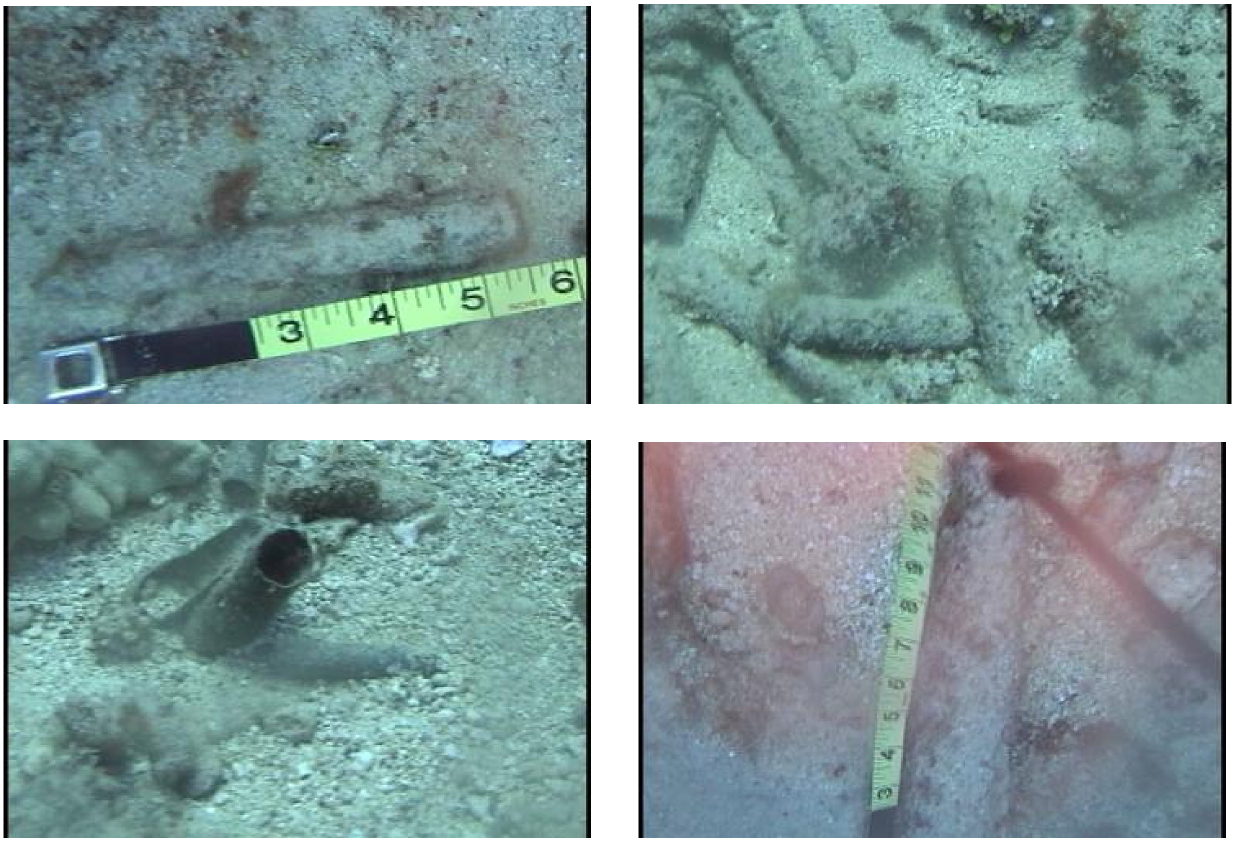
2002 Site 1

Described in the 2002 survey report as a bottom mine. Divers could not confirm mine, but imaged an object measured 4 inches in length and approximately 3 inches in diameter (Image below).



2002 Site 26

Identified in the 2002 survey report as having 100 lb old style fragmentation bomb, viewed from the surface and not diver verified. Divers did not locate target from 2002 survey. Two large rock outcroppings were seen in this area and .50 caliber rounds. This area was also in close proximity to shallow water targets 138,139, and 140 (Image below).



2002 Site 45
Described in the 2002 survey report as having 105mm cartridge casing was confirmed by NOAA divers (Image below).

Deep water survey

Researchers set the 1624 sonar's range to 100m (200m total range) for the deep water survey. This range scales was decided upon based on depth of water and resolution of image capture while maintaining 200% coverage applied to the shallow water study area. Deep water target evaluation can be found in Appendix E and side scan images of each target can be found in Appendix F of this report.

Three days of survey was needed to cover the deep water areas of the Ordnance Reef project. The project team identified five hundred and seventy six (576) sonar contacts were identified during this portion of the survey. As previously stated, the survey team acquired 200% coverage with a little more than half the targets appearing on adjacent survey lines.

The researchers deployed the Teledyne Benthos 1624 dual frequency side scan sonar fish from the R/V *Klaus Wyrtke*, a University of Hawai'i vessel (Figure 28). The survey team acquired the R/V *Klaus Wyrtke* after the dedicated deep water survey vessel became inoperable. The side scan unit was attached to a winch on the aft deck of the vessel and was deployed of the stern with the use of a deck mounted crane with a pulley wheel attached. The depth of the tow fish was controlled by the amount of cable played out by the winch controls. To ensure maximum clarity of the sonar image towing speed of the *Klaus Wyrtke* was 2.5 to 3.5 knots.

Figure 29. University of Hawai'i R/V *Klaus Wyrtke*.

The deep water study area is composed of unconsolidated hard bottom and undulates in depth along the survey lines. Divers and the ROV were sent to targets that had similar sonar returns. The purpose of this was to be able to distinguish geologic and biologic features from possible military munitions. The ROV and divers were able to rule out many of the targets acquired during the deep water survey as either geologic or biologic (coral heads). Of the 576 targets, only 5 proved to be new munitions' sites (Figure 30) not previously identified and multiple 2002 survey sites were reacquired and imaged.

Figure 30. Teledyne Benthos 1624 side scan sonar

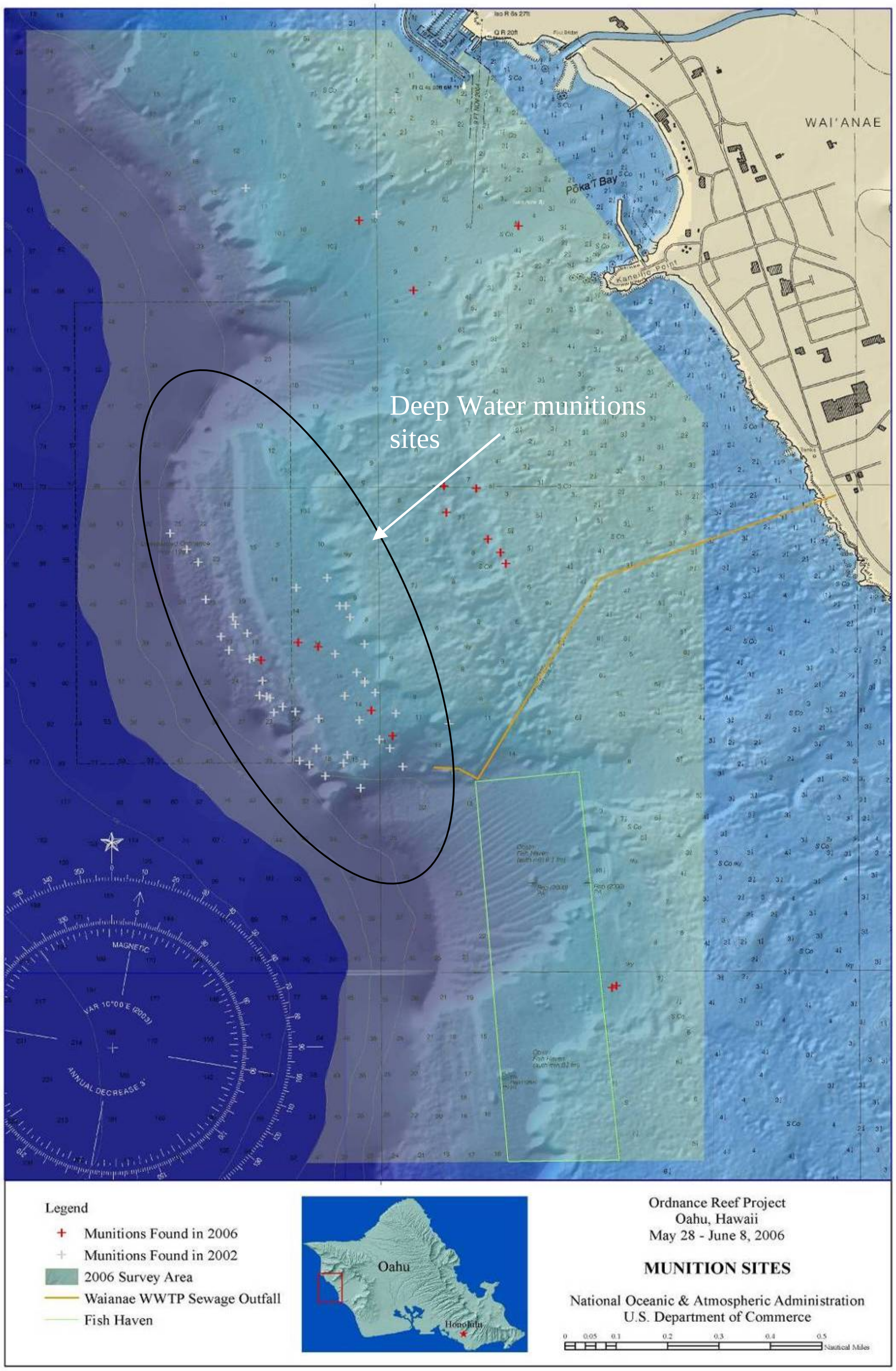


Figure 31. Deep water 2006 munitions sites.

