TECHNICAL SUPPORT DOCUMENT TO THE PRELIMINARY ASSESSMENT OF THE FWS – HAWAIIAN ISLANDS NATIONAL WILDLIFE REFUGE: TERN ISLAND SITE IN THE FRENCH FRIGATE SHOALS, HAWAI‘I

Prepared for the United States Environmental Protection Agency

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LIST OF ACRONYMS

%	percent
µg/L	micrograms per liter
AEC	U.S. Atomic Energy Commission
AST	above-ground storage tank
ATSDR	Agency for Toxic Substances and Disease Registry
bgs	below ground surface
BTEX	benzene toluene ethylbenzene xylene
CBD	Center for Biological Diversity
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act
CFR	Code of Federal Regulations
Chase	Chase Environmental Group, Inc.
cm	centimeter
CNES	Centre National D'Etudes Spatiales
CReefs	Census of Coral Reef Ecosystems
DDD	dichlorodiphenyldichloroethane
DDE	dichlorodiphenyldichloroethylene
DDT	dichlorodiphenyltrichloroethane
DERP	Defense Environmental Restoration Program
Docket	Federal Agency Waste Compliance Docket
DOI	United States Department of the Interior
EA	Environmental Assessment
EI	Environmental Investigation
EPA	United States Environmental Protection Agency
ESA	Endangered Species Act
ESNO	El Niño Southern Oscillation
ETI	Environmental Technologies International
FFS	French Frigate Shoals
FP	Fibropapillomatosis
ft	foot
FUDS	Formerly Used Defense Site
FWS	United States Fish and Wildlife Service
HAZMAT	hazardous material
HDLNR	Hawai‘i Department of Land and Natural Resources
HPU	Hawai‘i Pacific University
HRS	hazard ranking system
IAA	Inter-Agency Agreement
IARC	International Agency for Research on Cancer
IPCC	Intergovernmental Panel on Climate Change
IUCN	Internal Union for Conservation of Nature
LORAN	Long Range Aid to Navigation
mg/kg	milligrams per kilogram
mg/L	milligrams per liter
MHI	main Hawaiian Islands
MMC	Marine Mammal Commission

Monument	Papahānaumokuākea Marine National Monument
mph	miles per hour
NASA	National Aeronautics and Space Administration
Navy	United States Navy
NAWCP	North American Waterbird Conservation Plan
NCP	National Contingency Plan
ng/g	nanograms per gram
ng/mg	nanograms per milligram
NHRC	North Hawaiian Ridge Current
NMFS	National Marine Fisheries Service
NMNH	National Museum of Natural History
NOAA	National Oceanic and Atmospheric Administration
NPL	National Priorities List
NWHI	Northwestern Hawaiian Islands
OC	organochlorine
OHA	Office of Hawaiian Affairs
PA	Preliminary Assessment
PAH	polycyclic aromatic hydrocarbons
PBDE	polybrominated diphenyl ether
PBT	persistent bioaccumulative and toxic
PCB	polychlorinated biphenyl
PDO	Pacific Decadal Oscillation
PET	polyethylene terephthalate
PFC	perfluorochemical
pg/g	picograms per gram
PIFSC	Pacific Islands Fisheries Science Center
PMR	pacific missile range
POP	persistent organic pollutants
ppb	parts per billion
ppm	parts per million
PVC	polyvinyl chloride
RAM	Relative Abundance of Macroalgae
RCRA	Resource Conservation and Recovery Act
SCUBA	self-contained underwater breathing apparatus
SEMS	Superfund Enterprise Management System
SI	Site Inspection
SPA	special preservation area
STCZ	North Pacific Subtropical Convergence Zone
TPH	total petroleum hydrocarbons
TSCA	Toxic Substances Control Act
TSD	Technical Support Document
UH	University of Hawaiʻi
UNESCO	United Nations Educational, Scientific and Cultural Organization
URSGWC	URS Greiner Woodward Clyde
USACE	United States Army Corps of Engineers
USCG	United States Coast Guard

USGS	United States Geologic Survey
UST	Underground Storage Tank
WCFS	Woodward Clyde Federal Services
WWII	World War II
XRF	X-ray fluorescence

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1 INTRODUCTION

1.1 INTRODUCTION

This document will serve as a Technical Support Document (TSD) for the Preliminary Assessment (PA) of the United States Fish and Wildlife Service (FWS) – Hawaiian Islands National Wildlife Refuge: Tern Island, referred to hereafter as Tern Island. Tern Island is part of the atoll known as French Frigate Shoals (FFS) and is located 490 nautical miles northwest of Honolulu, Hawai‘i (Figure 1-1). FFS, or Kanemiloha‘i as it is known in the Hawaiian language, is the largest atoll in the Hawaiian Island chain. Tern Island is the largest of approximately 12 small sand islands contained within the low lying coral atoll called FFS. The atoll consists of two crescent-shaped reefs surrounding a large 140-square-mile lagoon (Figure 1-2). The crescent reefs forming the outer boundary of the atoll developed around the perimeter of a once active volcano. Tern Island is located along the northwest tip of the outer arching reef. When first documented in 1786, the island was a small carbonate sand shoal (FWS, 2002; Amerson, 1971) (Figure 1-1).

Tern Island is part of the Hawaiian Islands National Wildlife Refuge which is part of Papahānaumokuākea Marine National Monument (the Monument). The Monument was established in 2006, encompasses nearly 140,000 square miles of Pacific Ocean is dotted with small islands, islets and atolls and a complex array of marine and terrestrial ecosystems. FWS; the National Oceanic and Atmospheric Administration (NOAA); and the State of Hawai‘i Department of Land and Natural Resources (HDLNR) jointly manage the Monument, which was recently inscribed as a cultural and natural United Nations Educational, Scientific and Cultural Organization (UNESCO) World Heritage site, making it the only Mixed Heritage site in the United States. (UNESCO, 2014). Tern Island lies within other existing federal and state conservation areas, including the Hawaiian Islands National Wildlife Refuge, managed by FWS; the Northwestern Hawaiian Islands (NWHI) Coral Reef Ecosystem Reserve, managed by NOAA; and the State of Hawai‘i’s NWHI Marine Refuge, managed by HDNLR. Tern is also a Formerly Used Defense Site (FUDS) within the Defense Environmental Restoration Program (DERP) managed by the U.S. Army Corps of Engineers (USACE, 2012).

Home to more than 7,000 recorded marine species, over 2,000 of which are endemic, or exist only in the NWHI (NOAA, 2013a), FFS is nesting habitat for 95 percent (%) of the population of Hawaiian green sea turtles, is pupping habitat for 16% of the Hawaiian monk seals, and is the nesting site for approximately 6% of the world’s black footed albatross (FWS, 2013b; NOAA, 2012). Tern Island is also the breeding site of 18 species of seabirds, earning it distinction as the island with the highest avian species richness in the NWHI (FWS, 2002). The NWHI represent a global biodiversity hotspot. Populations are among the most isolated on earth and due to the lack of human influence, the reefs of the NWHI are nearly pristine. An overall global decline in marine biodiversity means that endemic hotspots like the NWHI are important areas for biodiversity conservation. The NWHI ranked 72 in the world out of 175,520 sites listed as protected or proposed to be protected and requiring conservation management (Le Saouet, et al., 2013). The unique biota, high conservation value and low-lying elevation, make the NWHI distinctly vulnerable to the effects of climate change such as sea level rise.

Hawaiian monk seals and Hawaiian green sea turtles, and many species of seabirds may be particularly vulnerable to habitat loss due to sea level rise. Laysan and Black-footed albatross nest almost exclusively in the NWHI, and these species are listed as threatened and endangered by the International Union for the Conservation of Nature (IUCN). Tristram's storm petrel is listed as near threatened, with the most populated breeding site being in the NWHI (Harrison, 1990). A significant proportion of the world's population of Tristram's petrels breeds in FFS (Hartzell et al., 2012). The higher elevation of Tern and East Islands relative to the other islands in FFS, offers future refuge to species that may be displaced by the likely inundation of most of the land masses in this area from projected sea level rise and wave erosion.

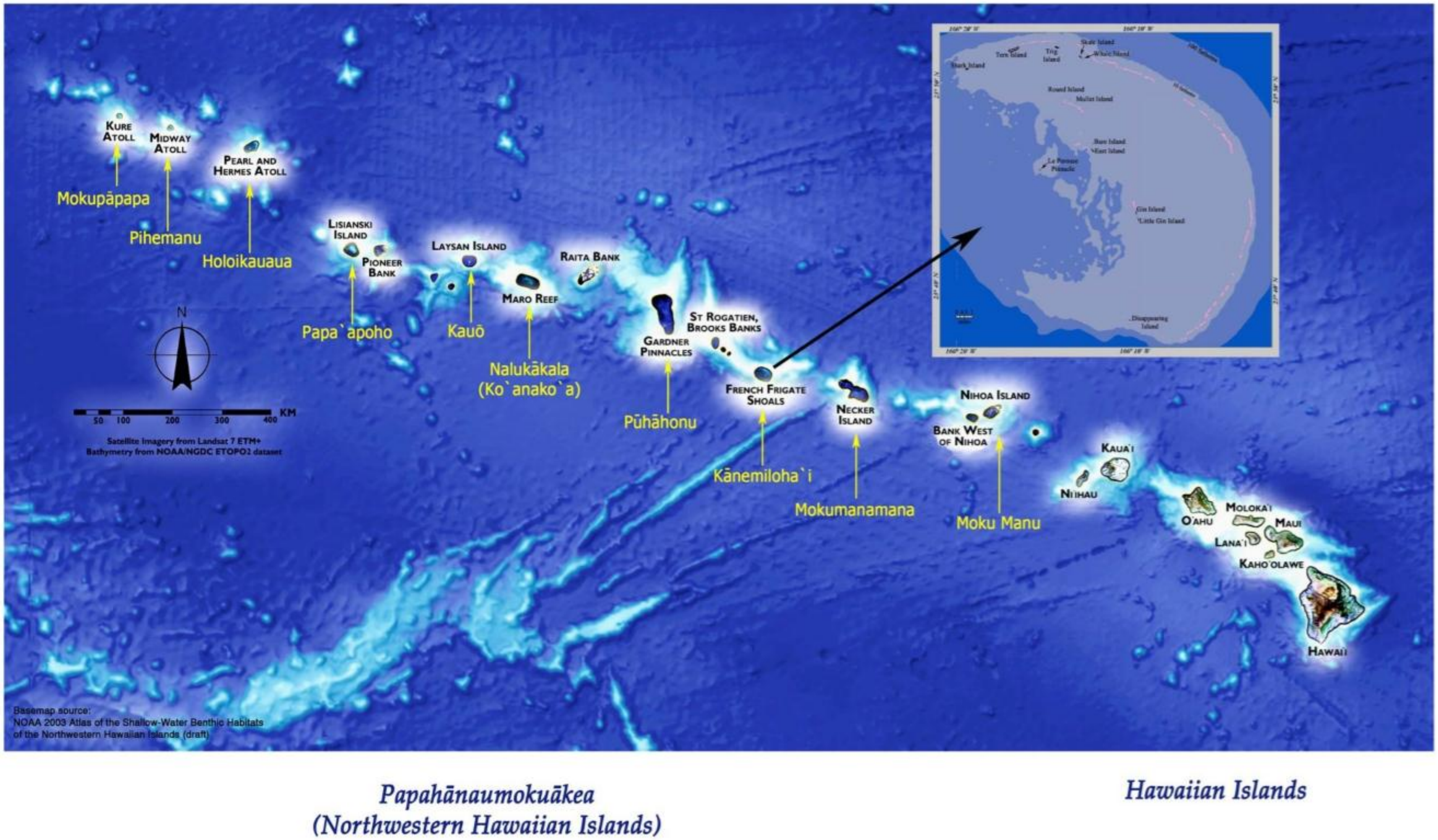
Anthropogenic activity has led to environmental contamination found on and around Tern Island. Environmental contaminants include dioxins/furans, polychlorinated biphenyls (PCBs), lead, hydrocarbons, and heavy metals. Exposure to these contaminants can have negative impacts on wildlife and the marine ecosystem. Discharges of pollutants include terrestrial and waterborne discharges.

The NWHI are located within the North Pacific Subtropical Convergence Zone (STCZ). The STCZ migrates between 23 degrees north and 37 degrees north with changes in atmospheric pressure (Pichel et al., 2007). A high concentration of marine debris accumulates within the STCZ, including plastics (EPA, 2011b; Friedlander et al., 2009a; Pichel et al., 2007). Persistent organic pollutants (POPs), such as PCBs, are commonly found in trace quantities in seawater. Plastics are known to attract and sorb these POPs on the plastic particle surface at concentrations far greater than the surrounding seawater. This tendency is known as hyperconcentration (Rochman et al., 2013a; Rochman et al., 2014). Recent evidence shows that the ingestion of microplastics (particles 5 millimeters and below) by marine organisms serves to biomagnify contaminants up the food chain (Engler, 2012; Rochman et al., 2013b; Rochman et al., 2014).

1.2 PURPOSE OF THE TECHNICAL SUPPORT DOCUMENT

A PA is part of the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) process as prescribed by the National Oil and Hazardous Substances Pollution Contingency Plan, more commonly called the National Contingency Plan (NCP), to evaluate releases of hazardous substances, pollutants, or contaminants that may pose a threat to human health or the environment. Given Tern Island's rich history and role as a critical wildlife resource, the related documents were too voluminous to fully summarize in the limited PA format. This TSD therefore will be used as a reference for the PA and includes and distills a wider array of the existing literature and data relevant to Tern Island and the environmental conditions, challenges, constraints, and vulnerabilities it faces.