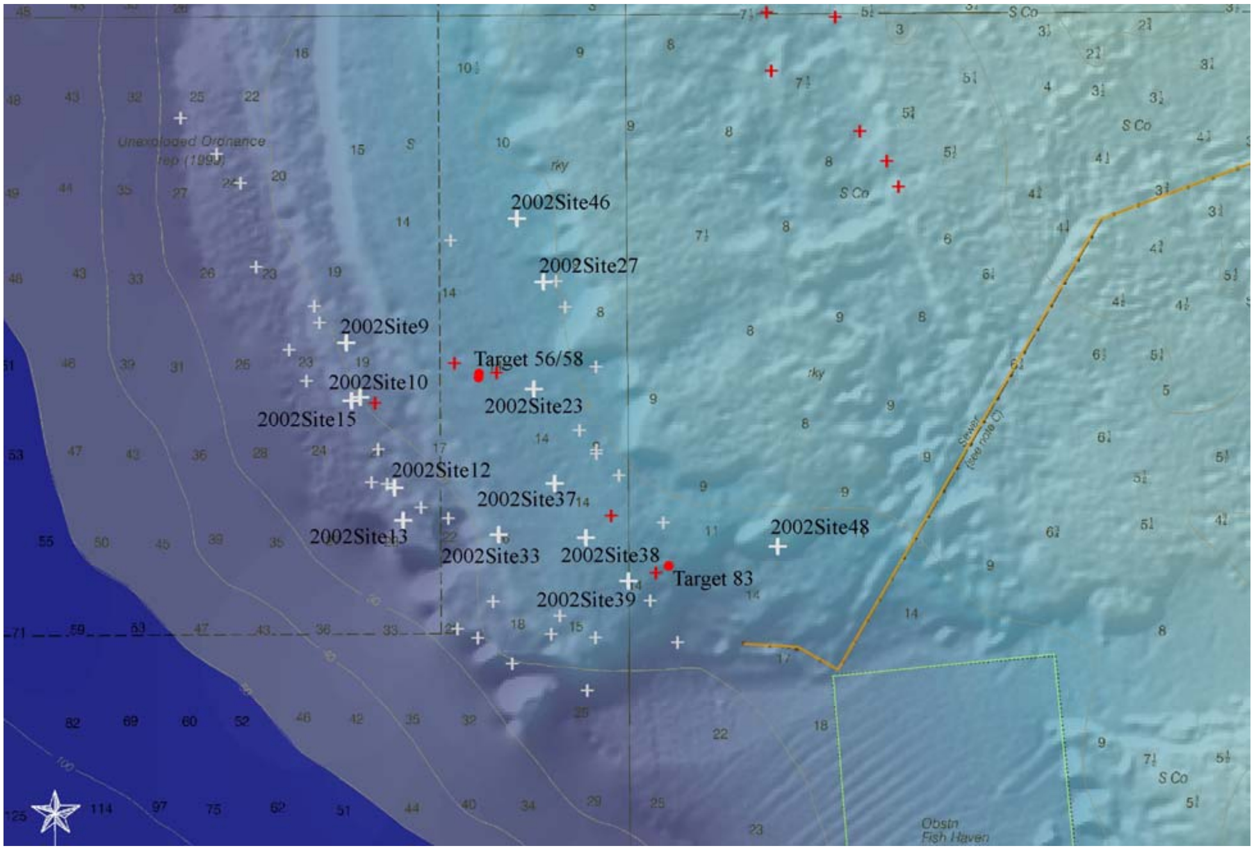
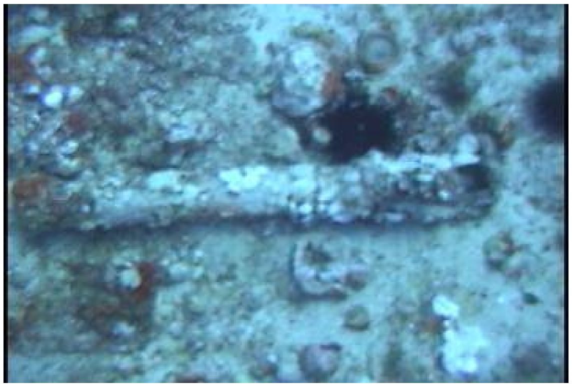


Figure 32. Deep water target sites.

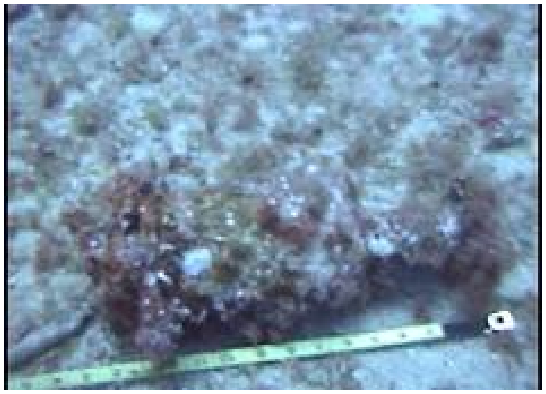
2002 Site 9

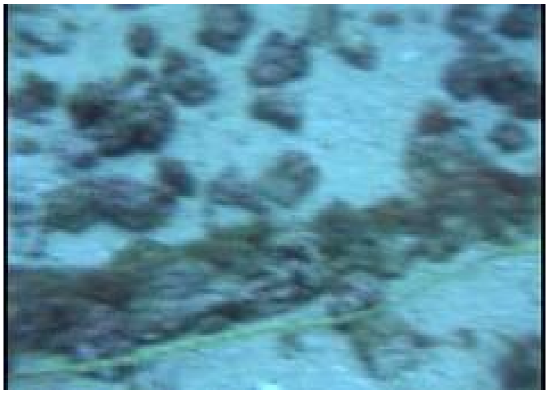
MDSU dive 1 on 6/7/06 at a depth of 37m. 2002 survey reported 17- 105mm rounds. Additional .50 caliber rounds and 3 foot long projectile were located in this area (Image below).

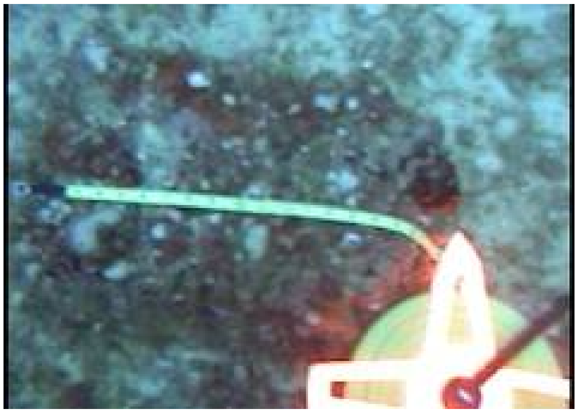


2002 Site 10

MDSU dive 2 on 6/7 in 38m of water. This area contained what was described in the 2002 survey report as having 20-155mm projectiles. Unknown object was located in the vicinity of .50 caliber rounds (Image below).

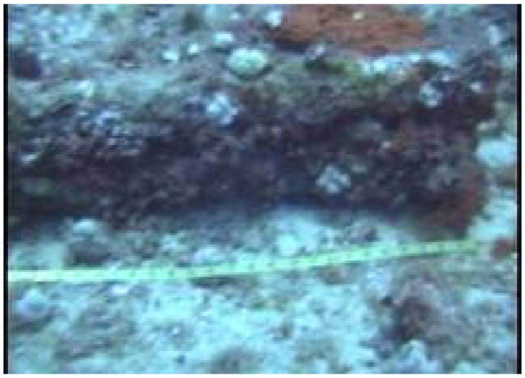






2002 Site 12

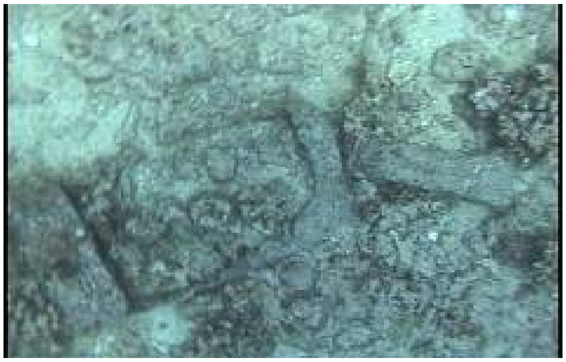
2002 survey reported finding 10-105mm and 15-155mm rounds. MDSU dive confirmed 2002 report findings. Fish traps were set in this area with no captures. Stacks of larger ordnance imaged by divers (Image below).



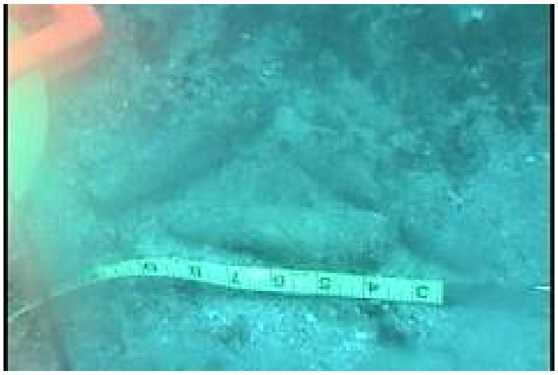
2002 Site 13

MDSU dive 4 on 6/7in 41 m of water. 2002 survey reported 20-105mm projectiles and 15-155mm projectiles. Divers report many different sized munitions, an ammunition box and retaining rings approximately 8” in diameter. (Image below)

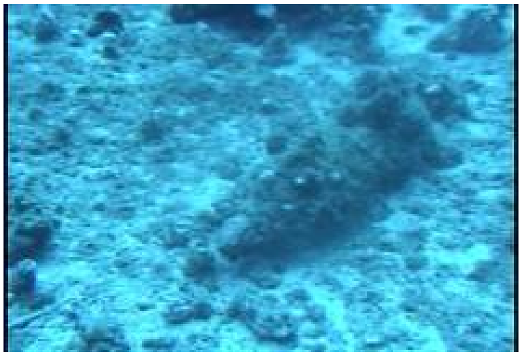
2002 Site 23
MDSU dive 4 on 6/8 in 24 m of water. 2002 survey report observed high concentration of 3 inch and 6 inch naval gun ammunition. Divers confirmed the 2002 report along with unidentified heavily corroded shell and long piece of an unidentified military munition (Image below).

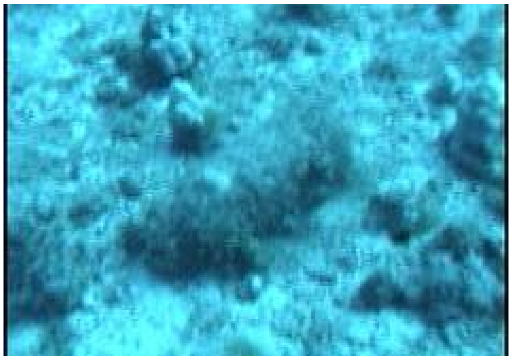


2002 Site 27
MDSU dive3 on 6/6 in 22 m of water. MDSU dives confirmed the location of naval gun ammunition ranging in sizes from 5 to 8 inches from 2002 survey. Area also contained a munitions box and larger munitions measuring 18 inches in length, heavily encrusted. This site correlates to side scan targets 9, 18 and 29 (Image below).



2002 Site 33
MDSU dive 1 on 6/6 in 30 meters (m) of water. Described in 2002 survey report as having 62 - 105 mm projectiles. MDSU dives confirmed presence of projectiles along with .50 caliber ammunition located within this general area. The project team captured two fish for analysis at this location. (Image below)












2002 Site 37

MDSU dive 1 on 6/8 in 26m of water. 2002 survey reported a large quantity of 20 mm rounds and 8 inch naval gun ammunition. Divers confirmed munitions and sediments samples were taken at this site. This site also corresponds to side scan target 77. (Image below)




2002 Site 38

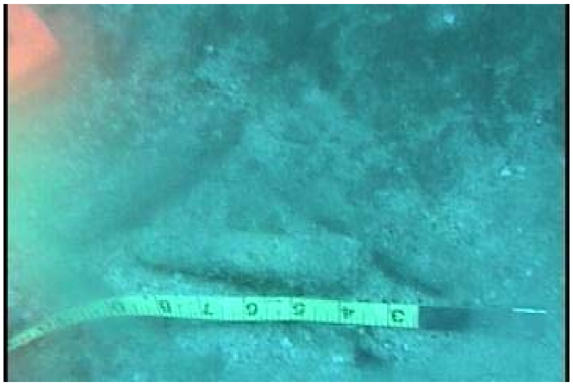
MDSU dive 2 on 6/8 in 25m of water. Naval gun ammunition 5 inch and a large quantity of 20mm rounds were reported in 2002. Divers observed stacked munitions heavily encrusted. Sediment samples were taken at this location. (Image below)

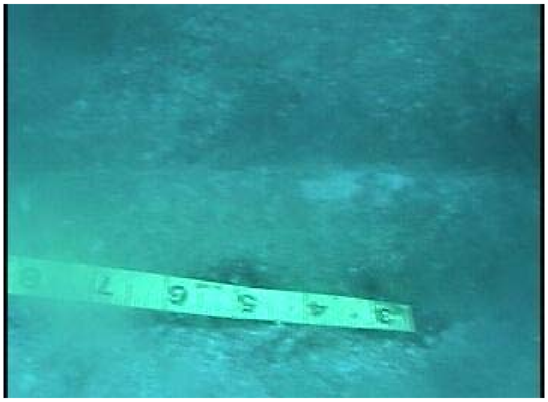

2002 Site 39

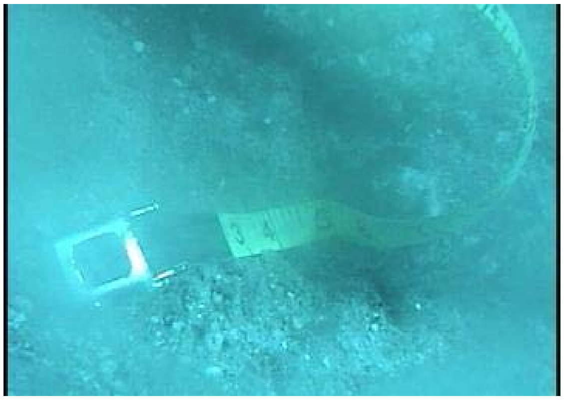
MDSU dive 3 on 6/8 in 26m of water. 8 inch naval gun ammo and a large quantity of 20mm rounds were reported in 2002. Divers confirmed ordnance and large quantities of .50 caliber rounds. Sediment samples were taken at this location. This site corresponds to side scan targets 83, 84 and 85. (Image below)

2002 Site 46

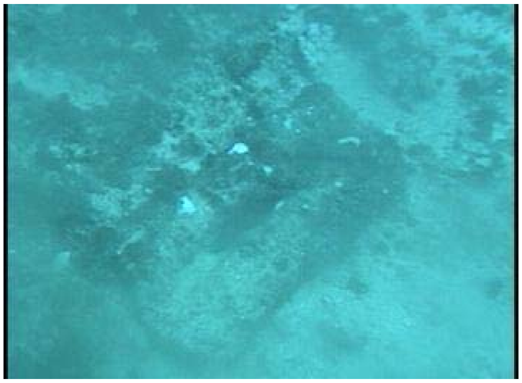
MDSU dive 4 on 6/6 in 22 m of water. The 2002 survey report stated this area had a high concentration of 6 inch projectiles and .50 caliber ammunition. Divers located .50 caliber ammunitions and 40mm or 37mm ammunition casings in the area. One fish sample was taken on 6/8 for analysis. (Image below)



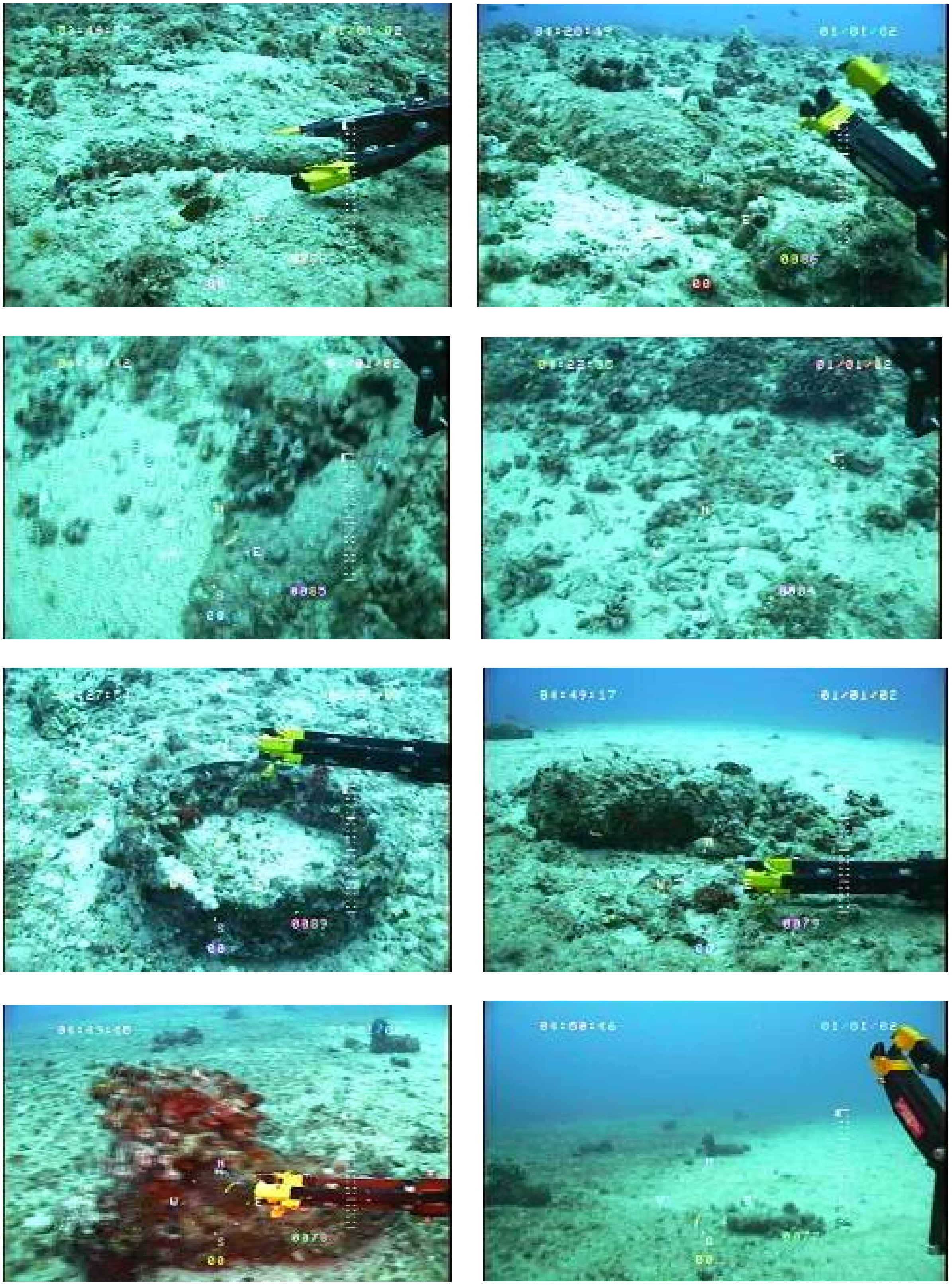




2002 Site 48
MDSU dive 2 on 6/6 in 19 m of water. Described in 2002 survey report as having a high concentration of 6 inch projectiles. MDSU reacquired 2002 munitions along with 155mm artillery shells. Also imaged by divers was a 6 inch pulley wheel. Both biological and sediment samples taken at this site. (Image below)

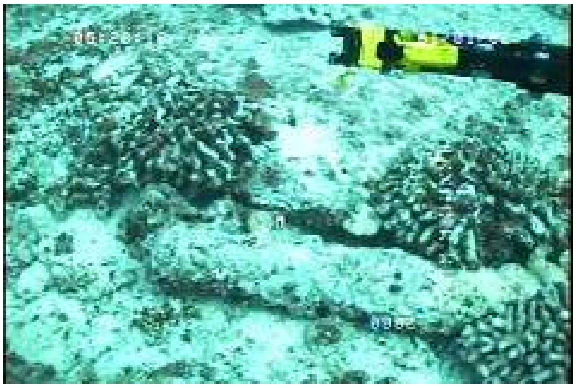


Target 56 and 58
8 inch projectiles and numerous large projectiles were acquired by the ROV in this area. Several large shells were broken open. Marine life was abundant throughout this area (Image below).



Target 83

Large ordnance was located by the ROV in this area. Many appeared in groups of three and heavily encrusted with coral. The area also contained piles of .50 caliber ammunition. This area included multiple sonar contact including targets 84 and 85. This area also coincides with 2002 survey Site 39 and 40 of naval gun ammunition, various sizes and a large quantity of 20mm rounds. (Image below)



Discussion

The extent of the discarded military munitions area extends from depths of 24 feet to the maximum depth of our study area (300 feet). Munitions clusters not previously located were found near shore. The munitions that were identified throughout this study ranged in size from .50 caliber ammunition up to munitions measuring up to four feet in length.

Due to the decades of exposure to the ocean elements, identification of individual military munitions proved difficult. The military munitions disposed within the study area have blended into the environment, often times encrusted with marine life growing off the munitions. Many isolated military munitions (smaller rounds) may have been transported into the shallow water area by storm surge or current and may not be indicative of disposal within the area. As stated earlier, the dynamic nearshore environment in this area may also be hiding other munitions not identified within this study. The only way to detect the presence of additional munitions would involve the upending of coral heads and examine what lies beneath.