Figure 1-1 Proximity of FFS to the Main Hawaiian Islands



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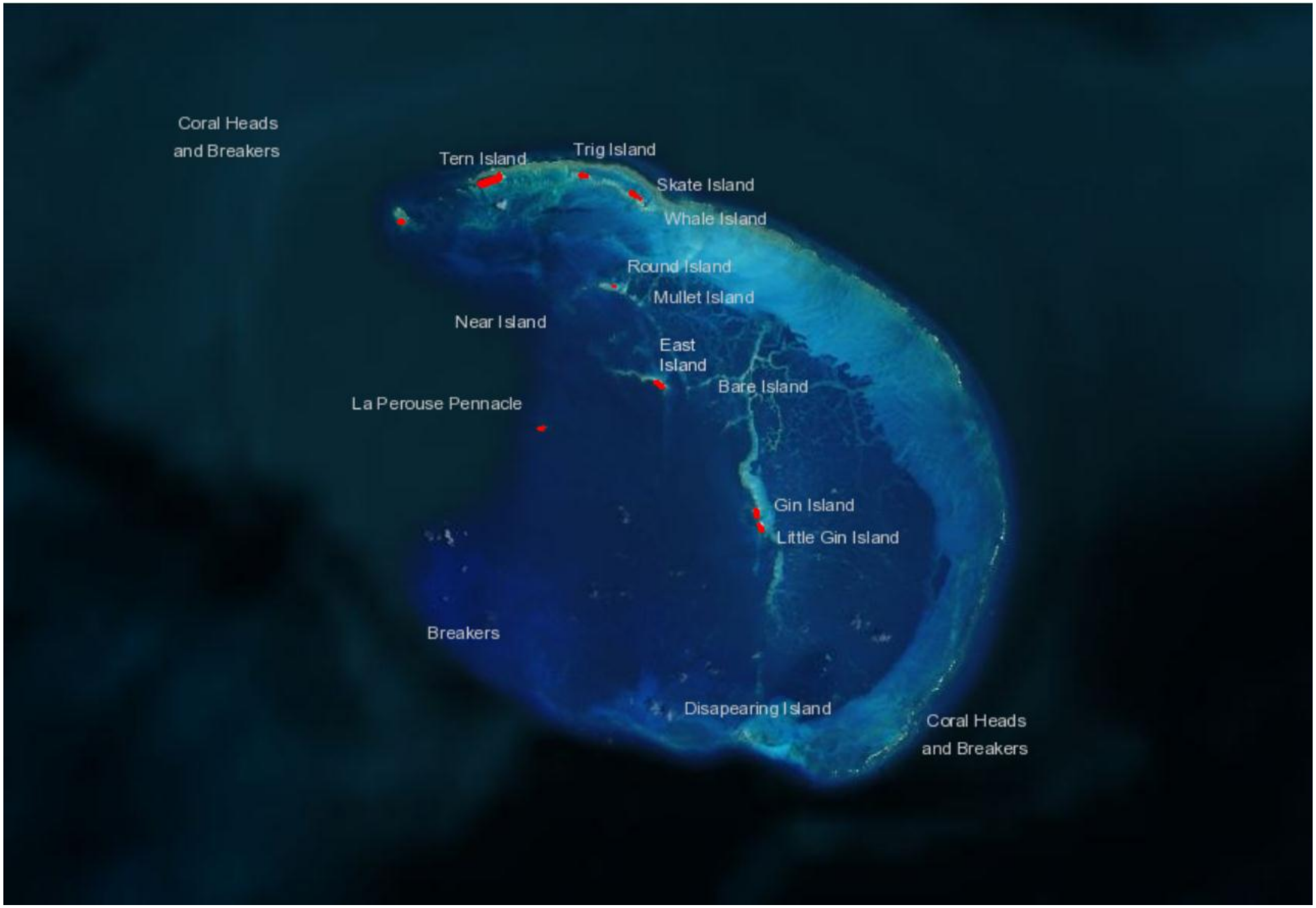

Source: EPA, 2014e

Figure 1-2 Islands of French Frigate Shoals

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The TSD will use available and existing information to assess the location and extent of contaminants remaining on Tern Island, examine known and suspected stressors on sensitive flora and fauna on and around Tern in FFS, and assess the potential role that microplastics play as a vector for POPs to enter into and biomagnify up the food chain. Sampling shows evidence of PCB loading in Hawaiian monk seals (Willcox et al., 2004) Hawaiian green sea turtles (Keller et al., 2014), as well as fish, coral, and crab in the waters surrounding Tern Island.

Beach counts of Hawaiian monk seals in FFS has been steadily declining since 1989. This is significant not only because Hawaiian monk seals are one of the rarest marine mammals in the world, but also because FFS boasts the second largest breeding site only to Laysan (Pacific Islands Fisheries Science Center (PIFSC), 2014). Survival of juveniles from weaning to age two declined almost 90% from the mid-1980s to as low as 8% in 1997 (the lowest year). Current survival rates for juveniles at FFS are approximately 50% from weaning to 1 year and approximately 65% from 1 to 2 years. National Marine Fisheries Service (NMFS) cites shark predation and decreased prey availability as major factors; also, poor care by the mother and aggressive adult male behavior have also accounted for pup mortality (NMFS, 2007).

In addition to poor pup survival, the onset of reproduction is later and the mean fecundity for mature females is lower for Hawaiian monk seals at FFS compared to Laysan Island (which has experienced less anthropogenic influence than FFS) (NMFS, 2007). Low fecundity, immune deficiency, and endocrine disruption are some of the effects pinnipeds display when exposure to PCBs has occurred (Shaw et al., 2005). Low fecundity is also a sign of chronic food limitation (Baker et al., 2014).

The toxicity risk from ingesting microplastics and the associated POPs that may be sorbed onto them or from consuming prey that has consumed microplastics requires further study and could be a contributing stressor to the sensitive species that reside in the NWHI.

1.3 DOCUMENT AVAILABILITY

A wealth of information in multiple formats has been accumulated over several decades for Tern Island; indeed, Tern Island and FFS boast some of the longest trend data on bird populations, turtles, and seals in the U.S. Numerous stakeholders have contributed to the information in this TSD. A list of these stakeholders is provided in Section 6. The majority of the information provided in the TSD summarizes the most recent and relevant published and peer reviewed data. We have also included pre-published studies in instances where data highly relevant to Tern Island are helpful.

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2 REGULATORY INVOLVEMENT

2.1 JURISDICTION

FFS and Tern Island fall within the concurrent and/or adjacent jurisdiction and/or management of the following entities and agencies:

- Hawaiian Islands National Wildlife Refuge, managed by FWS.
- Papahānaumokuākea Marine National Monument, jointly managed by HDLNR, FWS, NOAA, and advised by the Office of Hawaiian Affairs.
- Northwestern Hawaiian Islands Marine Refuge, managed by State of Hawai‘i DLNR.
- Northwestern Hawaiian Islands Coral Reef Ecosystems Reserve, managed by NOAA.

2.2 PAPAHĀNAUMOKUĀKEA MARINE NATIONAL MONUMENT CO-TRUSTEES

Management of the Papahānaumokuākea Marine National Monument is the responsibility of the U.S. Department of the Interior (DOI) through FWS, the U.S. Department of Commerce through NOAA, and the State of Hawai‘i through HDLNR (NOAA, FWS, HDLNR, 2008).

The Secretary of Commerce, through NOAA, has primary responsibility regarding the management of the marine areas of the Monument, in consultation with the Secretary of the Interior. The Secretary of the Interior, through FWS, has sole responsibility for the areas of the Monument that overlay the Midway Atoll National Wildlife Refuge and the Hawaiian Islands National Wildlife Refuge, in consultation with the Secretary of Commerce. The State of Hawai‘i, through HDLNR, has primary responsibility for the Northwestern Hawaiian Islands Marine Refuge and the State Seabird Sanctuary at Kure Atoll (NOAA, FWS, HDLNR, 2008).

2.3 U.S. FISH AND WILDLIFE SERVICE

Tern Island is managed by FWS; however, due to overlapping jurisdictions, management of the waters surrounding Tern Island is shared by the federal and state Monument Co-Trustees. In 1979 the U.S. Coast Guard (USCG) facilitated a transfer of Tern Island to FWS and FWS has occupied the facilities on the island since that time. The FWS field station at Tern Island was evacuated in December 2012, due to a storm that caused significant damage, and there has not been a continuous presence by FWS since that time (FWS, 2013a).

2.4 U.S. ENVIRONMENTAL PROTECTION AGENCY

On July 19, 2004, U.S. Environmental Protection Agency (EPA) added Tern Island to its Federal Agency Hazardous Waste Compliance Docket (Docket) as required by CERCLA. The Docket contains information about federal facilities that manage hazardous waste or from which hazardous substances have been or may be released. Tern Island was identified to EPA through FWS's submission of its biennial inventory of hazardous waste sites that it owns or operates as required by Section 3016 of the Resource Conservation and Recovery Act (RCRA). The Docket Name was updated to "FWS -- Hawaiian Islands National Wildlife Refuge: Tern Island" on January 26, 2014, Docket #26 (EPA, 2004; EPA, 2014a). A "Discovery Date" of July 19, 2004, was entered into EPA's Superfund Enterprise Management System (SEMS) for the Tern Island site, and it was assigned SEMS ID HI0000906379 (EPA, 2014c). SEMS is EPA's new information system that inventories and tracks releases addressed or needing to be addressed by the Superfund program. Prior to SEMS, EPA used the CERCLA Information System, or CERCLIS, to track this information.

The Docket serves to identify all federal facilities that must be evaluated through the site assessment process to determine whether they pose a risk to human health and the environment sufficient to warrant inclusion on the National Priorities List (NPL). The NPL is a list compiled by EPA of uncontrolled hazardous substance releases in the U.S. that are priorities for long-term remedial evaluation and response. The first step in the site assessment process is a PA. CERCLA Section 120(d)(1) requires that EPA take steps to assure that a PA be completed, and the Federal Register notes that for every federal facility included on the Docket, an evaluation shall be completed within a reasonable schedule, 69 Fed. Reg. 42990 (July 19, 2004). The PA satisfies any of FWS's obligations to complete a PA for Tern Island under Section 120(d)(1) of CERCLA.

A PA is a limited-scope investigation performed by EPA or a state for which the PA investigators generally collect readily available information and conduct a site and environs reconnaissance. Sampling is generally not conducted during a PA. The PA also identifies sites that may warrant a removal evaluation to assess whether a removal action is appropriate.

Using the existing information that has been compiled, a PA then evaluates a site using EPA's Hazard Ranking System (HRS) criteria to assess the relative threat associated with actual or potential releases of hazardous substances at the site. The HRS has been adopted by EPA to help set priorities for further evaluation and eventual remedial action at hazardous substance sites. The HRS is the primary method of determining a site's eligibility for placement on the NPL.

Based on the results of the completed PA, EPA may decide that further evaluation of the release is warranted and proceed to conduct additional evaluation. Most often EPA does this through a Site Inspection (SI), which routinely includes the collection of data through field sampling. The information contained in the TSD will be vital in developing the data quality objectives and associated sampling plan for further evaluation of Tern Island.

On December 11, 2012, the Center for Biological Diversity (CBD) petitioned EPA to conduct a PA of the NWHI, with the goal of assessing the impacts of marine debris on threatened and endangered species such as the Hawaiian monk seal, the most endangered marine mammal in the United States. EPA responded on November 14, 2013, indicating that it would partner with FWS to conduct a PA of Tern Island and would include an evaluation of the release of hazardous substances from Tern Island, including hazardous substances that adsorb to plastic marine debris in the surrounding surface water (CBD, 2012; EPA, 2013b).

Because Tern Island is within the jurisdiction, custody, and control of FWS, FWS has the delegated CERCLA lead agency authority to complete the PA. FWS has chosen to enter into an Inter-Agency Agreement (IAA) with EPA to conduct the PA in partnership with EPA (EPA, 2014d).

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3 HISTORY

3.1 EARLY HISTORY: 1750-1900


Figure 3-1 Guano Harvesting on Laysan Island (HDLNR website, undated)

Polynesians are believed to have visited the NWHI sometime before 1300 AD, based on archaeological evidence of early Polynesian artifacts found on Nihoa and Necker islands; however, no archeological evidence of their presence on Tern Island has been found. Exploitation of the NWHI by commercial harvest of whales, fish, seals, turtles, sharks, and sea cucumbers dates back to the 18th century, corresponding with visits from the earliest European explorers. The discovery of FFS is credited to a French explorer named La Perouse on November 7, 1786. After the French discovery of the islands, the islands remained unclaimed by any nation until January 4, 1859. U.S. Navy (Navy) Lt. John M. Brooke was on a sounding mission to find a route for an undersea telegraph cable from San Francisco to Japan when he took formal possession of the atoll. He took possession of FFS under the U.S. Guano Act passed in August 1856 (Amerson, 1971). The discovery of guano in the NWHI spurred excitement in Honolulu among businessmen and ships were sent to investigate the commercial viability of guano harvesting from FFS (Figure 3-1). These expeditions showed little promise of return on investment.

During this period there were many recorded shipwrecks. From 1859 to 1917 at least five vessels sank at FFS (Amerson, 1971). The Two Brothers Nantucket whaling ship was discovered in 2008 by NOAA divers in FFS near Shark Island. Maritime archeologists at NOAA linked this wreckage to the 1820s lost whaler that was thought to have sunk in the vicinity. Captain George Pollard, famous for the shipwreck of the Essex on which Moby Dick was based, was also captain of the Two Brothers when it sank (NOAA, 2014a). A late 19th century sailing vessel was discovered on the south side of the FFS atoll in 2005 by NOAA divers. Its cargo was dried coconut meat going from Tonga to Seattle. None of the shipwrecks in FFS are on the National Register of Historic Places, and although the exact locations of the shipwrecks are not public information, a representative from the NOAA National Marine Sanctuaries archeology division stated that none of the wrecks were near Tern Island (NOAA, 2014f).

The Republic of Hawai‘i took possession of FFS on January 13, 1895, when then President Sanford B. Dole appointed James A. King (then Hawai’i Minister of the Interior) as Special Commissioner to claim the Hawaiian atoll. The Republic officially claimed the atoll on July 13, 1895 (Amerson, 1971). The Republic of Hawai‘i was annexed by the United States on July 7, 1898 and subsequently became a U.S. Territory on April 30, 1900 (30 Stat. 750, 31 Stat. 141). With annexation, the FFS came under the jurisdiction of the United States.