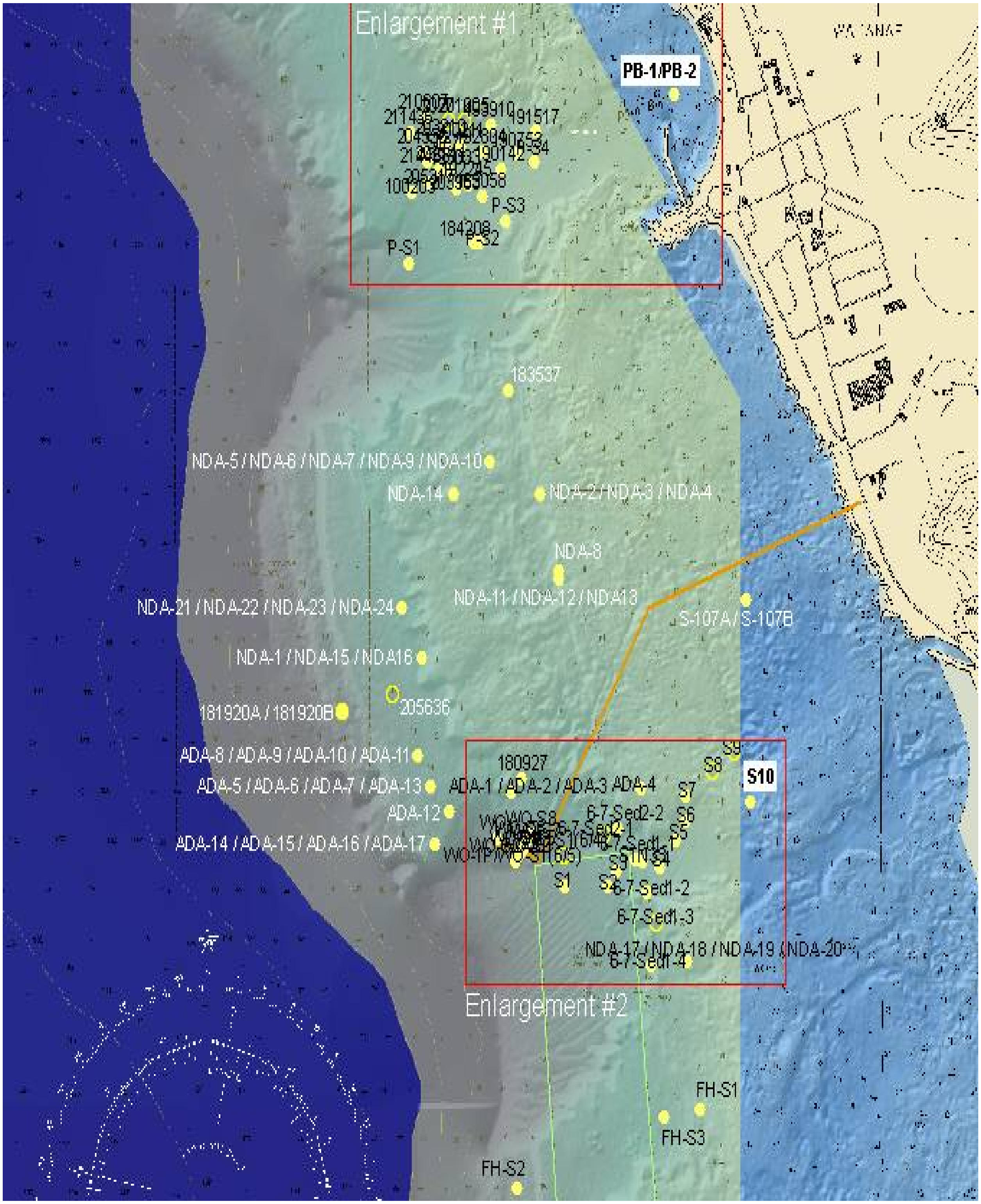


Figure 33. Sediment sampling sites.

6. SEDIMENT AND WATER COLUMN SAMPLING

The Geochemistry subtask of the Summer 2006 NOAA investigation of the Ordnance Reef area of the Leeward coast of the islaprojectaimed to evaluate the potential impact on the composition of water and sediment of past munitions disposal in the area. In order to achieve this objective, field operations recovered water and sediment samples for analysis. Sampling was also conducted at several other locations in order to evaluate if the composition of water and sediments collected in the Ordnance Reef study area differed significantly from those recovered in areas that were unlikely to be impacted by sea disposed military munitions.

Figure 34. Mobilization of Ponar grab.

Sample site locations are presented in Figures 33, 35 & 36. In total, sediment sampling was attempted at 105 locations within the SA, leading to the recovery of 96 individual samples. Sample identification, water depth and location are presented in Table J-1; Appendix J.

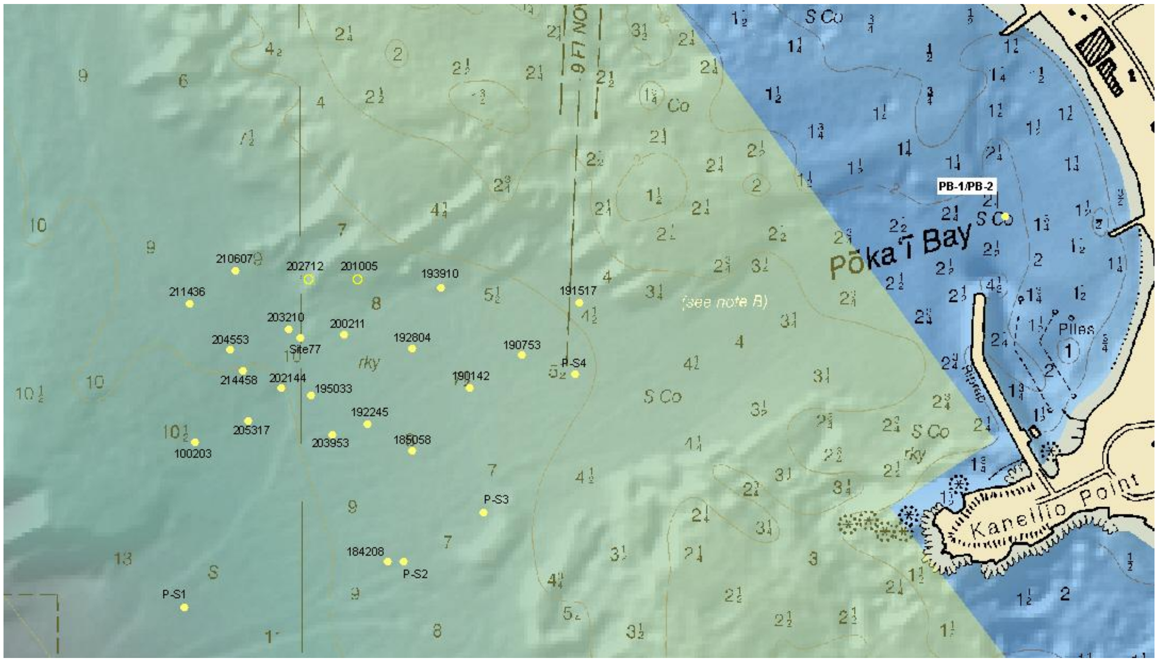


Figure 35. Enlargement of the area offshore of Pokai Bay, showing sediment sampling site locations.

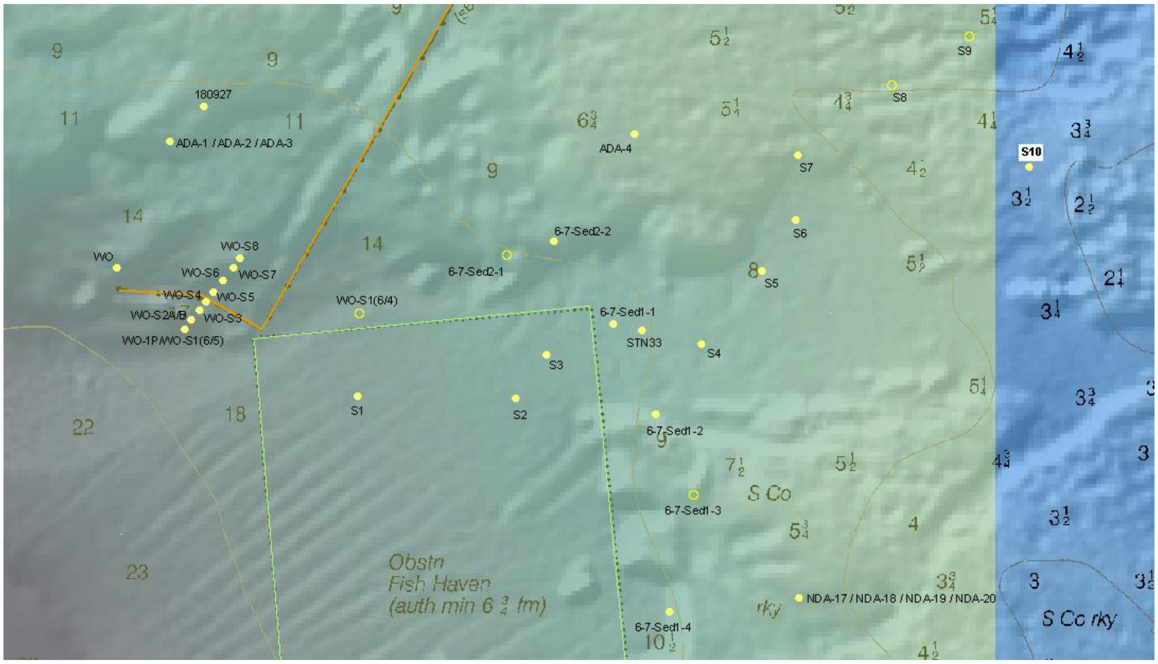


Figure 36. Enlarged view of sampling area near the Wai’anae Wastewater Treatment Plant outfall, labeled as "Enlargment #2" in Figure 33, showing sampling site locations.

Water Column Parameters

Profiles of *in situ* water column properties collected at a frequency of 0.5 Hz from three locations within the study area are presented in Table J-2 (see Appendix J) and graphically illustrated in Figure J-1. The YSI 6600 instrument used for this work recorded the concentrations of chlorophyll (µg/l) and dissolved oxygen (DO in mg/l and expressed as percent saturation), as well as the pH, specific conductivity (mS/cm), salinity, temperature (^{o}C), and turbidity (NTU) of the water.

Examination of the profiles in Figure J-1 reveals a relatively uniform salinity of 35.0-35.1 throughout the entire water column of Site 33 and 77. This value is close to that expected (34.8) for seawater throughout the Hawai'ian Islands and the slightly higher salinities may simply reflect the slightly drier nearshore environment, especially during the summer months, of the leeward coast of O'ahu. Bienfang and Szyper (1984) report similar values in their study of leeward coastal Hawai'ian waters. A small but well defined salinity minimum was observed at approximately 80 ft at Station WO, which most likely reflects input of freshwater from the diffuser of the outfall. Yet, the salinity did not decrease below ~35.0 at the latter, indicating that the (fresher) wastewater issuing from the outfall has a relatively minor, although clearly identifiable, impact on salinity.

The temperature structure of the water column was similar at Site 33 and 77, where a surface layer of 26.44-26.48 ^{o}C water progressively cools to ~25.73 ^{o}C below ~15 ft of water depth. At Station WO, however, the temperature profile shows a nearly homogenous surface layer of 26.2 ^{o}C down to 11 ft, below which the temperature drops steadily to 25.7 ^{o}C at 33 ft. The temperature then remains nearly constant down to the depth of the hypothesized outfall plume, where several sequential drops in temperature lead to a minimum temperature 25.0 ^{o}C at the bottom of the profile.

The pH profiles for Sites 33 and 77 (Figure J-1) are nearly constant with a pH value of 8.12 throughout the water column. A similar constancy is observed at Station WO, although, in this case the pH remains essentially constant at a value of 8.18 throughout the entire water column. The small difference in pH between the sites is difficult to explain. The difference may reflect the influence of the WWTP input, although salinity and temperature profiles suggest the influence of inputs from the outfall should not be uniform throughout the water column. The small difference in the pH values (8.12 vs 8.18), however, may also an artifact of the accuracy of the YSI pH probes that is only certified to ± 0.2 pH units, although the certified resolution of the probe is ± 0.01 pH units.

The DO profile at Station 33 (Figure J-1) suggests near surface water mass extending to approximately 13 ft, consistent with the definition of this layer by pH and temperature data. In this zone, DO is slightly under saturated (97%) with a sharp increase observed between 13 and 14.8 ft, at which depth the water becomes slightly oversaturated (102%). The DO profile at Site 77 is considerably different from that at Site 33, displaying a slight but steady decrease in DO saturation from 101.5% at the surface to 98.3% at 23 ft. A small increase DO is then observed to complete saturation at 29 ft, below which DO once again decreases slightly to 98.4% saturation at 48 ft and remains constant thereafter. At Site WO, the water column is marked by relatively constant but slightly unsaturated (~97.5%) DO conditions down to 33ft. A smooth but small increase in DO in the next few feet to 41 ft is followed by an even more gentle decrease over the next 20 ft with concentrations of DO in bottom waters tightly constrained between 97.5 and 98% saturation.

Water at Sites 33, 77 and WO (Figure 38) is characterized by a high degree of clarity. This is demonstrated by the extremely low turbidity evident throughout the entire water column of each site (Figure J-1). Although a slight increase in turbidity might have been anticipated at the depth of the plume from the outfall (Site WO), turbidity remains substantially below 1 NTU at each site, regardless of depth. The structure of the Chl-a profiles shown in Figure J-1, especially at Site WO, might suggest the existence of discrete layers within the water column where biological activity is enhanced. Although this is possible, concentrations of Chl-a are low, generally less than 2 µg/l at both Sites 33 and WO, and rather close to the operating limits of the YSI Chlorophyll probe. Concentrations of Chl-a at Site 77 are mostly in the range of 3-4 µg/l throughout the water column, suggesting a slightly enhanced biological activity at this site compared to the other two.

Explosives in Sediments

Results of analysis sediment samples for explosives using EPA method 8330 are presented in Table J-3. Only five of the 47 sediment samples analyzed displayed a quantifiable amount of explosive type compound and only two of the 14 compounds determined by this EPA method were detected above the reporting limit of 200 µg/kg (ppb). The two compounds found in these samples are 2,4-dinitrotoluene (DNT) and 2,6-dinitrotoluene. Concentrations of 2,4-DNT ranged from 3100 ppb (or 3.1 ppm) to 21,000 ppb (or 21 ppm), with an average and standard deviation of 8440 ppb and 7792 ppb, respectively. Concentrations of 2,6-DNT were much lower, with the two samples in which this compound was found exhibiting 602 ppb and 1400 ppb, respectively. Samples in which these substances were found (S-10, ADA5, ADA6, ADA11, ADA12) are all from the southern part of the study area (Figure 37). Four of the five samples with quantifiable concentrations of DNT were collected by divers. The divers carried out sampling in areas where munitions had been identified, hence they were targeting sediments most likely to be impacted by explosives residues. The findings reported here are therefore not surprising.

Both 2,4- and 2,6-DNT are used in a number of industries in addition to being used to produce explosives. DNT is typically used to make flexible polyurethane foams that are utilized by the bedding and furniture industries. DNT is also used in dyes and in air bags of automobiles. These substances have been found in at least 69 (2,4-DNT) and 53 (2,6-DNT) of the 1,467 National Priorities List sites identified by the US Environmental Protection Agency (EPA) (http://www.atsdr.cdc.gov/tfacts109.html). Although it is possible that the DNT in sediments from the study area derives from sources other than munitions, because four of the five samples containing DNT were collected from an area targeted based on visual identification of munitions, the DNT likely derived from munitions. The distribution of samples exhibiting DNT is largely restricted to this relatively small area, except for Sample S-10 (see Figure 37), which was collected much closer to shore in only about 20 ft of water depth.

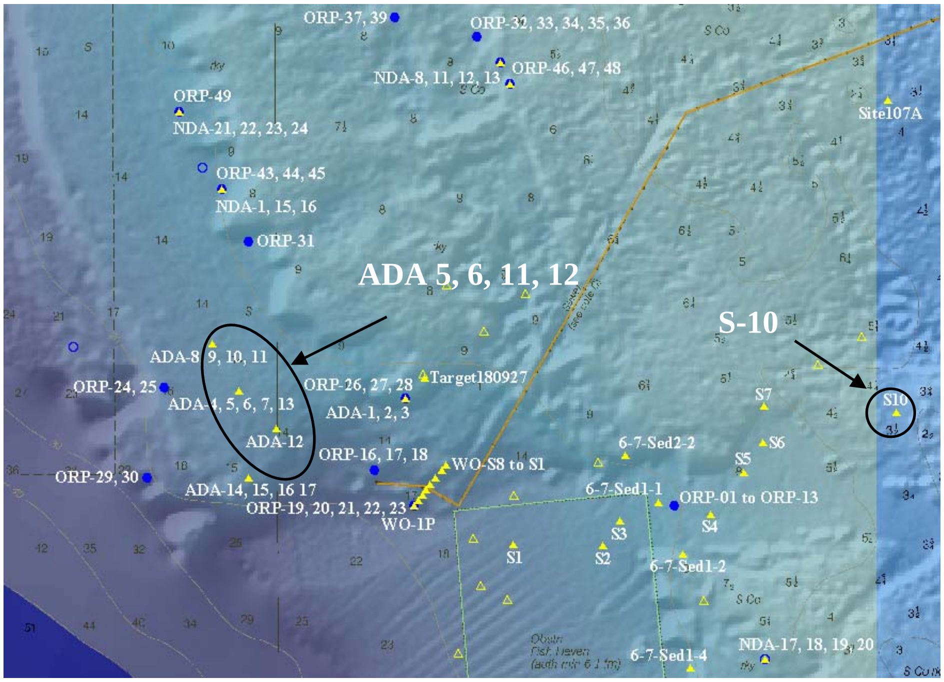


Figure 37. DNT sites.

Sediment Screening by XRF

Results of shipboard sediment screening for heavy metals and subsequent re-analysis at the NOAA laboratories in Seattle WA are presented in Table J-7. These data were obtained to provide shipboard assessment of metal concentrations in sediments that could be used to better identify target areas with potential contamination issues. The shipboard data will not be discussed extensively because results of more reliable shore-based quantitative analysis provide a better constrained data set from which the potential for metal contamination in the study area can be evaluated (see discussion below). Of interest, however, is the significant difference of results obtained shipboard relative to those obtained under laboratory conditions after the samples had been dried and better homogenized. This is not surprising as the shipboard samples were not homogenized and contained variable amounts of water. The former leads to poor precision, whereas the latter leads to deterioration of the emitted X-ray elemental signals.

Replicates of samples analyzed by XRF in the laboratory, however, generally show good agreement, although concentrations are rather different from those obtained by complete dissolution and spectrometric analysis of dried and powdered samples at the UH laboratory. XRF as applied under the conditions of this study is only a semi-quantitative assessment tool, whereas laboratory analyses of dissolved samples provide precise and accurate quantitative information.

Laboratory Based Elemental Analysis of Sediments

Elemental concentrations in sediments determined by ICP-OES and ICP-MS following complete dissolution of dry homogenized samples from the study area are given in Table J-8[4]. Scatter

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[4] "unreportable values" in the data table are marked in RED.

diagrams of the concentrations of individual elements plotted versus Ca, Mg and Fe (primary components of marine carbonates and terrigenous materials, respectively) are shown in Figure J-2.

The data in Table J-8 indicate that sediments recovered from the study area are predominantly marine carbonates with concentrations of Ca in the range of 4.95-35.3% by weight. Assuming that all the Ca is present as $CaCO_3$ this range converts to 12.4-88.2 % of the sediment in the form of $CaCO_3$. Although a fraction of the Ca can be attributed to other sources (e.g., volcanic minerals and lateritic soils), because the Fe content of the sediment is generally low (a few hundred to a few thousand mg/kg) and only a few samples display concentrations of Fe exceeding one weight percent, the amount of Ca associated with non carbonate minerals is extremely small and the above calculation of the carbonate content of the sediments is accurate within the needs of this study.

The three samples displaying enhanced Fe contents were all collected near the outfall. This finding suggests that much of the Fe in these samples may represent fine terrigenous particles derived from the discharged treated sewage. Not surprisingly, these three samples also contained the highest overall concentrations of trace elements that are typically considered to be of predominantly volcanic origin (i.e., Co, Cr, Ni, Ti, and V). Strong linear correlations between the concentrations of Fe and these elements (Fig. J-2) in the overall sample set and the results of factor analysis presented below support the interpretation that these elements are of a non marine origin and likely also not of anthropogenic origin. In the plot of Cu against Fe shown in Figure J-2 suggests the samples with high Fe also display relatively elevated Cu contents and define a linear trend that extends to other lower metal abundance samples. This observation indicates that some of the Cu in sediments from the study area is of natural origin. A similar trend line is defined with Zn (Fig. J-2) with a larger number of samples defining the "natural" trend line. In both cases, however, there are numerous samples whose concentrations of Cu and Zn fall above the natural linear trend, indicating an additional source.

Examination of the scatter diagrams in Figure J-2 also reveals that, among the trace elements, only Co, Cu, and Zn display distributions with some sediments defining a linear trend line with Fe and others falling off this line. Because a different number of samples define the latter group for each element, the sources of Co, Cu and Zn may not be identical. A lack of correlation between the concentrations of a given trace element and either Fe of Ca (i.e., for Mg and Sr) is therefore suggestive of anthropogenic inputs. Because many more samples display Zn concentrations that fall off the Fe-Zn trend line in Figure J-3 than samples with elevated Cu, two anthropogenic sources of Cu are likely. Previous work in Hawai'i by De Carlo and colleagues (2004, 2005) has attributed high Zn concentrations to anthropogenic activity, primarily in the form of wear particles from automotive tires that are deposited on road surfaces and subsequently transported to the nearshore marine environment by runoff during rain events. These authors also found a stronger correlation between Cu and Zn than observed in the current study (Table J-7), which they attributed to a combined automotive source (Cu from brakepads and Zn from tires). Relatively few of the sediment samples from the current study display concentrations of Co and Cu that are elevated over what is expected from the terrigenous trend lines. A similar observation can be made for Pb, although a definitive trend line with Fe is also lacking. Four samples display concentrations of Cu above 500 mg/kg, a value considerably above the mean of 55 mg/kg. For Co, approximately

15 samples fall above the trend line. In the case of Pb, fewer twelve samples display what might be considered anomalous concentrations, i.e., values above an artificially selected cutoff of 10 mg/kg. The latter value is nearly double the mean concentration of Pb of 5.6 mg/kg for all the samples from the SA. The highest concentration of Pb, however, is only 61 mg/kg (Table J-8) and remains far lower than found in urban estuarine sediments contaminated by anthropogenic Pb (e.g., De Carlo and Spencer, 1995, 1997; De Carlo and Anthony, 2002; De Carlo et al., 2004, 2005). Interestingly, many of the samples with elevated concentrations of Pb were collected close to shore or near the outfall, suggesting that the source of Pb in these sediments is either treated sewage or direct land runoff. Prior work has clearly revealed the impact of land runoff on Pb concentrations in suspended particulate matter and sediments (De Carlo and Spencer, 1995, 1997: De Carlo and Anthony 2002; De Carlo et al. 2004, 2005), and treated sewage is also enriched in a variety of trace elements including Cd and Pb (Laws 2000).