3.2 1900-WWII

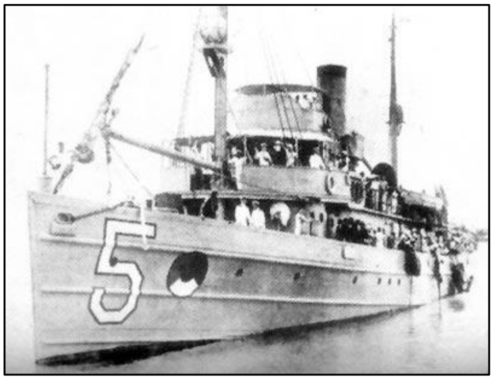

Figure 3-2: The USS Tanager Expedition (NOAA, 2013b)

As a result of egg and feather poaching in the NWHI, in 1909 President Theodore Roosevelt signed Executive Order No. 1019 protecting all of the NWHI (except Midway) under the designation of a Hawaiian Island Reservation (FWS, 2002). This action marked the first move by the U.S. to actively manage and protect the resources at FFS. The atoll was placed under the U.S. Department of Agriculture Bureau of Biological Survey, the predecessor agency to the FWS, and from 1912 to 1936, the U.S. Revenue Cutter Service sent various patrols to the NWHI looking for poachers. The U.S. Revenue Cutter Service would later be merged with the U.S. Life-Saving Service to form the USCG (Amerson, 1971). The 1923 Tanager expedition mapped 16 sand islets, and of those 16, they named 12; all of the names are still in use. The Tanager described Tern Island as a crescent shaped 11-acre sandbar (Figure 3-2) (Amerson, 1971). By the late 1920s, the Navy, realizing the strategic value of FFS, classified many of the hydrographic charts that had been created for the atoll. The NWHI were placed under a new designation (i.e., Hawaiian Islands National Wildlife Refuge) by Executive Order No. 2416 in 1940. This transferred jurisdiction of the atoll to the DOI.

FFS was occasionally used by the United States military from 1935 to 1942 as a seaplane refueling and rendezvous base (Figure 3-3) (Amerson, 2012).

Figure 3-3 East Island 1935 U.S. Encampment (U.S. National Archives)

3.3 MILITARY OCCUPATION OF TERN ISLAND 1942-1979

With the 1941 attack on Pearl Harbor and the attack on Midway in June of 1942, the U.S. constructed a Naval Airfield and aircraft refueling stop at Tern Island in 1942 (FWS, 2002).

The modification of Tern Island into a Naval Airfield and aircraft refueling stop was completed in March of 1943 (Figure 3-4). The island took on the appearance of an aircraft carrier when viewed from above. By 1944, 123 enlisted men and four officers operated the facility on 3-month shifts. The Naval Airfield consisted of eight buildings, barracks and galley facilities, fuel tanks, and a 90-foot (ft) high radar tower.

Figure 3-4 Tern Island August 1944 (U.S. National Archives)

Twenty fuel tanks held 100,000 gallons of aviation gasoline, and four other fuel tanks held 21,000 gallons of diesel fuel. The island accommodated 18 fighter or small bomber aircraft and had 22 aircraft parking spaces. The facility saw very little action during the war and when the war ended, the facility was placed on a "caretaker status." In August 1945, with World War II (WWII) ending, the Navy (not realizing that FFS was under the jurisdiction of the United States and part of a Wildlife Refuge managed by the DOI) tried unsuccessfully to transfer the atoll to the then Territory of Hawai'i. The Naval Airfield was officially decommissioned on June 9, 1946 (URS, 1999). The Territory assumed control based on a misunderstanding over jurisdiction regarding FFS in 1948.

Figure 3-5 Guns on the Perimeter of Tern Island 1943 (U.S. National Archives)

The Territory of Hawai'i allowed commercial fisherman to use the runway at Tern Island beginning in June 1946. Other fishing interests visited the NWHI in the 1950s and 1960s with varying degrees of success. Fishing operations chartered planes to transport the fresh fish to Honolulu to sell. Japanese and Russian fishing boats were reportedly using NWHI waters to fish in the 1970s (Manta Corp; 1979). Fishermen were allowed to fly their fish back to Honolulu using the airfield. By the 1960s, the fisheries surrounding Tern Island became overfished and prices fell so low that flying fish to Honolulu was no longer lucrative (Manta Corp., 1979).

Figure 3-6 Buildings, USCG airplane, and dump. (Wood, year unknown)

USCG built a Long Range Aid to Navigation (LORAN) station in 1944 on East Island, which is directly southeast of Tern Island. Thirteen buildings and structures were erected, including Commanding Officer's quarters and recreation hall, two buildings for barracks, a mess hall and galley, a generator hut and a storeroom, a machine shop, a LORAN hut and radio room, an office, a boatswain's locker, distiller shed, paint locker, vehicle shed, and the restroom. Unlike Tern Island, it was not necessary to alter the shape of East Island to build the station (Amerson, 2012).

USCG abandoned the LORAN station on East Island in 1952 in order to build the LORAN station on Tern Island, and in January of 1952, the Territory of Hawai‘i granted USCG permission to construct a LORAN Station on Tern Island. Since FFS was under the jurisdiction of the United States and under the management of DOI, DOI questioned the legality of USCG occupation of Tern Island (USCG, 1966). In 1966, DOI and USCG reached an agreement with the former granting USCG official permission to operate the LORAN Station (Amerson, 1971).

Figure 3-7 Pacific Missile Range (Wood, year unknown)

During the period from 1960 to 1963 when USCG was operating the LORAN Station on Tern, a Pacific Missile Range (PMR) facility was installed and operated by the Navy. The PMR facility included a 50,000-gallon neoprene fuel tank, generators, and electrical switching equipment (Amerson, 1971).

According to personal accounts, Tern Island was used as a tracking station for the Starfish mission in 1962 that was responsible for detonating a thermonuclear bomb in the atmosphere that was visible from Honolulu.

The U.S. Atomic Energy Commission (AEC) used Tern Island beginning in 1967. In a memorandum of understanding between FWS, the AEC, and USCG, a 3-year extension for the AEC's use of Tern Island was granted on May 23, 1969 (AEC, 1969).

3.4 FWS MANAGEMENT OF TERN ISLAND: 1979 TO PRESENT

When the LORAN Station was decommissioned in 1979, USCG returned Tern Island to DOI's FWS, which took over management of the atoll (URS, 1999). From 1979 to 2012, FWS operated a field station on Tern Island, resulting in 40 years of uninterrupted seabird research data. FWS also collaborated for decades to collect Hawaiian green sea turtle data and facilitated monk seal research since the 1980s. Since evacuating the island in December 2012, FWS has had intermittent presence on Tern Island.

In December 2000, President William Jefferson Clinton established the Northwestern Hawaiian Islands Coral Reef Ecosystem Reserve by Executive Order 13178. The new designation established conservation measures that restricted, and in some cases prohibited, consumptive or extractive uses in the marine environment. In 2006, President George W. Bush placed the NWHI under the more protective and expansive designation of a National Monument. The Monument designation required a shift in management from FWS, NOAA, and the State of Hawai‘i to a Monument Management Board consisting of NOAA, FWS, HDLNR and the Office of Hawaiian Affairs (OHA) (NOAA, FWS, HDLNR, 2008). The Board further restricted activity (such as commercial fishing) within the boundaries to minimize human activities that could cause a threat to the ecosystem. Later the name of the Monument was officially changed to Papahānaumokuākea Marine National Monument (Monument). In 2010, the Monument was inscribed as a UNESCO World Heritage Site.

3.5 CONSTRUCTION AND MAINTENANCE HISTORY OF TERN ISLAND

The first and most transformative construction activity completed at Tern Island was building the Tern Island Naval Airfield and aircraft refueling stop during WWII. The island was originally approximately 1,800 ft long and 450 ft wide. In August 1942, the Navy began dredging 660,000 cubic yards of coral from an adjacent lagoon to construct a landing strip and a channel (Figure 3-8). Construction of the island was completed by creating a seawall from 5,000 ft of double-walled steel sheet piling, with another pile constructed 4 ft away to hold the sea back. The seawall around the perimeter encapsulated the dredged coralline material, giving the island structure. The Navy transformed the island from an 11-acre natural island to a 34-acre naval facility with seaplane landing areas and a landing strip. The island's modified dimensions measured 3,100 ft by 350 ft. The land modification gave Tern the characteristic look of the deck of an aircraft carrier (Amerson, 1971; Woodbury, 1946). When

Figure 3-8 Constructing Tern 1942 (National Archives)

completed, the Tern Island facility had eight buildings, 21 underground storage tanks (USTs) and a 90-ft radar tower. Twenty tanks, each with 5,000 gallon capacity, held a total of 100,000-gallons of aviation fuel on the island, and one tank held 6,000-gallons of diesel fuel (URS, 1999). The island could accommodate 22 airplanes. It had a 12,000-ft long channel, 200 ft wide and 20 ft deep. An area adjacent to the island measuring 8,000 ft by 1,000 ft was cleared of coral heads to create a seaplane landing area. The facility was commissioned on March 17, 1943.

New barracks were constructed at Tern Island on January 30, 1944. During WWII, the island was used as a base from which daily reconnaissance missions were flown. WWII ended September 2, 1945, and the facility was decommissioned in June 1946 (Amerson, 1971).

The next major construction and repair efforts were performed by USCG. It received permission from the State of Hawai‘i to construct a LORAN Station on Tern in 1952. The station was commissioned on October 14, 1952. The station consisted of barracks, power buildings, signal buildings, recreational buildings, five water tanks, numerous transformers and capacitors, eight above-ground storage tanks (ASTs) for fuel oil, and the antennae system. In 1956, USCG renovated six 5,000-gallon USTs left by the Navy to hold fuel oil, increasing the Tern Island fuel oil capacity to 46,000-gallons (URS, 1999).

USCG completed a variety of repair activities at Tern Island from 1952 to 1979. To maintain the integrity of the seawall, a large number of corroded sheet piling were repaired. In 1959, repair of the northwestern corner of the island was completed. New sheet piling was installed by USCG seaward of the existing wall on the east and west sides of the island in 1964 (FWS, 2002). During this seawall repair, USCG built a new LORAN building, repaired the recreational building and barracks, and moved two air-conditioning trailers to the barracks for field personnel use (Amerson, 1971).

Figure 3-9 Seawall in 2013 in Calm Seas (FWS photo credit)

The island was inundated by high water on December 1, 1969. The waters flooded power equipment, which necessitated its shutdown. The inundation damaged the seawall in various areas and large amounts of soil were swept away from around the 129-ft LORAN tower. Vegetation from large portions of the northwest side of Tern Island was also washed away. Some structures were demolished and others were damaged. All personnel were rescued a day after the flood event. Repairs to the LORAN system were completed by January 6, 1970 with the help of the crews of multiple USCG ships and a Navy vessel. The evacuated crew returned to the island to complete the needed repairs to the facility. By January 15, 1970, the facility was back in working order (Amerson, 1971). It is assumed that an extensive repair of the sheet piling occurred after its destruction during the inundation, but no documentation exists of such activities (FWS, 2013c).

Repairs to address the bulkheads and eroded areas likely included the use of waste material as backfill (FWS, 2002).

3.6 SEAWALL REPAIR

FWS repaired several sections of the seawall (1,200 ft) for the protection of the shoreline. In 2004, FWS was allocated approximately $12 million for the project, which proved sufficient to finance only half of the proposed improvements to the island (FWS, 2013c).

In addition to the seawall repair, FWS made repairs to the small runway and buildings, and completed construction of a small boat ramp at Tern Island in 2004. This seawall repair was needed to halt the erosion of the island and to eliminate the risk of entrapment, injury, and death to endangered Hawaiian monk seals and threatened Hawaiian sea turtles (NOAA, FWS, HDLNR, 2008). In addition to the physical hazards presented by the failing seawall and the resulting erosion, contamination hazards were found to be present on Tern Island (URS, 1999).

The seawall has been repaired numerous times by USCG and FWS, although many of the repairs are undocumented. The deterioration of the seawall coupled with the resulting erosion and exposure of the landfilled hazardous materials poses both physical and chemical hazards to wildlife (Figure 3-10).