Enrichment of Co, Cu, and Pb in the samples from this study that are not accompanied by an elevated Zn content, therefore, likely reflects an additional source of the trace elements, possibly discarded military munitions. Yet, Cu is the only trace element among those analyzed in this study that displays extreme anomalous values. The elevated concentrations (~500-2100 mg/kg) observed in the four most enriched samples are also considerably higher than concentrations of Cu previously observed in soils, road deposited sediments, and estuarine and coastal sediments reported by De Carlo and colleagues (1995, 1997, 2002, 2004, 2005). These four samples (ADA 9, 11, 13, and 17) were collected close to visually identified munitions. Hence, the most likely source of the Cu enrichment in these sediments is discarded munitions. It should be pointed out, however, that the other ADA sediment samples, all of which were targeted by US Army divers to areas close to discarded ordnance exhibit concentrations of Cu that are close to or less than the (highly skewed) mean of 55 mg/kg. Thus, even in the targeted sampling described above, only sparse evidence of Cu contamination was observed, suggesting that Cu contamination is highly localized and does not extend far from the source (i.e., discarded military munitions).

Although concentrations of As and Cd (Fig. J-2) in most samples are scattered and do not define trend lines with either Fe (terrigenous), of with Ca or Mg (marine carbonates), an independent, but much more common, source of these elements must exist. This source appears to be distinct from those for Co, Cu, Pb and Zn. Recent work (De Carlo et al., 2004, 2005) has hypothesized a potential agricultural source of these elements in Hawai'i. A complete lack of covariance between the As and Cd (Table J-4) observed in sediments from the SA, however, argues against a common source. Because concentrations of both elements are relatively low overall (Cd < 0.5 mg/kg, As <30 mg/kg), contamination is not apparent.

Overall trace metal enrichment in sediments from the study area is very low, with the exceptions noted above for Cu. This observation suggests that little contamination of the Ordnance Reef area is derived from discarded military munitions.

Principal Component Analysis

The elemental concentration data shown in Table J-8 were subjected to Principal Component Analysis (PCA) using the SPSS statistical software package. Table J-4 is an inter-element correlation matrix, displaying the correlation coefficients between individual elements determined in this study. These correlations represent best fit linear regressions between individual variables. Table J-5 shows the distribution of the variance of the data set. A total of 14 factors are necessary to account for 100% of the variance in the data set. Rotation of the initial eigenvalues, however, yields four principle components that together account for 80% of the variance. Of these, two components account for 58% of the variance and the other two minor components combined account for 22% of the variance. Finally Table J-6 presents factor loadings for each element, based on a varimax rotation of the factor scores. Cross plots of the four principal factors that account for most of the variance of the elemental data set are shown in Figure J-3. Figure J-4, presents the factor loadings for individual samples, providing a means of readily visualizing the predominant "sources" of elements in each sample.

A summary of the theory and application of PCA to data from natural samples is provided in Li (2000). Although there are some problems with and restrictions to using PCA, in particular to explain geochemical processes (Reimann *et al*., 2002), these and other authors (Grande *et al.*, 2000; Helena *et al.*, 2000; Li, 2000; Ruiz-Fernandez *et al.*, 2001; Haag and Westrich, 2002; Townend, 2002) concur that using PCA to look for patterns in data can be useful. In this study, PCA was applied to the compositional data specifically to evaluate elemental associations that could potentially indicate individual sources of the elements. PCA is most successful in such an approach when samples close to the idealized end member compositions (as determined by PCA) of each source exist within the sample population.

In the current study, the results of PCA show that the variance of the elemental composition of most samples is primarily controlled by the first two components (or factors). The first factor (Component 1 in Table J-6) loads strongly on Co, Cr, Fe, Ni, Ti, V and, to a much lesser extent, As, which is interpreted to represent the effect of terrigenous material (volcanic minerals and their weathering products) input on the sediment composition. This is henceforth referred to as F1. The second factor (Component 2 in Table J-6) loads strongly on Ca, Sr and, to a lesser extent, Mg, is henceforth labeled F2 and is interpreted to represent the influence of marine carbonate on the sediment composition. The two remaining factors (F3 and F4) load on Cu and Zn (Component 3 or F3) and Pb (Component 4 or F4). These two minor factors are interpreted to represent lesser but highly variable amounts of two other distinct and likely anthropogenic components. It is not possible to unequivocally identify either of these factors as representing a particular source of contamination, but based on results of prior work, geographic distribution of samples loading on these factors as well as the elemental associations; it is likely these two factors represent the impact of "urban" runoff and sewage discharge, respectively.

Examination of the plots shown in Figure J-4 allows evaluation of how individual samples load on a given factor, thereby providing some indication of the primary sources of elements to the composition of the sediments. Not surprisingly most samples show a distribution that is controlled by F1 (terrigenous) and F2 (carbonate). For ease of examination each plot is shown twice with a different scale that allows removal of the undue influence exerted by the extreme members of each sample population. For example only two samples contained sufficiently high concentrations of Fe to result in values of F1 above 5. Removal of these samples allows a clearer view of the distribution of the remaining samples in terms of how marine carbonate and terrigenous materials contribute to their composition. Of potentially interest to this study, however, is the distribution of samples with respect to F3 (Cu, Zn) and F4 (Pb). Enriched concentrations of these elements are most likely indicative of anthropogenic contamination of the sediments and, not surprisingly, the ADA samples collected near visually identified munitions show the greatest loading on F3 supporting the hypothesis that the Cu enrichment in these samples is anthropogenic. Other samples loading on this factor, however, more likely represent slight contamination from land runoff affected by automotive traffic. In the case of F4, the samples displaying a high loading are more scattered, with those collected near the outfall (WO samples) standing out. A few other samples collected closer to shore (i.e., S7 and S10) exhibit an even higher loading on F4. Based on these results it is reasonable to suggest that elevated concentrations of Pb likely derive either from land runoff or sewage rather than military munitions disposal within the study area.

Comparison of sediment compositions with data from other studies

In order to better evaluate natural versus anthropogenic contributions to the composition of sediments from the study area it is useful to compare elemental abundances with those observed in sediments from other locations. Table J-9 provides a compilation of data from the literature and includes sediments from various locations in Hawai'i (De Carlo and Anthony, 2002; De Carlo and Spencer, 1995, 1997; De Carlo et al., 2004, 2005; McMurtry et al., 1995), other carbonate dominated sediments (Caccia et al., 2004; Cantillo et al., 1999; Gonzalez-Caccia, 2002; Gough et al., 1996; Palanques et al., 1995; Presley, 1994; Puig et al., 1999; Vazquez and Sharma, 2004), as well as in major sediment and rock types (e.g., Ribbe, 1983; Kabata-Pendias, 2000)

It should be noted from the outset, that few data for carbonate-dominated sediments exist for Hawai'ian locations. De Carlo and Spencer (1995, 1997) and De Carlo and Anthony (2002) reported trace element compositions for sediments from the Ala Wai Canal in urban Honolulu, but most of the cores were dominated by terrigenous sediments, with only a few layers displaying elevated carbonate contents. Consequently, most trace element concentrations reported by these authors are elevated relative to those observed in the current study. Hence a more appropriate comparison would examine layers enriched in Ca (carbonate mineral dominated), which these authors observed near the bottom of the cores. Such a comparison is even more relevant when one considers that deeper and carbonate dominated layers in these cores represent sediments deposited relatively soon after the canal was opened in 1928, sediments likely to display lesser anthropogenic contributions to their trace element content than more recently deposited materials. Other appropriate comparisons can be made with sediments from Florida Bay (e.g., Caccia et al., 2004) a large subtropical embayment located at the southern extremity of the Florida peninsula.

Examination of the data in Table J-9 immediately reveals a dearth of comparative data for As. Concentrations measured in sediments from the study area, however, generally fall within the range reported by De Carlo and Anthony (2002) in Ala Wai Canal sediments, but are typically higher than cited by Ribbe (1983) for marine carbonates. Closer examination of the data by De Carlo and Anthony reveals that As concentrations are not significantly lower in Ca enriched layers of the sediment cores they studied, although the minimum value measured (6.2 mg/kg) occurs in a carbonate rich layer near the bottom of Core G8-98. Yet, concentrations of 15-17.6 mg/kg occur in the three deepest, and ostensibly least contaminated (as indicated by the lowest

Pb concentrations), layers of these sediments. The mean concentration of As (10.3 mg/kg) observed in sediments from the current study, therefore, indicate that there is little or no contamination with this element.

More data are available for Cd, an element whose natural abundance in earth materials is typically very low, than for As. Mafic and ultramafic rocks, typical of the main island forming volcanics in Hawai'i, exhibit Cd contents of between 0.1 and 0.2 mg/kg, values similar to those observed in most of the sediments from the study area (Table J-6). Limestone and marine carbonates reported by Ribbe (1983), however, all display near zero concentrations of Cd. These values are consistent with data reported by De Carlo and Anthony (2002), who measured concentrations of Cd below 0.3 mg/kg in the carbonate rich layers found near the bottom of the cores. Other older data from Hawai'i reported by McMurtry et al. (1995) are generally higher than the maximum value observed in the current study; however, it should be borne in mind that data generated over thirty years ago were subject to inferior detection limits and accuracies than available today. Hence, it is possible that the values reported in McMurtry et al. (1995) are artificially elevated. Trefry et al. (1976) reported a wide range of Cd concentrations in sediments from Galveston Bay, Texas, ranging from 0.2 to 3.5 mg/kg. This nearly doubles the range reported by De Carlo and Anthony (2002) for the most contaminated sediments in the Ala Wai Canal. More recent data reported by Schropp et al. (1990) for Biscayne Bay, Florida reveal up to ten times the Cd content observed in the current study. Based on these various comparisons, it appears that, although a slight enrichment of Cd exists in samples from the SA (see Fig. J-2) relative to the least contaminated sediments from the Ala Wai Canal, sediments from the SA are not widely contaminated with Cd.

Concentrations of Co, Cr, Ni and V span approximately two orders of magnitude (Table J-9) in sediments from the study area. Previous work in Hawai'i (De Carlo and Spencer 1995, 1997; De Carlo and Anthony, 2002, De Carlo et al., 2004), however, indicates that concentrations of these elements are strongly impacted by the amount of detrital volcanic material found in the sediments, consistent with results of PCA reported above and in the earlier Hawai'ian studies. Mean concentrations of these elements in the current study, however, are consistent with earlier results for carbonate-dominated sediments in Hawai'i (e.g., McMurty et al., 1995) and carbonate enriched layers of sediments from the Ala Wai canal reported by De Carlo and Spencer (1995, 1997) and De Carlo and Anthony (2002). Concentrations of Cr and Ni are also similar to those reported by Cantillo et al. (1999) for Florida sediments. Although carbonate-dominated sediments from Hawai'i display concentrations of Co, Cr, Ni, and V that are somewhat elevated relative to the results reported by Gough et al. (1996), Gonzalez-Caccia (2002) and Caccia et al. (2004) for sediments from the Bahamas and Florida, the latter areas are not influenced by inputs of material derived from volcanic rocks. Mafic and ultramafic rocks display extremely elevated concentrations of these four elements (Table J-9 Kabata-Pendias 2000), well in excess of any observed in sediments from the study area. Consistent with interpretation of the trend lines observed in Figure J-2 and results of PCA, anthropogenic contamination of sediments from the SA is not considered significant with respect to Co, Cr, Ni and V.