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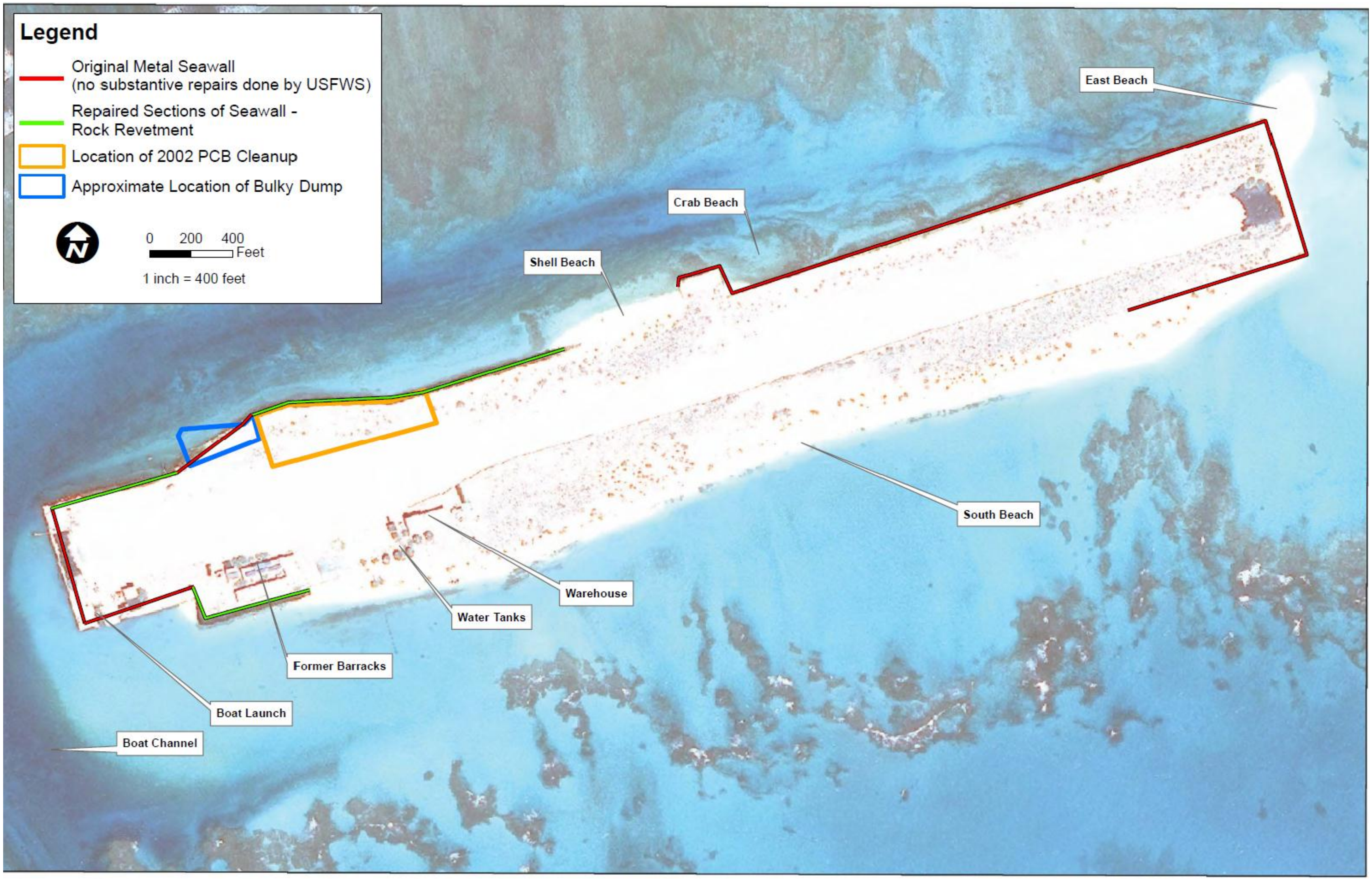

Figure 3-10 Island Features

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4 ENVIRONMENT

4.1 PHYSICAL ENVIRONMENT

The Hawaiian Archipelago, which consists of seamounts and 132 islands, is of volcanic origin, naturally forming new islands as the oldest subside into the sea during the decay process. The NWHI chain is composed of dozens of tiny islands, atolls (ring shaped islands), and shoals (sandbars), including Nihoa, Mokumanamana (Necker), FFS, Gardner Pinnacles, Raita Bank, Maro Reef, Laysan Island, Pioneer Bank and Neva Shoals, Lisianski Island, Pearl and Hermes Atoll, Midway Atoll, and Kure Atoll. The landscape of the NWHI is naturally changing based on this geomorphology of atolls and ephemeral islands (islands that become regularly inundated with seawater). The species that inhabit the NWHI, however, are highly vulnerable to changes in sea level and changes in wave action due to their low elevation (Storlazzi et al., 2013). The NWHI's diverse biological ecosystems, including fish, corals and other invertebrates, algae, turtles, seabirds, and marine mammals, are significantly influenced by ocean currents, waves, supply of nutrients, sea water temperatures, and other measures of water quality and oceanographic conditions (Friedlander et al., 2005).

The FFS atoll includes approximately 230,000 acres of coral reef habitat and approximately 67 acres of emergent land. There are nine to 14 islands in FFS, only two of which, Tern and East Islands, are currently vegetated. Both Tern and East Islands have also been significantly modified by military activity. Shark, Trig, Gin, Little Gin, and Disappearing Islands comprise the five emergent sandy islands of FFS. There are also from two to seven ephemeral islands in the atoll, including Round, Mullet, Gin Spit1, Gin Spit 2, and Little Gin Spit, and occasionally one or two unnamed smaller ephemeral spits. La Perouse Pinnacle is the only basaltic island in the atoll (Hartzell et al., 2012). Although the land area is only ¼ square kilometer (67 acres), the total coral reef area of the shoals is over 938 square kilometers (232,000 acres), making it the largest atoll in the NWHI (NOAA, 2013a).

Whale/Skate Island has been submerged since the 1990s due to heavy erosion that began in the 1960s (Friedlander et al., 2009a). Tern Island, with an area of approximately 30 acres, had an active landing strip until 2010 and permanent habitations for a small number of people until 2013. FWS maintained a field station on Tern Island until December 2012 when FWS ceased field camp activities due to significant damage to the facilities from a large storm event (FWS, 2013a).

4.1.1 Geology

The NWHI are part of a chain of volcanoes that began to form more than 70 million years ago (USGS, 2001). Formation of the islands began as eruptions from the Hawaiian volcanic hotspot (a continuous lava source) formed shield volcanoes that grew above sea level. As the Pacific Plate moved to the northwest, the volcanoes became extinct, began to erode, and subsided. During the initial erosion and subsidence, fringing coral reefs formed around the extinct volcano and usually created shallow lagoons. As subsidence continued, the fringing reef became a much larger barrier reef, with a much deeper lagoon from the shore. A ring-shaped island or an atoll is formed when waves break and erode the coral, and then wind and waves deposit the broken coral and sand on the reef. As the plate moved northwest into cooler waters, the coral reef atoll began to die and became a guyot or seamount.

FFS is a well-developed coral atoll consisting of a 20-mile (32 km) long crescent-shaped reef surrounding ephemeral sandy islets and the 120 ft (37 meters) high La Perouse Pinnacle, the only remnant of a great shield volcano. None of the sand islets reaches more than 13 ft (4 meters) above sea level. The number and form of the islets changes from time to time with changes in wave conditions. The crescent-shaped outer reef has tips that point to the west. An irregular inner reef joins the tips of the outer reef, and the two reefs form the atoll, which is oriented from northwest to southwest with the lagoon opening to the west.

4.1.2 Hydrology

The hydrology of Tern Island is such that there is very little to no fresh water available in the subsurface. Rain events may lead to the accumulation of short-term fresh water lenses in localized areas. These lenses may exist by temporarily sitting above the tidally influenced sea water that flows through the native and constructed carbonate and sand fill. Typically brackish groundwater is available from 5 to 8 ft below ground surface (bgs). Water catchment, filtration, and other means of water purification are used to provide water for field personnel operating on Tern Island (URS, 1999).

There are currently anthropogenic sources of water pollution found on Tern Island. Some of the fill material in the island consists of disposed waste material contaminants, which have subsequently been exposed by water movement and erosion. PCBs, lead, and other contaminants have been detected in sediment, seawater, and/or biota around Tern Island as a result thereof (Miao et al., 2000a; Miao et al., 2000b; URS, 1999; Chase, 2002). Contamination concentrations and distribution will be discussed in Section 4.3.

4.1.3 Soils and Sediments

The NWHI are composed mainly of sand and coralline materials. Tern Island is composed of a mixture of the natural coralline structures and dredged fill material made up of carbonate, sand, and crushed coral materials. The runway accounts for approximately half of the land mass of Tern Island and it is composed of densely compacted crushed coral (USCG, 2000). Manmade materials are also known to have been buried at Tern Island. These are believed to consist mainly of electrical equipment, batteries, closed USTs, and other wastes (FWS, 2002). Because of the large amount of plastic deposition on Tern Island (through ocean and bird deposition), it is likely that a percentage of the soil consists of marine plastic, including microplastics; however, the soils have not been studied to identify the percentage. What little soil exists on Tern Island is subject to both erosion as well as deposition as a result of natural processes: wind, ocean current, and wave action. The erosion is visible where the support structures are failing (FWS, 2002).

There are small quantities of soil and humus on Tern Island, formed mainly from bird guano. Some soil and plants were introduced from Honolulu, and others were likely introduced by seeds or plants adhered to equipment transported to the island over the course of its occupation.

The organic content of the soil is related to many properties. For low lying atolls, it typically varies between 2 and 20%, depending on the age of the soil, the vegetation, and soil management. In subsoils, the organic carbon values in low lying atolls are always very low, less than 0.5%. Nitrogen values follow the organic contents closely, as carbon-to-nitrogen ratios generally range from 9:12 for topsoils and 8:12 for subsoils. The calcium carbonate content is high for topsoils, ranging from 55 to 90% and greater than 90% for subsoils. The dominance of carbonate leads to high pH values (Morrison, 1990).

Phosphorus supply is replenished by guano deposits. Potassium levels are generally extremely low. Similar to potassium levels, sulfur is generally deficient in low lying atoll soils. Micronutrients such as iron, manganese, copper, and zinc are inadequate or unavailable to plants. Such deficiencies are common in low lying atoll soils (Morrison, 1990).

4.1.3.1 Microbial Environment

Microbial growth is dependent not only on physical soil requirements such as temperature, pH, and osmotic pressure, but also, just as importantly, on the chemical soil requirements. Carbon is the most important chemical requirement for microbial growth followed by nitrogen, sulfur, and phosphorus. Trace elements of minerals such as iron, copper, and zinc are also required for microbial growth as well as oxygen (Tortora et al., 2012).

Based on the soil chemistry and mineral content of low lying atolls, there is a low likelihood of available carbon, potassium, sulfur, and trace minerals; thus, the microbial habitat at Tern Island is assumed to be very poor. A study of a carbofuran (an insecticide)-contaminated site dubbed “the dead zone” at Laysan Island was conducted in 1997 and 1998. The results of this study showed the degradation rate of the pesticide, carbofuran, to be greatly extended when compared to degradation rates reported elsewhere in freshwater systems. Biodegradation of carbofuran typically takes 20 to 40 days to reach half-life values. However, the carbofuran contamination at Laysan, first detected in 1993, had not reached half-life values when sampled again in 1998. Due to the lack of degradation, the microbial community was assumed to be very poor on Laysan Island. Degradation cannot be attributed to microbes alone; hydrolysis and photolysis also play important roles (David et al., 2001). The example of Laysan Island’s microbial community is used here because there have been no microbial studies performed on Tern Island and the soils are assumed to be similar.

4.1.4 Climate

4.1.4.1 Wind

FFS has mild temperatures and moderate humidity year-round, persistent northeast trade winds, and infrequent severe storms with increased surf and swell in the winter months. The Pacific High Pressure System dominates during the summer months, which causes the prevailing Trade Winds. During the winter, especially from November through January, the Aleutian Low System moves southward over the Pacific (Friedlander et al., 2009a). The average seasonal temperature fluctuation in the NWHI is between 11 and 33 degrees Celsius. Annual rainfall over the last 26 years has been 73.28 centimeters (cm) on average (Friedlander et al., 2009a). A snapshot of satellite collected winds is shown in Figure 4-1 (NASA SeaWinds). Average annual wind speeds are over 14 miles per hour (mph), with winter maximums higher than 50 mph. Hurricanes are rare in the NWHI; however, personnel have been evacuated from Tern Island due to large winter storms and the wave surges that they can create (FWS, 2002).

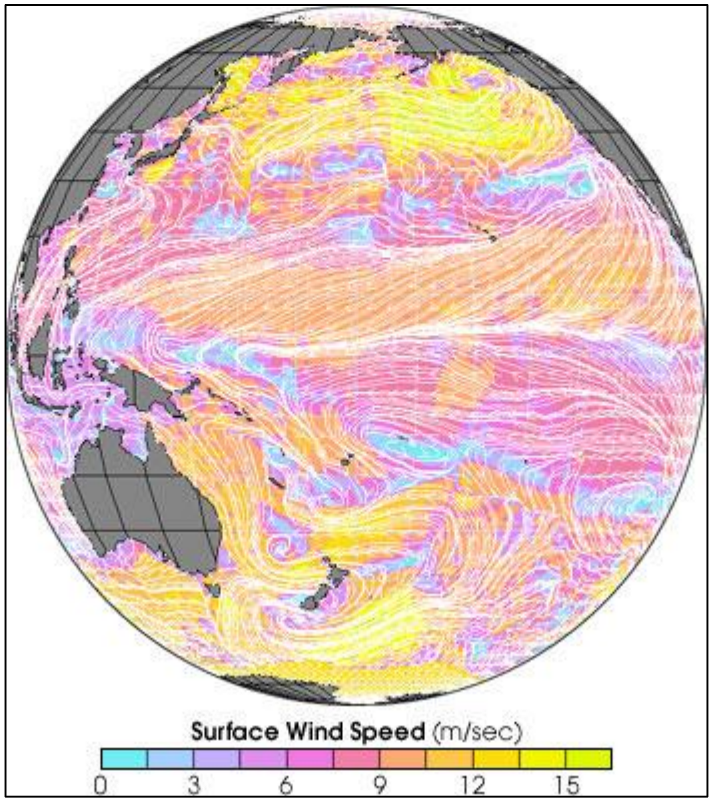


Figure 4-1 Surface Wind Speeds

Increased frequencies of storm surges due to global climate changes are generally predicted by the Intergovernmental Panel on Climate Change (IPCC). Changes in the frequency, trajectories, and intensity of tropical cyclones could result from alterations to the surface temperatures of the ocean and large-scale atmospheric circulation (Christensen et al., 2013).

The El Niño – Southern Oscillation (ESNO) (oscillating between both El Niño and La Niña events) is an inter-annual global climate phenomenon that results from the large-scale coupling of atmospheric and oceanic processes, which creates significant temperature fluctuations in the tropical surface waters of the Pacific and other oceans. During El Niño events, the Aleutian Low pressure system tends to be more intense and extend further south, producing stronger winds, larger waves, and cooler water temperatures in the NWHI than are typical.

This shift weakens trade winds and cancels upwelling on the equator that leads to warmer water temperatures in the eastern and central Equatorial Pacific, creating a disruption in the food web:

lack of phytoplankton and few zooplankters, which adversely affects the fish populations. The seabirds that rely on these food resources must also perish or fly farther in search of food (Cornell, 1998). Fish eating birds that feed on prey within a 1- to 2-mile radius of the shoreline are typically severely affected. During extreme El Niño events, such as the one in 1982 and 1983, the Blue-footed Booby in the Galapagos had to use more energy looking for prey than is typical. During 1982 and 1983, the Blue-footed Boobies were still present in the Galapagos but they did not reproduce. Other bird populations such as the Lesser Frigatebird, Magnificent Frigatebird, and Brown Pelican also experienced high mortalities. Many individuals of these and other species survived by migrating away from the Galapagos Islands, abandoning their chicks. The strongest impacts to seabirds occur in tropical waters off South America, where avian reproductive failure and high morality have been frequently recorded. Ground-nesting birds can suffer direct negative impact from ENSO-generated coastal storms and flooding (California Natural Resources Agency, 1997). While, some of the species represented in this study are not found at Tern Island; changes during ENSO events can be expected.

On a global scale, coastal storms can have an impact on other species similar to the effect on seabirds. Seal and sea lion populations in parts of the world have crashed following ENSO events due to the resulting decline in available prey. However, in Hawai‘i, El Niño events are associated with an influx of water with cooler surface temperatures which can result in increased prey availability. Studies have shown improved body condition and survival of Hawaiian monk seal pups and juveniles following El Niño years (NMFS, 2007). A strong El Niño is developing and is forecast to peak in the summer of 2014 (NOAA, 2014b).

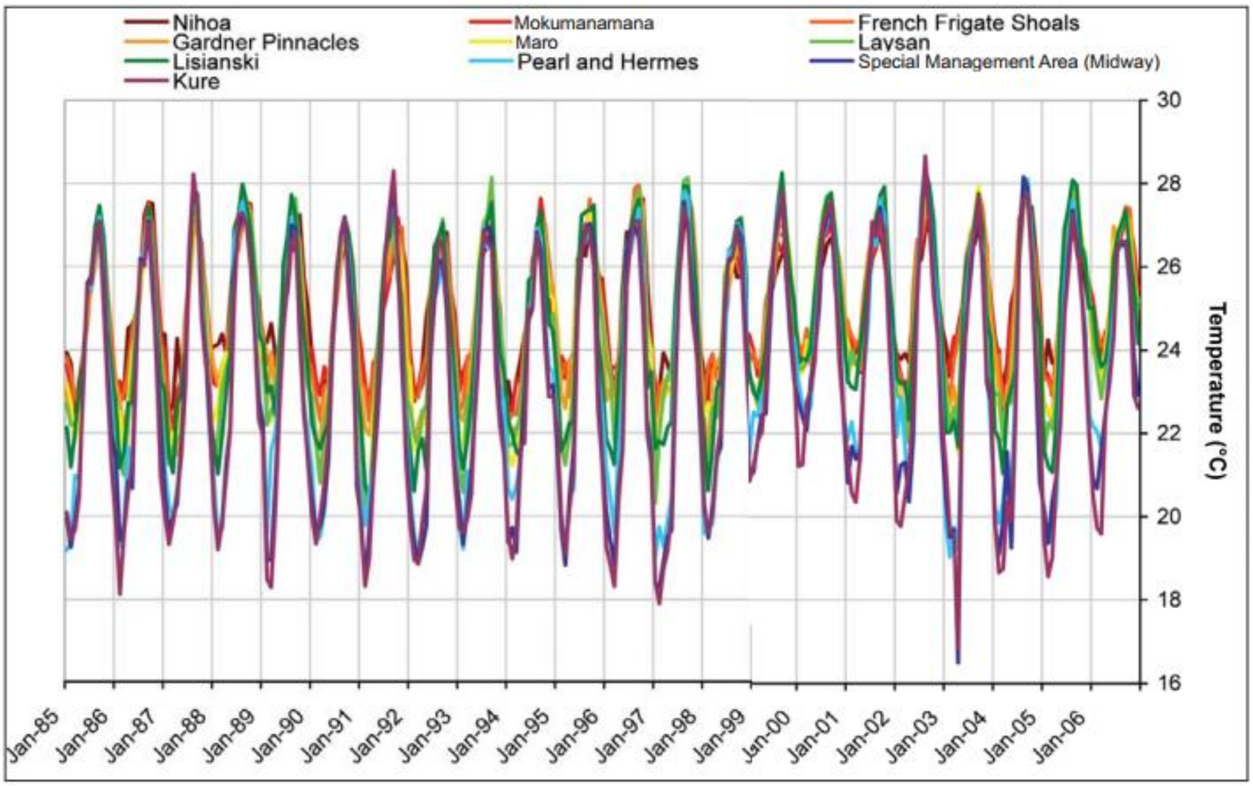
The Pacific Decadal Oscillation (PDO) is another important mode of climate variability in the North Pacific. Unlike ENSO, culminating in the tropics and having an intrinsic time scale of five to seven years with individual El Niño or La Nina events only lasting for six to 19 months, PDO occupies high and mid-latitudes and in the 20th century PDO events persisted for 20-30 years (Friedlander et al., 2009a).

ENSO and PDO can strongly modulate the weather patterns in and around FFS. Changes in atmospheric circulation patterns causing increases to wind, wave or ocean currents can increase the stresses placed on the exposed faces of Tern Island.

4.1.5 Seawater Temperature

Ocean temperature is an important physical factor that influences coral reefs and other marine ecosystems in the NWHI. FFS ocean surface temperature typically stays between 23.3 and 27.5 degrees Celsius (Figure 4-2). Surface temperatures undergo a diurnal cycle, intra-annual variations, an annual cycle, and significant interannual and decadal variability. FFS experiences less surface water temperature variability than the rest of the NWHI, which directly correlates to the unique assemblage of fish and corals found at FFS.

Coral bleaching is a process in which corals stressed by changes in conditions such as temperature, light, or nutrients expel the symbiotic algae living in their tissues, causing the coral to turn completely white. Corals can survive a bleaching event, but they are under more stress and are subject to mortality (NOAA, 2014c). Although coral bleaching can be caused by a range of variables acting alone or in combination, the predominant cause of coral bleaching globally is believed to be persistent warmer than average water temperatures. Record high water temperatures were recorded in the summer of 2002 in the NWHI, and significant bleaching was documented during that same summer (Jokiel and Coles, 1990; Friedlander et al., 2005; Jokiel and Brown, 2004; Hoeke et al., 2006; Kenyon et al., 2006).



Source: Friedlander et al., 2009a

Figure 4-2 Ocean Surface Temperatures throughout the Monument (1985-2006)

4.1.6 Sea Level Rise; Variations and Trends

Low-sitting atolls, such as the FFS, are critically vulnerable to changes in the level of the ocean. Two basic models are used to discuss impacts of sea level rise on the coastline: passive and dynamic models, a.k.a. the bathtub and wave models. In the simpler bathtub model, the ocean is stagnant and sea level rise is depicted above the mean sea level. The wave model uses the same rate of sea level rise as the bathtub model; however, it incorporates important surf zone wave dynamics. The wave model predicts a doubled impact from the same amount of sea level rise (Figure 4-3 from Storlazzi et al., 2013) in terms of the areas that can be potentially inundated.

Sea level rise, forecasted by models, extending through the year 2100, will place a potentially devastating stress on many of the species that live in the NWHI. As the ocean level rises, it will cause more inundation events and potentially complete loss of some of the lower lying islands found in FFS. Species like the federally endangered Hawaiian monk seal, federally threatened Hawaiian green sea turtles, and nesting seabirds require land for propagating their species. As the global sea level rise occurs, these species and others will face much higher competition for resources, loss of nesting or pupping habitat, and increased stress. Research on Whale/Skate Island, once the second largest island used by Hawaiian monk seals in the FFS, has shown that when the land mass of an island disappears, pup survival rate can be negatively affected. The latest IPCC evaluation of a number of model scenarios yielded a central value of a 48-cm rise by 2100. Using these predictions, some islands in FFS are expected to lose anywhere from 40 to 57% of their landmass (Baker et al., 2006). In the NWHI, the impact of a small amount of sea level rise is significantly amplified by the natural sinking and erosion of the islands.

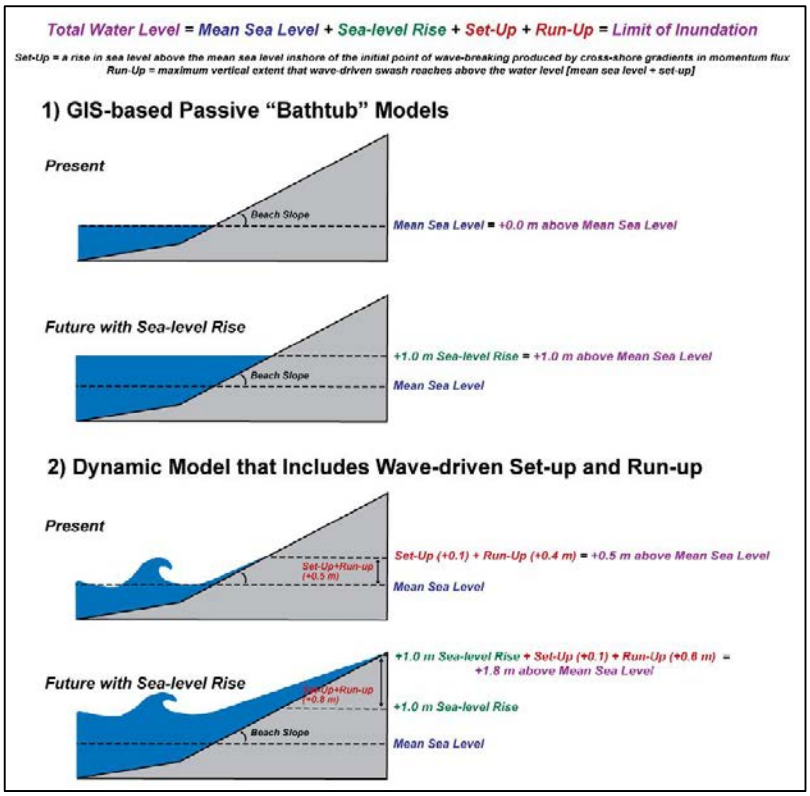


Figure 4-3 Bathtub and Wave-Driven Sea Level Rise Models

While warming climate causes sea level rise by adding to the ocean water from melting glaciers and sea ice and through thermal expansion of the ocean volume, the observed rise is not uniform geographically (Figure 4-4) (Centre National D'Etudes Spatiales (CNES), 2013). Modulated by the current phase of PDO in the most recent two decades, the sea level has been rising in the western Pacific (resulting in higher than usual intensity of tropical storms) but was more stable or even decreasing in some areas of the central and eastern Pacific, including NWHI. The impending switch of the PDO is expected to greatly enhance the effect of sea level rise in coming decades.

Firing et al. (2004) suggest that in the last 100 years, the sea level in Hawai‘i has risen by at least 10 cm (Firing et al., 2004).

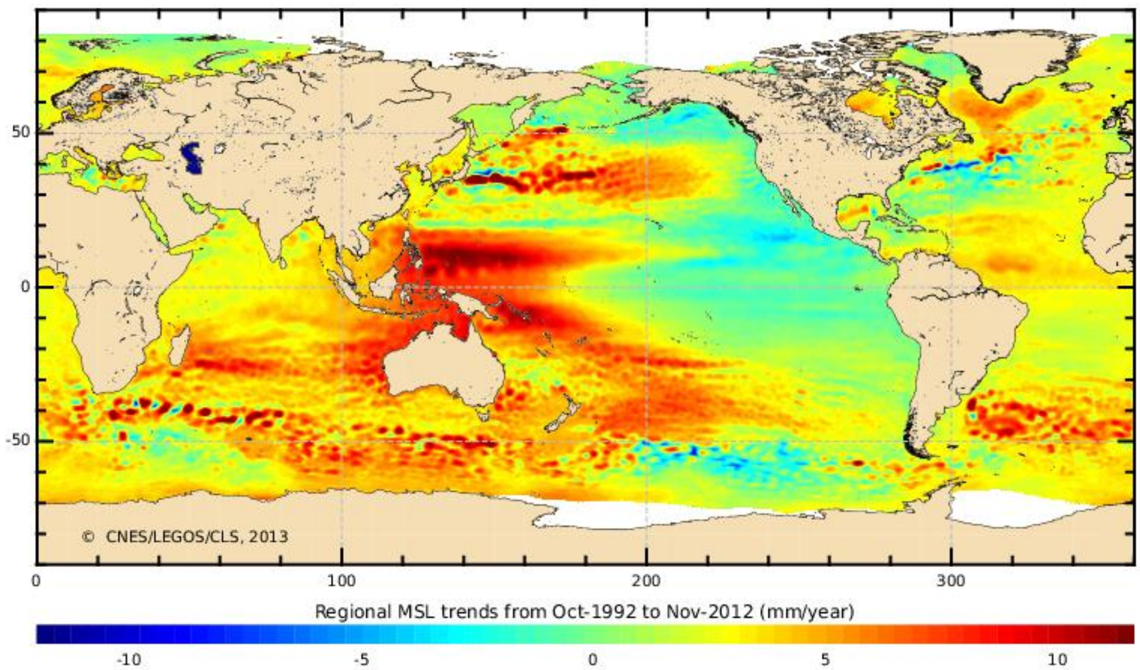


Figure 4-4 Mean Sea Level Trends from October 1992 to November 2012

Sea level combines with other phenomena, such as ocean eddies, tides, and waves. Ocean eddies passing through NWHI from the east have diameters of 100-300 km and may alter local sea level by 10-20 cm. As illustrated by the dynamic model in Figure 4-3, these relatively small changes in the background sea level can greatly enhance the effect of wind waves. Under some scenarios, the magnitude of the biggest waves may also increase in the changed climate. Physical factors, combined with the rate at which NWHI are sinking due to geological processes offset by the rate of coral reef growth, will determine the longevity of the FFS in the long term.