Concentrations of Cu, Pb and Zn shown in Table J-9 display a broad range that reflects the various potential sources of these elements. Natural sources generally contribute very small amounts of Pb to the environment. For example, the Pb content of mafic and ultramafic rocks is always below 10 mg/kg. This value, however, is nearly twice the mean (6.7 mg/kg) observed in the current study. Concentrations of Pb in sediments from Hawai'i above a few mg/kg, however, typically reflect anthropogenic contamination of some sort (De Carlo and Spencer, 1995; 1997). De Carlo and Anthony reported Pb concentrations below 2 mg/kg in the deepest layers of cores collected in the Ala Wai Canal in Honolulu. De Carlo et al. (2005) also reported that uncontaminated stream sediments from forested areas on O'ahu also rarely contain more than a few mg/kg of Pb. Because carbonate sediments from Florida Bay also exhibit concentrations of Pb that do not exceed 3.3 mg/kg (Caccia et al., 2004) and limestone and carbonate sediments reported by Ribbe always display concentrations below 10 mg/kg, it can be argued that any amount of Pb in carbonate sediments exceeding about 5-10 mg/kg should be considered to reflect some anthropogenic contamination. There are now numerous references in the literature reporting the impact of tetra-alkyl-Pb anti-knock additives to automotive fuels on sediment compositions (e.g., De Carlo et al., 1995 and references therein). Sediments from areas adjoining urban centers, harbors, and other developed areas typically display large enrichments of Pb, several orders of magnitude above what are considered natural abundances (see Table J-9). With a mean Pb concentration of 6.7 mg/kg in the current study, a value skewed upward by less than a dozen samples displaying concentrations between 15 mg/kg and the maximum concentration of 61.7 mg/kg, it is reasonable to conclude that little contamination of sediments from the SA exists with respect to Pb. The actual source of the slight contamination observed in the current study, however, is difficult to elucidate, but evidence discussed earlier in this report suggests that sewage discharge and urban runoff are the most likely contributors. Concentrations of Zn reported here also display a wide range (1.5-162 mg/kg) that suggests some contamination of the sediment exists. Examination of data for carbonate-dominated sediments from other Hawai'i locations, the Bahamas, Florida Bay, elsewhere in Florida, as well as the Gulf of Mexico reveal a very wide range of Zn concentrations (Table J-9). Uncontaminated sediments as well as deep-sea carbonates generally display levels of Zn that range from a few to a few tens of mg/kg. The lowest value of 0.5 mg/kg, observed in sediments from the Bahamas (Gonzalez-Caccia, 2002), which are dominated by aragonite sands is three times lower than the minimum reported here. Yet, examination of Figure J-2 shows that sediments from the study area generally fall in two categories; those defining a trend line with Fe, hence displaying terrigenous control on their Zn concentration, and those falling above this trend line, hence likely displaying anthropogenic inputs. It should be noted, however, that the maximum concentration of Zn reported here is considerably lower than reported in contaminated sediments of the Ala Wai Canal, Pearl Harbor, Biscayne Bay in Florida, and especially Galveston Bay, Texas (Table J-9). Anthropogenic contributions to the Zn content of sediments from the study area cannot be denied, yet, the source is most likely urban runoff as suggested in prior work in Hawai'i.

Very similar arguments to those above for Pb and Zn can be made for the range of concentrations of Cu observed in sediments from the study area. In this case, however, there are four samples, which stand out with respect to their Cu content (Fig. J-2). As noted previously each of these was collected close to discarded shell casings, providing strong arguments for the source of contamination. Excluding these four samples, however, the range of Cu content of sediments from the study area narrows to 0.3-80 mg/kg. This range is consistent with prior data for sediments from Hawai'i. De Carlo and Anthony (2002) reported less than 52 mg/kg in the deepest layers of Ala Wai Canal sediments whereas McMurtry et al. (1995) report values between 4 mg/kg and 43 mg/kg, excluding sediments from Pearl Harbor. The higher end of the range of Cu concentrations observed in sediments from the study area (excluding the four discussed above) are generally found in sediments collected close to shore or near the outfall, again consistent with an urban source of this element. Concentrations of Cu in sediments from areas subject to extensive boating and shipping activity (e.g., Narragansett Bay, Houston Ship Channel) exceed by far the values observed here. Thus, outside of four samples collected close to munitions, little contamination of sediments with Cu directly attributable to military activities is evident in the current study.

Discussion

Properties of the water column within the SA are consistent with those anticipated for clear, clean subtropical seawater elsewhere in Hawai'i. Results do not indicate any significant impact of munitions disposal on the water quality of shallow coastal waters of the Wai'anae Coast of O'ahu and only minor evidence of changes in water quality were observed near the outfall.

This study also provides little evidence of contamination of sediments as a result of the disposal of munitions in coastal waters of the Wai'anae Coast. Several sediment samples showed impacts from adjoining disposed munitions. Yet, there is no evidence of widespread contamination or impact of disposed military munitions on the composition of sediment within the SA. The overall ranges of concentrations of trace elements found here are consistent with those observed in uncontaminated settings, with the few exceptions as noted above.

Results of PCA indicate that two principal sources, marine carbonates and terrigenous volcanic matter, can account for the majority of the variance in the composition of the sediments. Two other sources of elements, both likely anthropogenic, account for most of the remaining variability. One of the latter two sources is interpreted to be anthropogenic activity on the adjoining land is responsible for much of the Cu and Zn observed in sediments from the SA. A fourth source, which accounts for the variability in the Pb content of the sediments, is also likely anthropogenic, but currently remains unidentified. Yet, because most samples displaying elevated concentrations of Pb were collected either near shore or close to the Wai'anae WWTP outfall, it is possible that the source of Pb is treated sewage or land runoff.

Area	Frequency of Detection	Reporting Limit (mg/kg)	Range (mg/kg)	Sample with highest concentration	Sediment Guidelines Effects Range Low (mg/kg)	Probable Effects Level (mg/kg)
Outfall Area						
As	4 of 9	9.7	10.9-29.4	WO-S4	8.2	41.6
Cd	2 of 9	0.22	0.29-0.36	WO-S7	1.2	4.21
Co	9 of 9	0.49	0.95-23.0	WO-S4	n/a	n/a
Cr	9 of 9	0.46	8.1-157.9	WO-S4	81	160
Cu	9 of 9	0.50	1.4-71.4	WO-S4	34	108
Ni	9 of 9	0.60	3.1-211	WO-S4	20.9	42.8
Pb	7 of 9	2.1	2.2-35.9	WO-S8	46.7	112.2
V	9 of 9	0.77	4.3-91.6	WO-S4	n/a	n/a
Zn	8 of 9	4.9	5.4-47.7	WO-S4	150	271
Ordnance Reef						

Area						
As	42 of 89	9.7	9.8-21.6	195033	8.2	41.6
Cd	51 of 89	0.22	0.22-0.56	ADA-12	1.2	4.21
Co	82 of 89	0.49	0.63-15.9	NDA-7	n/a	n/a
Cr	89 of 89	0.46	2.4-53.3	190753	81	160
Cu	89 of 89	0.50	0.6-2147	ADA-11	34	108
Ni	89 of 89	0.60	0.8-22.6	190753	20.9	42.8
Pb	79 of 89	2.1	2.1-61.7	S7	46.7	112.2
V	89 of 89	0.77	2.1-28.7	190753-Dup	n/a	n/a
Zn	70 of 89	4.9	5.3-162	ADA-13	150	271
Control (Fish Haven)						
As	2 of 4	9.7	10.0-12.2	FH-S3	8.2	41.6
Cd	2 of 4	0.22	0.29-0.30	FH-S3	1.2	4.21
Co	4 of 4	0.49	0.49-2.03	FH-S3	n/a	n/a
Cr	4 of 4	0.46	7.6-25.1	FH-S3	81	160
Cu	3 of 4	0.50	0.7-2.9	FH-S3	34	108
Ni	4 of 4	0.60	2.2-9.9	FH-S3	20.9	42.8
Pb	3 of 4	2.1	3.3-8.9	S1	46.7	112.2
V	4 of 4	0.77	0.9-17.3	FH-S3	n/a	n/a
Zn	3 of 4	4.9	6.6-19.8	S3	150	271

Sediment guidelines from NOAA SQRT's

Table 2. Metals, frequency of detection, range of concentrations for sediment samples.

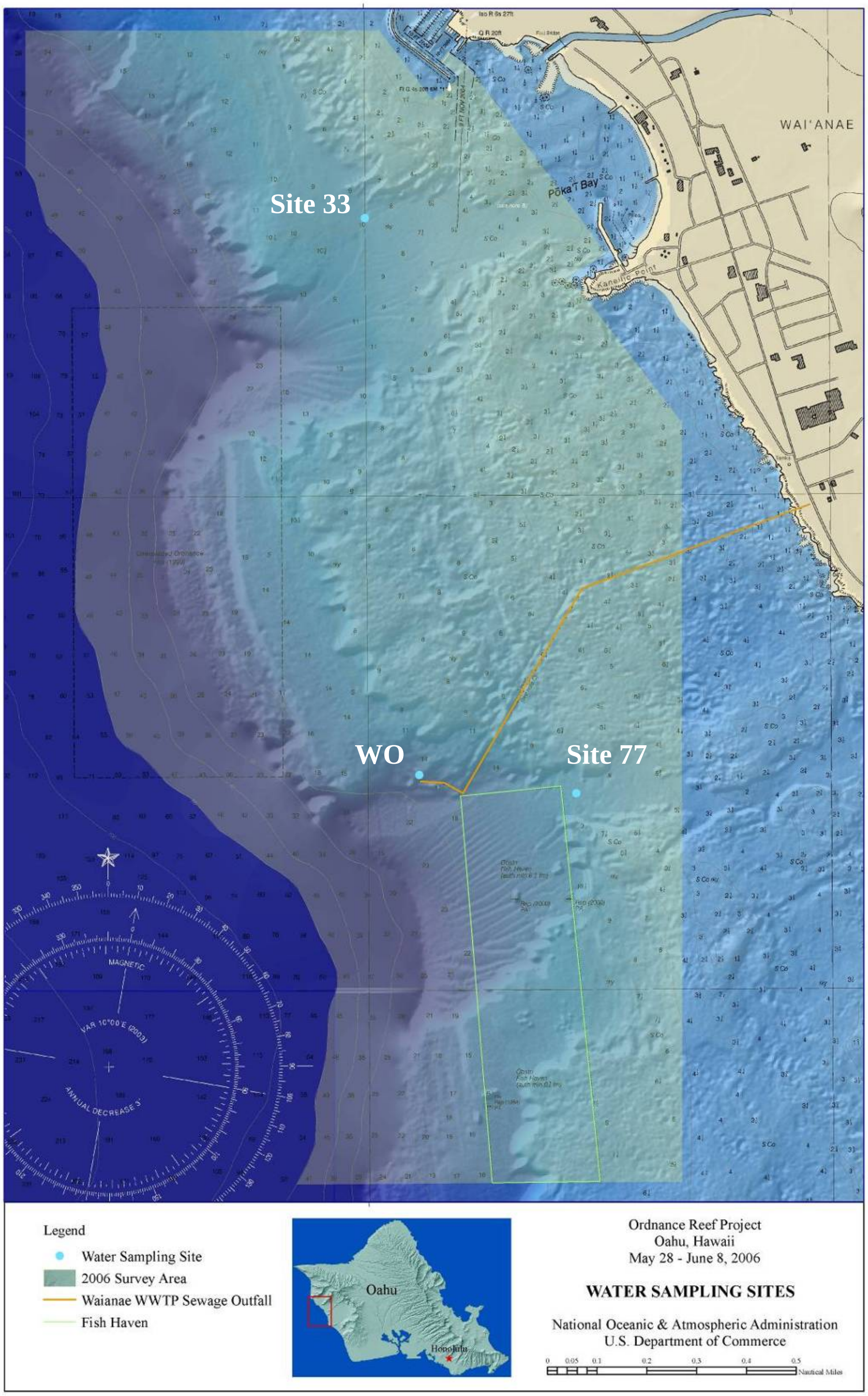

Figure 38. Water sampling sites.