FFS passive inundation scenarios were studied by Reynolds et al. in 2013, and they found that seabird nesting habitat would be greatly depleted on the islands of FFS. Valuable Hawaiian green sea turtle nesting and Hawaiian monk seal pupping beaches would be inundated under a 2.0-meter mean sea level rise (Figure 4-5).

Passive or bathtub inundation models were used to predict potential island area lost with four sea level rise scenarios: (1) with a 0.5-meter rise above the mean high tide, the loss would be 0.7% of the landmass; (2) with a 1.0-meter rise above the mean high tide, the loss would be 4.3% of the landmass; (3) with a 1.5-meter rise above the mean high tide, the loss would be 9.4% of the landmass; and (4) with a 2.0-meter rise above mean high tide, the loss would be 13% of the landmass on Tern island. With a 2-meter rise in sea level, Shark, Round, Gin, Little Gin and Disappearing Islands would all be inundated (Reynolds et al., 2013).

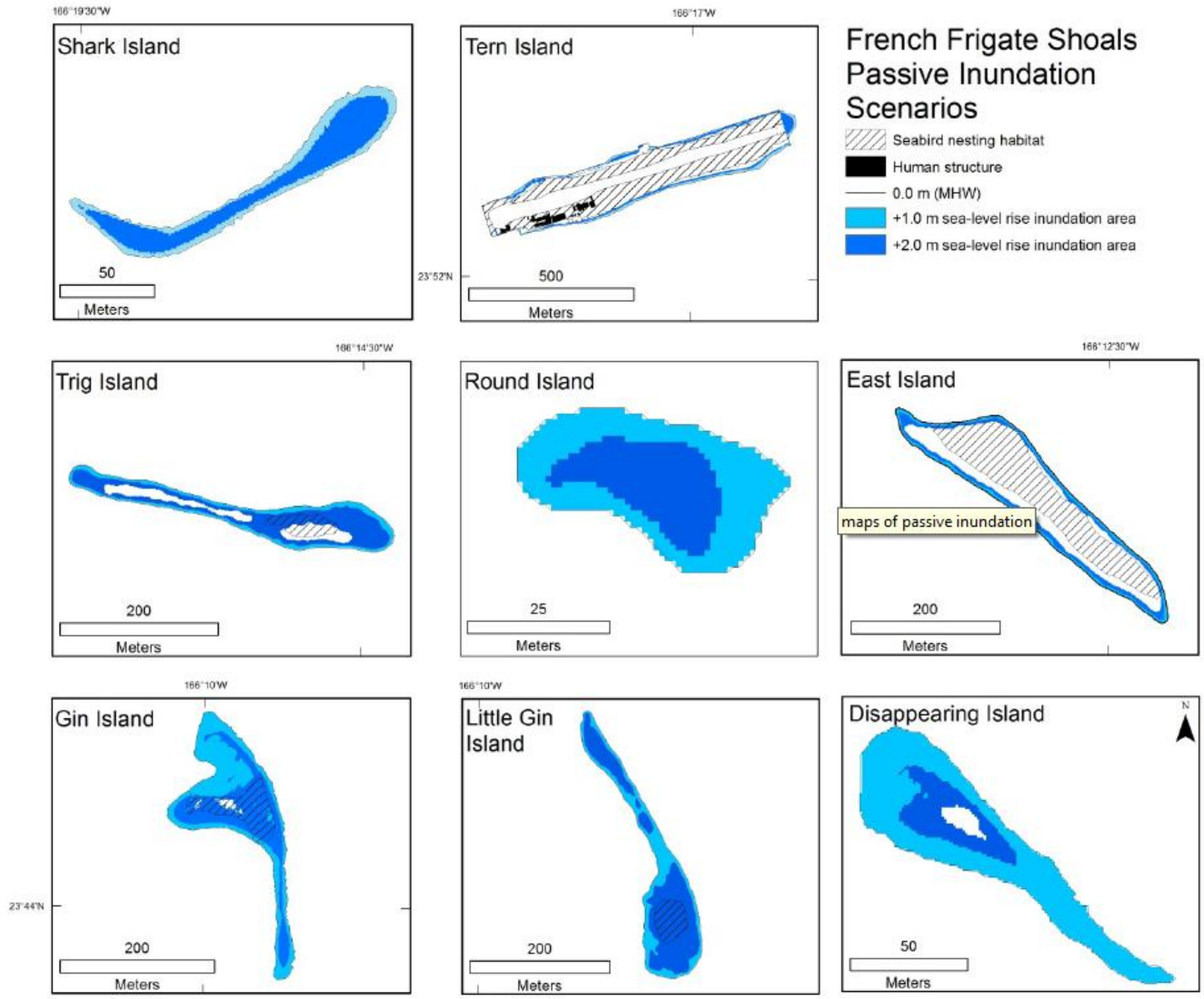


Figure 4-5 Passive Inundation Scenario Maps for Eight Islands of FFS

4.1.7 Currents

Ocean currents transport suspended matter, larvae, phytoplankton, and marine debris such as plastics around islands and across the ocean. Several studies have identified the primary transport mechanisms by which marine debris accumulates in the convergence zones of the world's oceans (Kubota, 1994; Martinez et al., 2009; and Ingraham and Ebbesmeyer, 2000). The NWHI are located in the central part of the North Pacific Subtropical Gyre, fringed in the east by the southward-flowing California Current, in the south by the westward North Pacific Equatorial Current, in the west by the northward Kuroshio Current, and in the north by the eastward Kuroshio Extension and North Pacific Current (Figure 4-6). These mechanisms are a combination of Ekman transport and geostrophic currents, and to a lesser degree, Stokes drift. Ekman currents, induced by wind, are limited to the top 100 meters of the water column. In the Northern Hemisphere, at the sea surface they are oriented to the right from the direction of wind and further spiral to the right and decay with depth. Integral Ekman transport is to the right and perpendicular to the direction of the prevailing winds (Pond and Pickard, 1983). In the North Pacific, the prevailing wind patterns are the northeast trade winds, blowing generally from east to west in the low latitudes, and the westerlies, blowing from west to east in the mid-latitudes.

These winds create converging surface Ekman currents, which are responsible for accumulation of marine debris in the so-called Garbage Patch (Maximenko et al., 2012), where it may reside for years or even decades. During this time plastic items degrade and fragment to produce "plastic sand" or microplastics that commonly wash up onto Main Hawaiian Islands (MHI) and NWHI due to variations in ocean currents and winds.

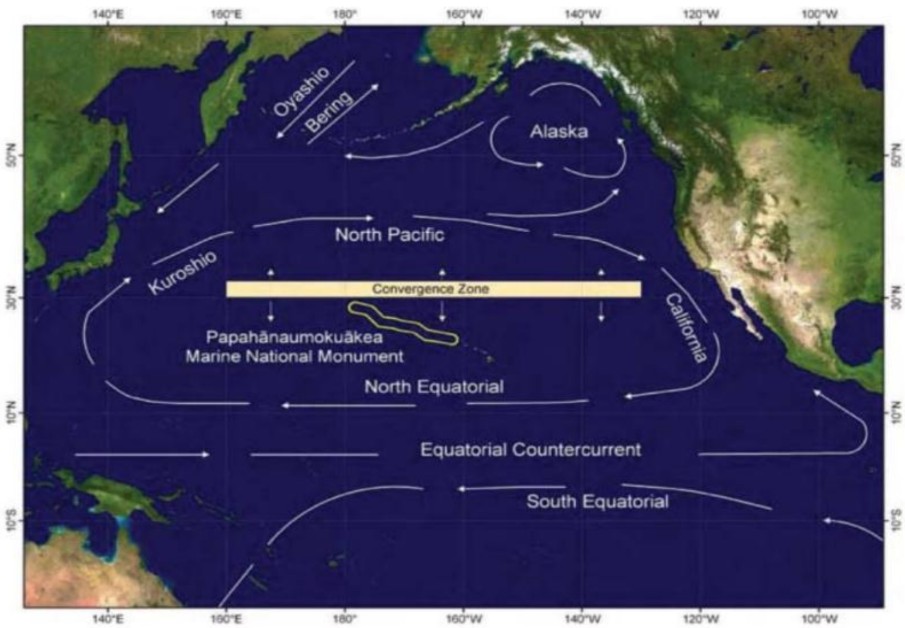


Figure 4-6 Generalized Illustrations of Primary Currents in the North Pacific

Convergence of Ekman transport also generates (through the so-called Sverdrup mechanism) a geostrophic gyre, in which the overall subsurface equatorial transport is compensated by an extraordinarily strong western boundary current (Kuroshio current).

Geostrophic currents are the result of balance between pressure gradient and Coriolis force (a force due to Earth rotation acting on moving objects). In the ocean, geostrophic currents travel along lines of constant sea level with higher level on the right (in the Northern Hemisphere; Brown et al., 1989). The combination of geostrophic and Ekman currents defines clock-wise rotation of the North Pacific Subtropical Gyre (Maximenko et al., 2009).

The NWHI, including Tern Island, are located close to the STCZ, which migrates between 23 degrees north and 37 degrees north with changes in atmospheric pressure (Pichel et al., 2007). STCZ is induced by the interaction between the ocean and the atmospheric circulation. A high concentration of marine debris accumulates within the STCZ, including plastics (EPA, 2011b; Friedlander et al., 2009a; Pichel et al. 2007).

The surface or upper ocean occupies 10% of the volume in the ocean, separated from deeper ocean by the main thermocline, located on average around 400 meters deep. Deep currents dominate the remaining 90% of the ocean volume. Deep currents are much slower than the upper currents and are driven by water density and gravity. Basin-scale ocean circulation is induced by wind forced applied to the ocean surface, whereas world-wide ocean circulation is strongly influenced by spherocity and the rotation of the earth on its axis. Figure 4-7 illustrates the direction and speed of the surface currents around the Hawaiian Island chain (Qiu et al., 1997).

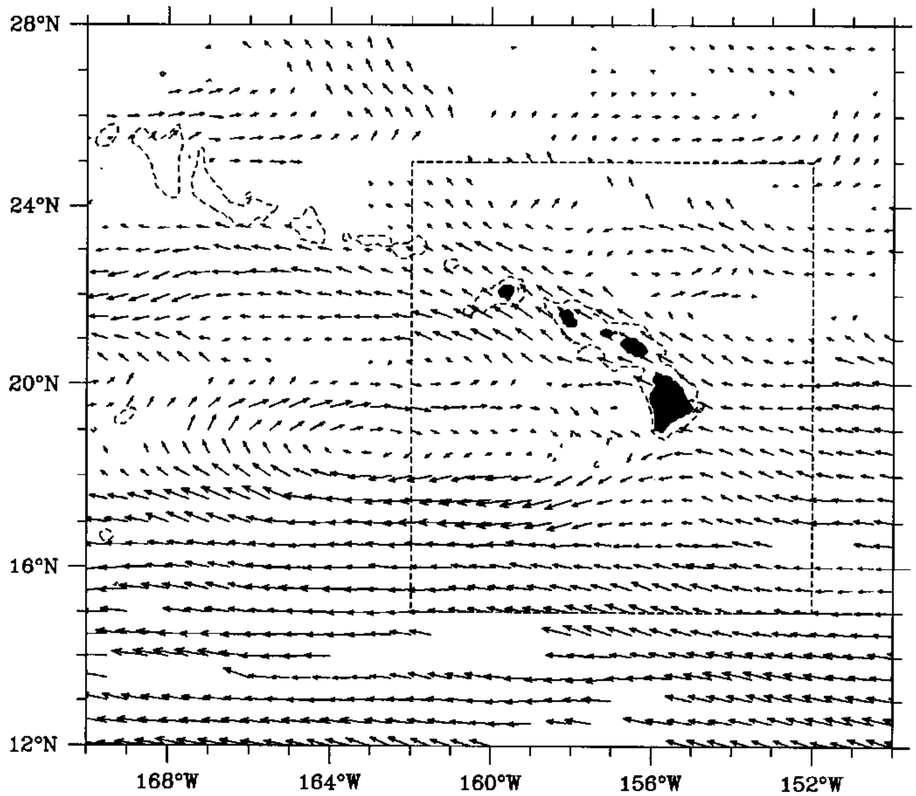


Figure 4-7 Generalized Illustrations of Currents around the Hawaiian Islands

The Westward North Equatorial Current, flowing just south of the Big Island of Hawai'i, branches northwards to create the North Hawaiian Ridge Current (NHRC) (Qiu et al., 1997). NHRC flows northwest along both the northeast and southwest faces of all MHI and its weakened extension continues along NWHI and past FFS. High variability of currents is induced by the small scale ocean eddies coming to the islands from the east and eddies induced by the trade wind interaction with the islands topography.

Pathways of marine debris have been modeled using the trajectories of satellite-tracked Lagrangian drifter buoys. A global study found the drifter buoys to aggregate at five main sites, all centered in the subtropics at approximately 30 degrees latitude. The aggregation sites were subsequently sampled for microplastics and it was confirmed that the plastics accumulated at those sites (Maximenko et al., 2012).

Waters in the NWHI have been shown to have a complex structure with highly variable speeds and directions. Water movement near the NWHI is highly influenced by wind conditions, water depth, and the shape of existing coral structures. The ocean floor modifications made by dredging the waters around Tern Island have changed the local flow patterns around the island (FWS, 2013c).

4.1.8 Waves

Waves have a significant effect on the NWHI. Tropical storms bring significant wave events and regularly move across the North Pacific in the winter months, generating high surf and swell. Among the NWHI, the distributions of species of corals and algae and their associated fish and invertebrate communities are often determined not only by ocean currents, but also by wave exposure. Many species of corals can only survive in sheltered habitats, whereas other species can thrive in high wave-energy habitats on the northwestern facing reefs that are exposed to the tremendous winter waves (Friedlander et al., 2009a).

Extreme wave events (greater than 10 m) influence the growth forms and distribution of coral reef organisms and negatively affect the reproductive performance of winter-breeding seabirds nesting in low lying areas. Most large wave events approach the NWHI from the west, northwest, north, and northeast, with the highest energy waves generally occurring from the northwest. Mean wave energy and wave power (energy transferred across a given area per unit of time) are highest between November and March and lowest between May and September. Extreme wave events bring at least one order of magnitude more energy than the typical winter waves (Grigg et al., 2008; Friedlander et al., 2009a). Extreme wave events, caused by anomalous winds, are also predicted to cause higher mass transport of marine debris, including microplastics, and not only affect the deposition of floating plastics, but also plastics with higher density than seawater. Data on the sub-surface microplastic abundance and distribution within the marine environment are limited and requires more study (Ballent et al., 2013).

Extreme wave events fluctuate over decadal time scales. Over the past 20 years, wave measurements from a NOAA buoy near Nihoa Island have shown a pattern of numerous extreme wave events during 1985 to 1989 and 1998 to 2002 with low numbers of events in the early 1980s and from 1990 to 1996. This variability of extreme wave events possibly is related to the PDO (Mantua et al., 1997; Friedlander et al., 2009a).

Tern Island is vulnerable to storm events due to the dilapidated seawall and the large erosion potential associated with damaging waves. Waves play a role in both transporting microplastics to Tern Island and in taking away previously deposited plastics from Tern Island. Because wave energy is much higher in the winter, it is assumed that more deposition of microplastics by wave action occurs in the winter months.

4.1.8.1 Productivity and the Chlorophyll-a Front

High chlorophyll-containing waters intersect the northern portions of the NWHI during the southward winter migrations of the STCZ. This point of intersection is a major ecological transition zone, known as the North Pacific Transition Zone Chlorophyll-a Front (Chlorophyll-a Front). Productivity of the marine environment in the NWHI is largely influenced by the position of the STCZ and associated high chlorophyll content of the waters in the Chlorophyll-a Front. The Chlorophyll-a Front moves seasonally and inter-annually, occasionally going beyond the boundaries of the Monument. The influx of nutrients to the NWHI from the Chlorophyll-a Front is a significant factor influencing different trophic levels (Polovina et al., 1995; Friedlander et al., 2009a). The Chlorophyll-a Front is used by many species as an important feeding and migration zone. Both permanent and seasonal residents of the NWHI make use of this productive zone. When the Chlorophyll-a Front has had a southern track, correlated increased fish catches in the Hawaiian Islands were documented (Polovina et al., 2001). Coral reefs are also impacted because the higher chlorophyll level allows for population increases of the coral eating crown-of-thorns sea star (Hoeke et al., 2006). The NWHI are located at the southern edge of the Chlorophyll-a Front in the North Pacific Subtropical Gyre ecosystem (Figure 4-8).

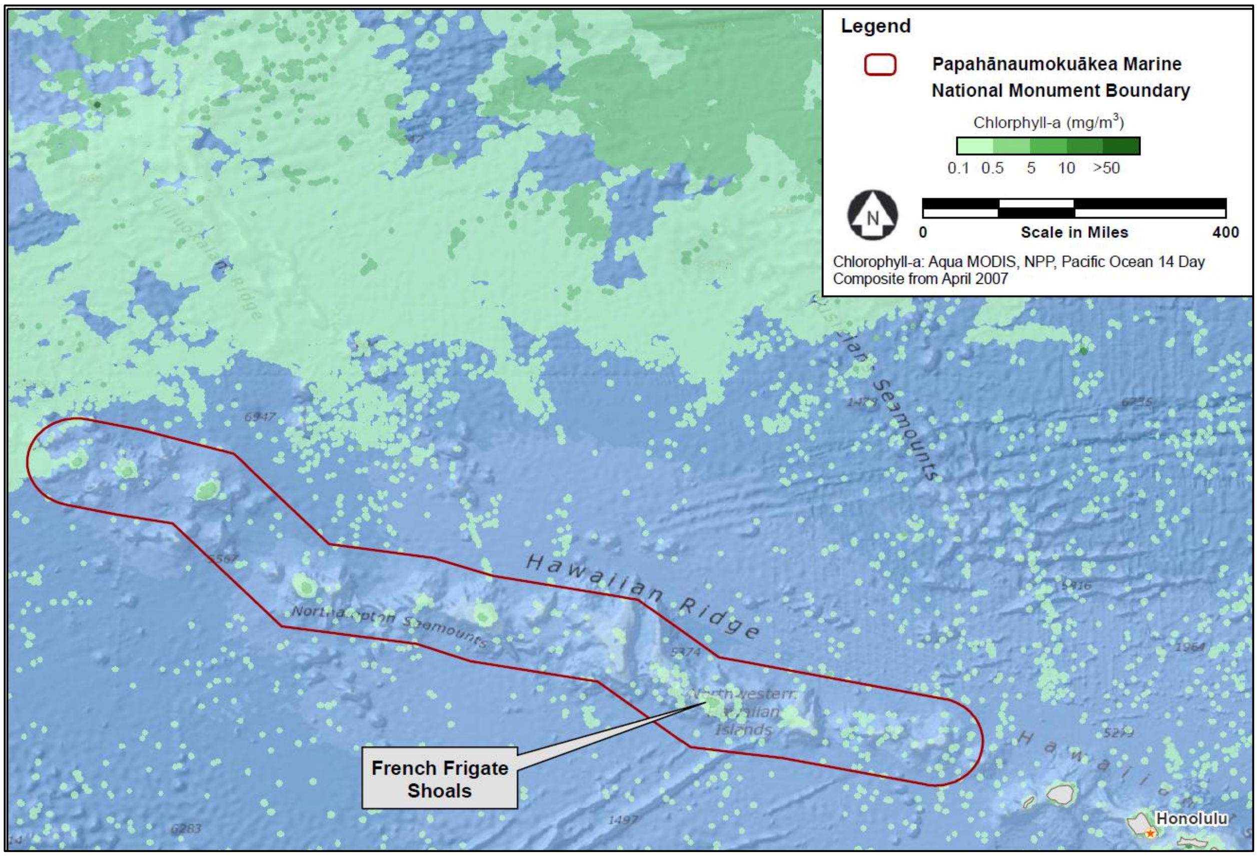


Figure 4-8 Chlorophyll-a Front in April 2007

Chlorophyll concentrations are cyclical and generally move south into the NWHI during the winter months and retreat far north in the summer. Trends in chlorophyll concentration anomalies can be correlated with the PDO and ENSO. In FFS, the typically cooler tropical waters in the eastern Pacific during cool phase PDO correlate with higher chlorophyll counts. ENSO events from the mid-1980s to 2006 yielded data that showed much higher chlorophyll concentrations than normal in the northern islands of the NWHI. During El Niño events, the low pressure system is more intense and extends south into the NWHI, resulting in stronger winds, more mixing, and cooler surface ocean temperatures. La Niña phases show the opposite characteristics in the NWHI, with warmer waters and lower chlorophyll concentrations (Friedlander et al., 2009a). In recent years researchers have recognized that the same forces that influence the presence and movement of the Chlorophyll-a Front similarly influence the movement of plastics in the STCZ (Pichel et al., 2007).

4.2 BIOLOGICAL ENVIRONMENT

The Hawaiian Island chain, consisting of both the MHI and the NWHI, is one of the most isolated place in the world, approximately 2,400 miles from the closest continent. FFS is about 490 nautical miles (560 miles) northwest of Honolulu. Because of this remoteness, species evolved undisturbed over thousands of years, creating endemic flora and fauna. Endemism is when a species occurs naturally in only one particular area. Areas of high endemism are considered biodiversity hotspots and Hawaiʻi has the highest percentage of endemism for warm-water fishes in the world, about 24% (NOAA, 2013a).

The remoteness and current protected status of the NWHI have minimized anthropogenic impacts in the last 20 years, including limited fishing and minimized reef degradation. Alien species were restricted to the anthropogenically impacted habitats of Midway Atoll and FFS (Friedlander et al., 2009a), however Laysan, Pearl and Hermes, Kure, and Nihoa have been reported to have at least one alien species present. The NWHI ecosystem also exhibits a large percentage of apex predators that have few natural enemies and exist at the top of their food chain. Apex predators such as sharks and monk seals help control and structure food webs in the ocean by ridding prey communities of the sick or weak members. Apex predators have been depleted elsewhere in the world. Le Saout et al. took data from the World Database on Protected Areas to determine the World's most irreplaceable conservation areas. The NWHI ranked 72 in the world out of 175,520 sites listed as protected or proposed to be protected and requiring conservation management (Le Saouet et al., 2013).

The Hawaiian Archipelago contains the highest level of marine fish endemism in the Pacific (Friedlander et al., 2009b). Figure 4-9 shows the Monument boundaries and highlights the Special Preservation Areas (SPA). NWHI represents a global biodiversity hotspot and one of the last remaining intact large-scale, predator-dominated coral reef ecosystems on Earth (Freidlander and DeMartini, 2002). Marine life in NWHI evolved over many millions of years in isolation from neighboring islands and archipelagos. It is plausible that some species were able to survive and thrive without the threat of newer species displacing them, as was likely the case in other archipelagos (Friedlander et al., 2009a).

4.2.1.1 Fish

The marine communities of NWHI are among the most isolated on Earth and because of the lack of human influence, the reefs are nearly pristine. An overall global decline in marine biodiversity means that endemic hotspots like the NWHI are important areas for biodiversity conservation. The endemic fishes found here are small bodied and have very restricted geographic ranges of less than 50,000 km. Because small-bodied species tend to have a narrower range of habitat requirements, they may be associated with a higher extinction risk (Friedlander et al., 2009b). Therefore, both body size and endemic status give cause for the conservation of these species.

Of the 21 fish species that are known to be endemic to the NWHI (Table 4-1), five are found in the area of the FFS: the Slingjaw wrasse (*Epibulus insidiator)* is found in shallow reefs, the Serrate coronetfish (*Fistularia petimba)* is found in moderate to deep waters, the Deepwater cardinalfish (*Epigonus devaneyi)* is found in deep water, the Black trevally (*Caranx lugubris)* is found in shallow to deep waters, and the Splendid perch (*Grammatonotus macrophthalmus*) is found only in deep water off the FFS (Friedlander et al., 2009b). All five of these species are on the IUCN Red List as threatened or endangered.

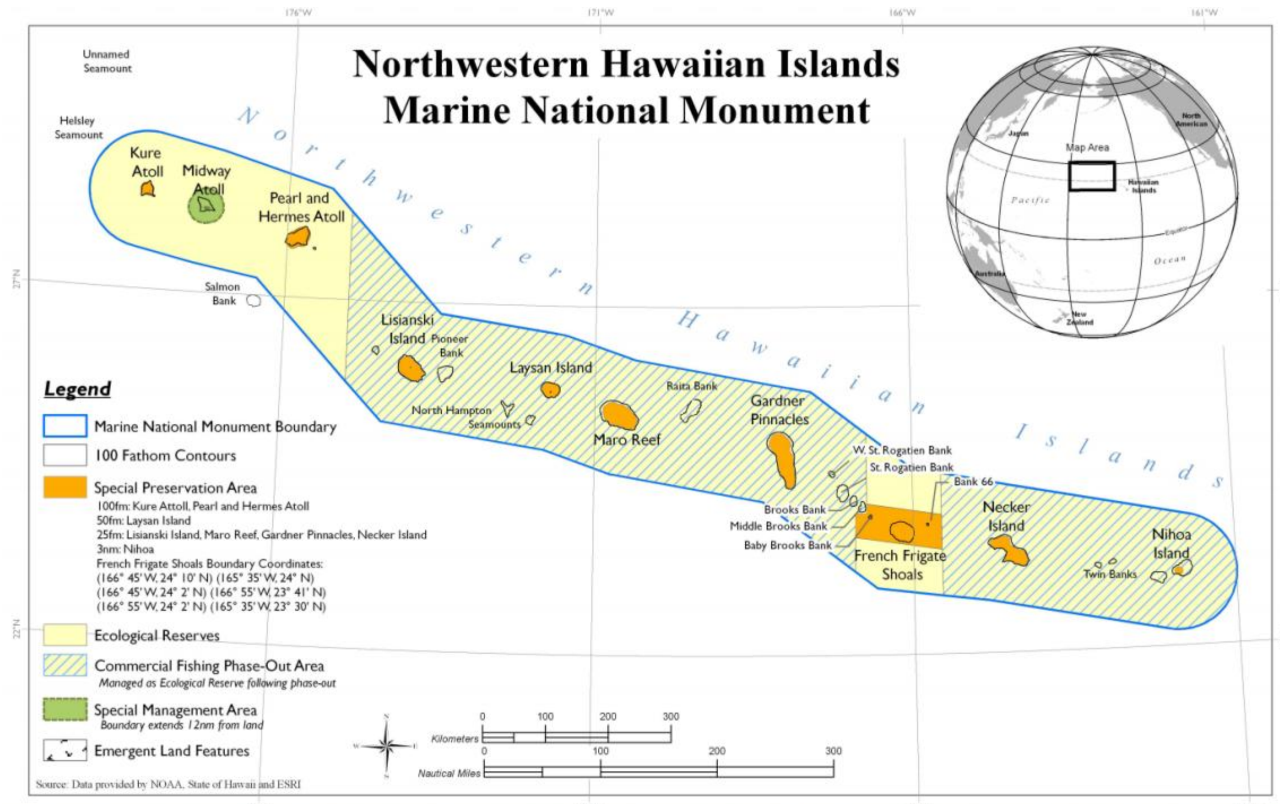


Figure 4-9 Special Preservation Areas in the Papāhānomokuakea National Monument

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Table 4-1 Fish Species from the NWHI and Not Found in the MHI (NOAA, 2009)