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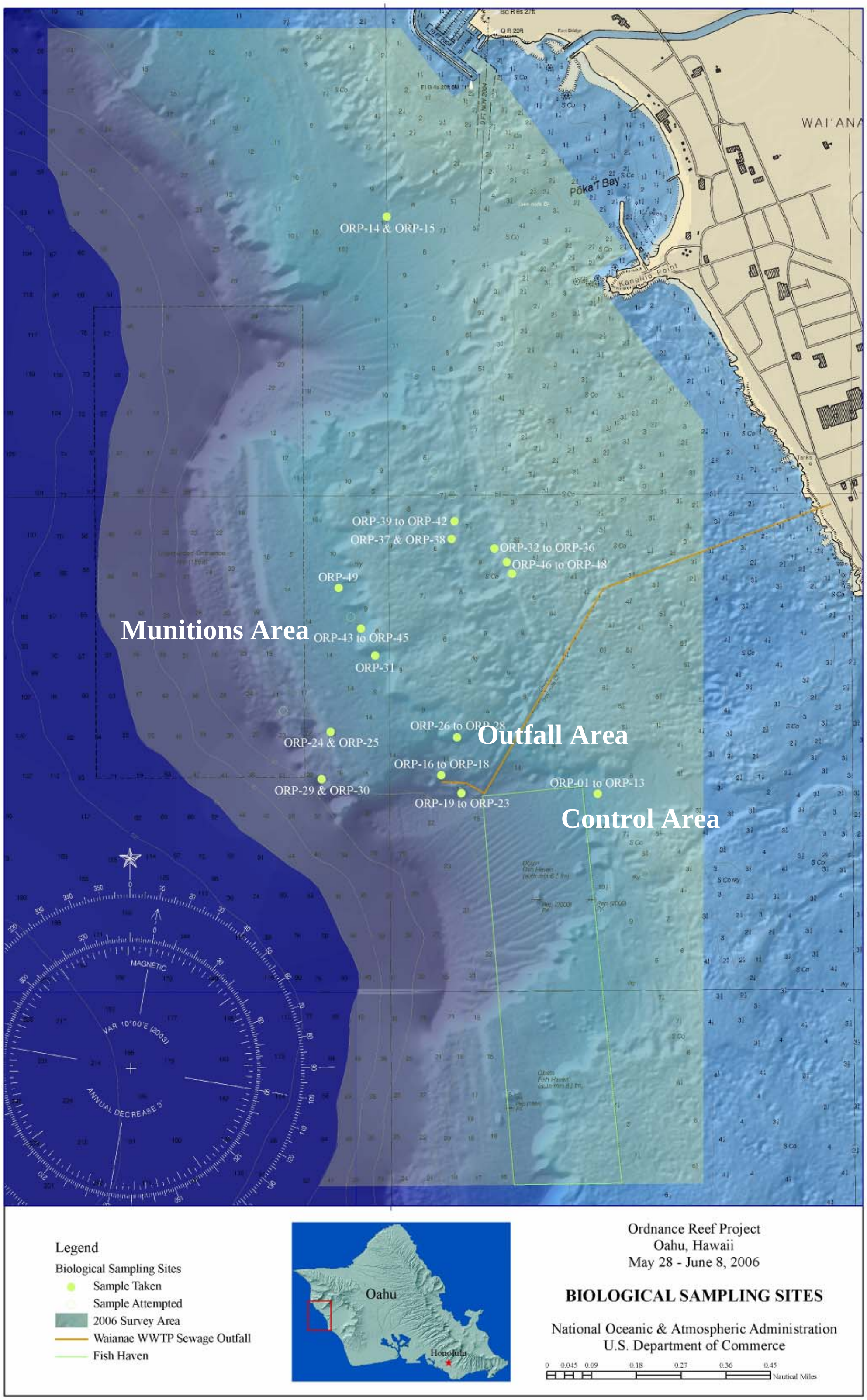

Figure 39. Biological sampling sites

7. BIOLOGICAL SAMPLING

Biological specimens were collected during the project. The goal of the study was to provide an indication of potential impacts to the human food chain and the potential for significant adverse impacts on the local ecosystem from the disposed munitions. The marine resource study focused on a target species list developed by NOAA Fisheries and DLNR/DAR. The species were selected to represent a range of trophic levels and fishing niches and focused on sessile filter feeders, popular food fishes, and higher end predators.

A total of 49 individual representative reef fish from various trophic levels were collected throughout the designated study area. Fish species were selected based on foraging levels in the ecosystem, long term residence time within the study area, and importance as local food fish to the resident population of the Wai’anae Coast of O’ahu.

The 49 fish were collected using standard techniques (spears or hook and line). Thirteen were from the Fish Haven (Reference Area) which is south of the Munitions Area, 8 were collected adjacent to the outfall (Outfall Area), and 28 came from 11 locations where military munitions was suspected or known (Munitions Area) (Figure 39).

Most of the samples (38 of 49) were from the goatfish family (*Parapeneus multifasciatus*, *P. pleurostigma*, *P. porphyreus* and *Mulloidichthys flavolineatus*) and feed on worms, crustaceans, small mollusks and heart urchins living in rubble and sand habitats. These species were specifically targeted in the sampling as they are relatively stationary, high end predators which are important local food fish and that might show evidence of biomagnification of contaminants. 2. Two species (*Stegastes fasciolatus* and *Ctenochaetus strigosus*) feed primarily on benthic algae and detritus. One species (*Chromis ovalis*) feeds primarily on zooplankton, and the remaining species (*Gymnothorax flavomarginatus*, *Lutjanus kasmira*, *Coris ballieui*, *Parapercis schaunislandii*, *Sufflaman fraenatus*, *Malacanthus brevirostris*, and *Melichthys vidua*) are carnivorous species, feeding on a variety of invertebrate and vertebrate prey, and therefore might show biomagnifications of contaminants. Sample numbers and fish species are presented in Table 3.

Fish Species	Sample Numbers (ORP-)			Total Number of Samples
	Control Area	Outfall Area	Munitions Area	
Goat Fish Family				
Mulloidichthys flavolineatus	2			**1**
Parapeneus multifasciatus	3, 4, 6, 7, 8	16, 17, 18, 19, 20, 22, 23	14, 26, 28, 29, 30, 32, 33, 34, 35, 36, 37, 39, 40, 41, 42, 45, 46, 47, 48, 49	**32**
Parapeneus porphyreus	5			**1**
Parapeneus pleurostigma	10 ,12, 13		15	**4**
Other				
Stegastes fasciolatus	9			**1**
Ctenochaetus strigosus	11			**1**

Chromis ovalis		21		**1**
Gymnothorax flavomarginatus			24, 31	**2**
Lutjanus kasmira	1			**1**
Coris ballieui			44	**1**
Parapercis schaunislandii			27	**1**
Sufflaman fraenatus			25	**1**
Malacanthus brevirostris			38	**1**
Melichthys vidua			43	**1**
Total Number of Samples	**13**	**8**	**28**	**49**

Table 3. Fish species collected, numbers, and areas

Discussion

The fish samples were analyzed for explosives and metals. No explosive related compounds were detected in fish tissue. Ninety-eight percent (48 of 49) fish sampled had detectable levels of Zinc, and 93% (46 of 49) had detectable levels of Arsenic. Arsenic is a natural component of sediments, especially in Hawai’i, and is not generally toxic except as the trivalent form of inorganic Arsenic. The majority of Arsenic in fish tissue samples is organic arsenic, non-toxic forms (Neff 1997). The concentration of Zinc in these samples was not related to the area of sampling or fish total length. Zinc is an essential micronutrient for fish metabolic reactions and is not considered toxic to fish or humans.

Six of the samples had detectable levels of Mercury (Control and Munitions Areas), 2 had detectable levels of Lead (Munitions Area) or Cadmium (Control and Munitions Areas), and 1 had detectable levels of Barium (Reference Area). Methyl mercury is considered toxic, however mean concentration of total mercury and other metals in these fish tissues are below FDA “Levels of Action” established for crustaceans (Arsenic, Cadmium, Lead) or fish (methyl mercury) (2001).

	Frequency of Detection	Reporting Limits (mg/kg)	Range of Detected Concentrations (mg/kg)	Sample with Highest Concentration	95% UCL (mg/kg)	FDA Level of Action (mg/kg)
Control Area						
Arsenic	11/13	5.0	13 - 80	ORP-2	54.1	76
Zinc	13/13	NA	12 - 110	ORP-2	53.9	None
Mercury	1/13	0.0833 - 0.100	0.121	ORP-5	NA	1.0
Lead	0/13	5.0 - 7.1	ND	ND	NA	1.5
Cadmium	1/13	0.5 - 1.0	0.52	ORP-7	NA	3.0
Barium	1/13	5.0-7.1	5.0	ORP-9	NA	None
Outfall Area						
Arsenic	8/8	NA	33 - 110	ORP-23	83.0	76
Zinc	8/8	NA	22 - 50	ORP-21	38.6	None
Mercury	0/8	0.0893 - 0.100	ND	ND	NA	1.0
Lead	0/8	5.0	ND	ND	NA	1.5
Cadmium	0/8	0.5	ND	ND	NA	3.0
Barium	0/8	5.0	ND	ND	NA	None
Munitions Area						

Arsenic	27/28	10	15 -110	ORP-30	55.3	76
Zinc	27/28	50	13 - 100	ORP-27	57.8	None
Mercury	5/28	0.0714 - 1.25	0.033 - 0.342	ORP-31	NA	1.0
Lead	2/28	5.0 - 50	13 - 16	ORP-44	NA	1.5
Cadmium	1/28	1.0 - 5.0	1.2	ORP-25	NA	3.0
Barium	0/28	5.0 - 50	ND	ND	NA	None

Note: Analytical results are in mg/kg wet weight. FDA Level of Action values are for crustacean or fish tissues (FDA 2001).
ND – not detected
NA – not applicable

Table 4. Metals, frequency of detection, range of concentrations, and 95% UCL for fish samples (mg kg^{-1} wet weight fish tissue).

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