	Species	Common Name	NIH	MMM	FFS	GAR	MAR	LAY	LIS	PHR	MID	KUR	Habitat
Scyliorhinidae	*Apristurus spongiceps*	Spongehead catshark	x										Deep-water
Muraenidae	*Gymnothorax atolli*	Atoll moray								x	x		Cryptic
Platytroctidae	*Mentodus mesalirus*	Tubeshoulders								x	x		Deep-water
	Astronesthes nigroides	Dragonfish								x	x		Mesopelagic
Stomiidae	*Eustomias cancriensis*	Scaleless black dragonfish								x	x		Mesopelagic
	Bassozetus zenkevitchi	Cusk-eel									x	x	Deep-water
Ophidiidae	*Spectrunculus grandis*	Cusk-eel									x	x	Deep-water
Macrouridae	*Cetonurus crassiceps*	Grenadier, Rattail					x						Deep-water
Holocentridae	*Myripristis murdjan*	Blotcheye soldierfish									x	x	Shallow reefs
Fistulariidae	*Fistularia petimba*	Serrate coronetfish	x	x	x	x	x	x	x	x	x	x	Moderate-deep water
Laysan	*Scorpaenopsis pluralis*	Laysan scorpionfish						x					Deep-water
Callanthiidae	*Grammatonotus macrophthalmus*	Splendid perch			x								Deep-water
Epigonidae	*Epigonus devaneyi*	Deepwater cardinalfish		x	x	x	x						Deep-water
	Caranx lugubris	Black trevally		x	x	x	x	x	x	x	x		Shallow to deep water
Carangidae	*Decapterus macrosoma*	Shortfin scad					x						Pelagic
Pomacanthidae	*Centropyge interruptra*	Japanese angelfish									x	x	Shallow reefs
Kyphosidae	*Girella leonina*	Blackedge nibbler									x		Waif
Labridae	*Epibulus insidiator*	Slingjaw wrasse			x	x	x	x	x	x	x	x	Shallow reefs
Ammodytidae	*Lepidammodytes macrophthalmus*	Sand lance					x						Poorly known
Ephippidae	*Platax boersii*	Boer's spadefish									x		Waif
Luvaridae	*Luvarus imperialis*	Louvar						x					Epipelagic

Notes:
x = IUCN threatened and/or endangered species

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The fish assemblages of the NWHI differ from other reefs and the MHI as a result of oceanographic conditions such as water temperature and habitat, differences in coral and reef type, and anthropogenic influences such as effects from fishing. The slingjaw wrasse (*Epibulus insidiator)* and chevron butterflyfish (*Chaetodon trifascialis*) are associated with the Acropora corals that occur only in the central portion of the NWHI. This type of site fidelity may result in an increase in vulnerability.

Apex predators account for 47% of total fish biomass in the NWHI. FFS has the second highest percentage of apex predators only to Pearl and Hermes within the NWHI at 61%. Figure 4-10 illustrates the biomass density of apex predators in the NWHI. A comparison of biomass density relative to species size showed that there is a greater number of large individual fish at FFS and at Pearl and Hermes Atoll than in the rest of the NWHI. The giant trevally or ulua made up slightly more than 65% of the predator biomass observed in the NWHI. Sharks account for 28% of apex predator biomass. Grey reef, Galapagos, and White-tip reef sharks comprise the majority of sharks in the NWHI. The grey reef shark is more prolific in the southern NWHI, including the FFS, and less abundant in the northern NWHI and in the MHI (Friedlander et al., 2009b).

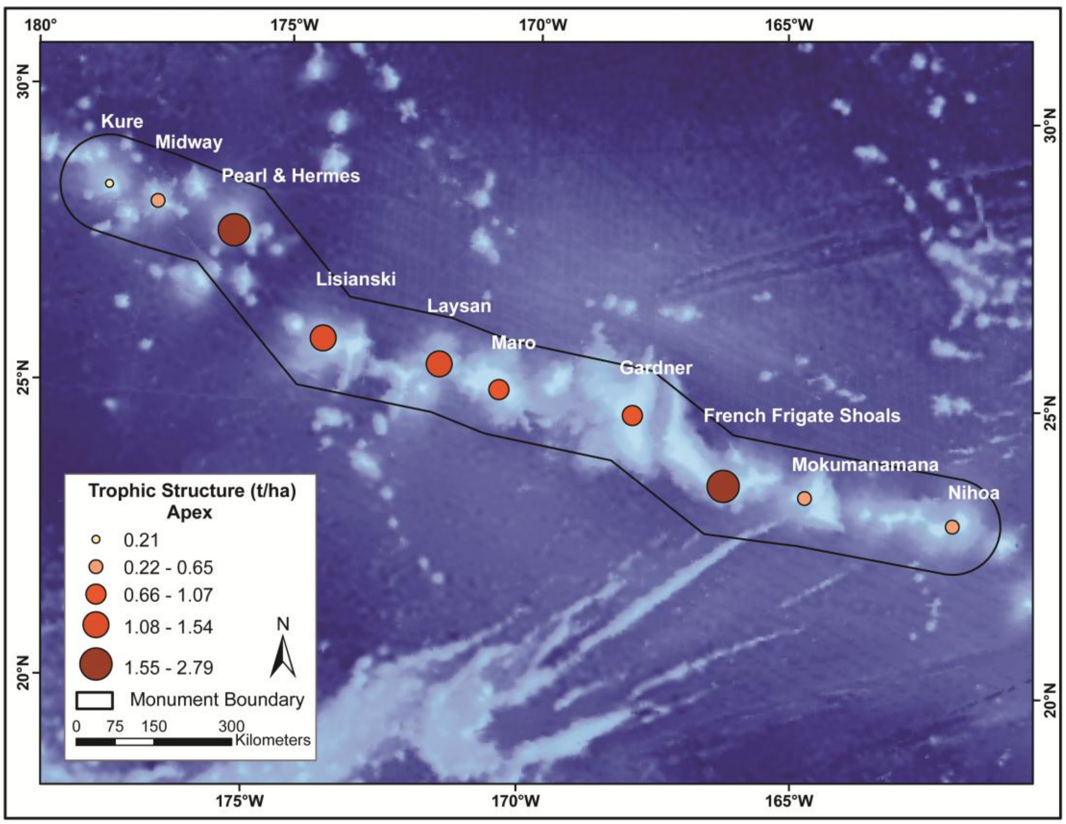


Figure 4-10 Percent Biomass of Apex Predators at the Ten Emergent NWHI Reefs (Friedlander et al., 2009b)

Overall biodiversity of fish species is actually higher in the MHI than in the NWHI. There are a variety of reasons why this is the case. Many shallow water species of fish are adapted to warmer water and cannot survive in the NWHI because winter water temperatures there can dip as much as 7 degrees Celsius cooler than at the MHI (Friedlander et al., 2009b). A correlation was found between movement north and south along latitudinal gradients of the NWHI and the percentage of fish species that showed a temperate/subtropical affinity and a tropical affinity. Fish species in FFS showed a 27.45% affinity for temperate/subtropical conditions and an 8.57% affinity for tropical conditions (Friedlander et al., 2009b). Other possible reasons for the lower number of species in the NWHI include insufficient sampling efforts and a scarcity of high island habitats such as estuaries and rocky shorelines similar to those found throughout the MHI. Despite lower species richness in the NWHI, the total number of species observed on quantitative transects in the NWHI was similar to a quantitative study of total number of species around the MHI (Friedlander et al., 2009b).

The highest level of overall fish species richness in the NWHI is found at FFS and at Pearl and Hermes Atoll (Figure 4-11). FFS high species richness is likely a result of its high level of coral species richness and greater habitat diversity (Friedlander et al., 2009b). Fish species richness at FFS tends to be higher on the windward fore reef habitats, followed by back reef, and then lagoon habitats. Fish density, however, is greatest in the lagoon habitat, where the domino damselfish, saddle wrasse, and goldring surgeonfish are dominant, and lowest in the fore and back reef, where both the saddle wrasse and the blackfin chromis each averaged around 10% of total number of individuals (Friedlander et al., 2009b). Two areas of the FFS, Tern Island and the pass near Disappearing Island, had the greatest number of individuals observed. Fish biomass density is highest on the fore reef lower in the lagoon and lowest on the back reef. In all three areas, the giant trevally was the primary species, making up 26%, 13%, and 25% of the fore reef, the lagoon, and the back reef, respectively (Friedlander et al., 2009b). The grey reef shark was second with 21%, 6%, and 10%, respectively. The bluelined snapper contributed to 14% of the back reef biomass density (Friedlander et al., 2009b). Tern Island and the pass near Disappearing Island again yielded the highest biomass in FFS (Friedlander et al., 2009b).

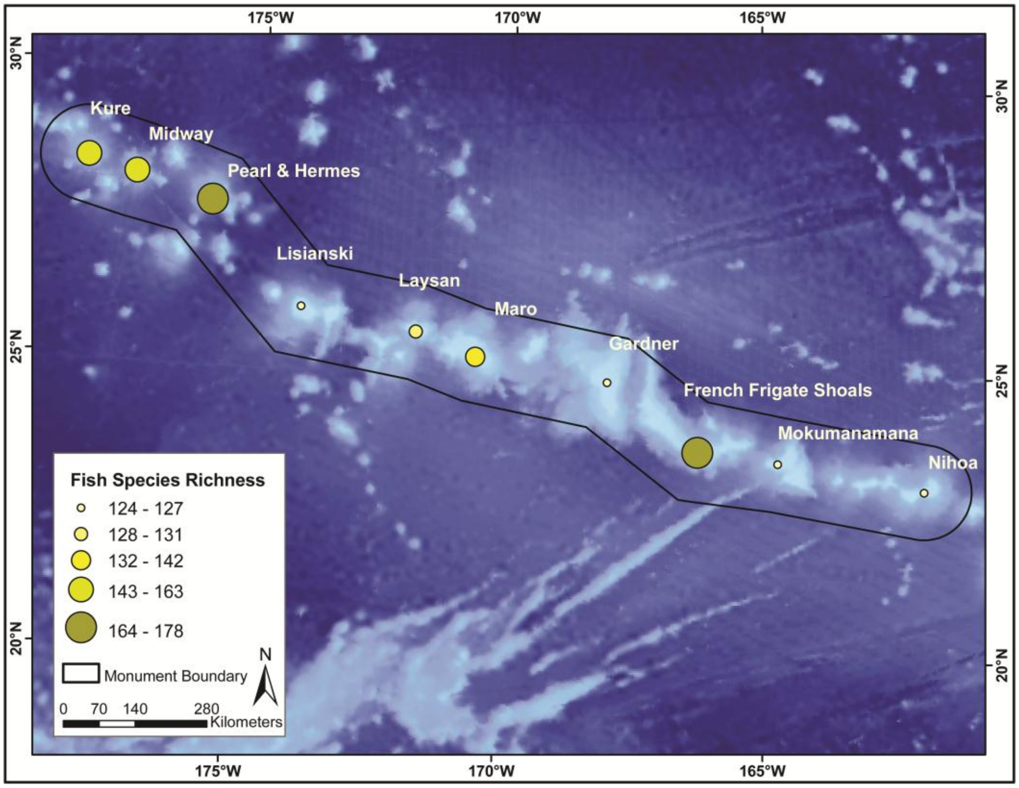


Figure 4-11 Total Fish Species Richness at the Ten Emergent NWHI Reefs (Friedlander et al., 2009b)

4.2.1.2 Coral

FFS has some of the highest richness of coral taxa in the NWHI. This could be due to FFS having optimal habitat and environmental conditions (wave shelter, temperature, and low anthropogenic disturbance). In the NWHI, a recent study revealed 57 species of zooxanthellate (or stony corals) (Maragos et al., 2009). Stony corals are of significance because they are the reef building corals that give the reef structure and integrity.

Wave exposure is a major determinant controlling the development of coral reef in Hawai‘i. Higher coral cover developing in sheltered bays and areas protected from direct swells, and moderate coral cover in areas exposed to winter waves are the trends in coral studies in the NWHI. The same is true for species richness: reefs with the highest richness of corals (including FFS) are protected, have shelter from the large north-west swell, and strongly correlate with the amount of reef within 10 fathoms; whereas, low species richness is found at the southern end among the small basalt islands that are openly exposed to severe wave events, particularly during the winter months. At the northern edge of the NWHI chain, fewer stony coral species are found. This species decline is linked to lower winter water temperatures and lower average solar radiation, as well as extensive sand in the shallow eastern sides of the lagoons.

The make-up and distribution of benthic communities in the subtropical NWHI are affected by numerous influences, including geographic isolation, latitude, exposure, and the successional age of the islands the communities inhabit. The benthic habitats in the NWHI are mainly coral-dominated areas, stretches of hard-bottomed (rock) algal-dominated meadows, and vast expanses of unconsolidated sediment (sand and mud) at depths greater than 20 meters. Information on benthic habitats at depths greater than 20 meters is largely unavailable and will not be discussed in detail here (Maragos, et al., 2009).

An examination of a spatial distribution of reefs in the Monument based on the presence or absence of coral species concluded that the coral assemblage at FFS appeared unique when compared with all other locations. Possible explanations are the high proportion of species belonging to the genus Acropora, and as detailed within, the possible connectivity with Johnston Atoll, a territory of the U.S. 478 nautical miles south and slightly west of FFS (Maragos, et al., 2009; Grigg et al., 1981; Maragos and Jokiel, 1986; UH, 2011).

The genus Acropora is almost completely absent in the MHI; however, seven species of the genus are known in the NWHI. Several newly discovered undescribed species of Acropora were photographed in FFS in 2006 (Maragos et al., 2009). The Census of Marine Life cruise to FFS in October 2006 saw rare species, including *Diaseris distorta, Cycloseris tenuis, Leptoseris scabra,* and *Acropora sp.1*. A rare species previously known only from a survey by Vaughan in 1907 in the MHI was reported for the first time off the southeast fore reef of FFS; an unidentified species, *Porites sp.15*, was documented off the northern reef crest (Maragos et al., 2009).

Diver-collected data categorized the benthos (or ocean bottom) into six categories based on the percent cover at a study site. Benthic cover distribution results from 2006 to 2010 are depicted in Figure 4-12 (NOAA, 2014h).

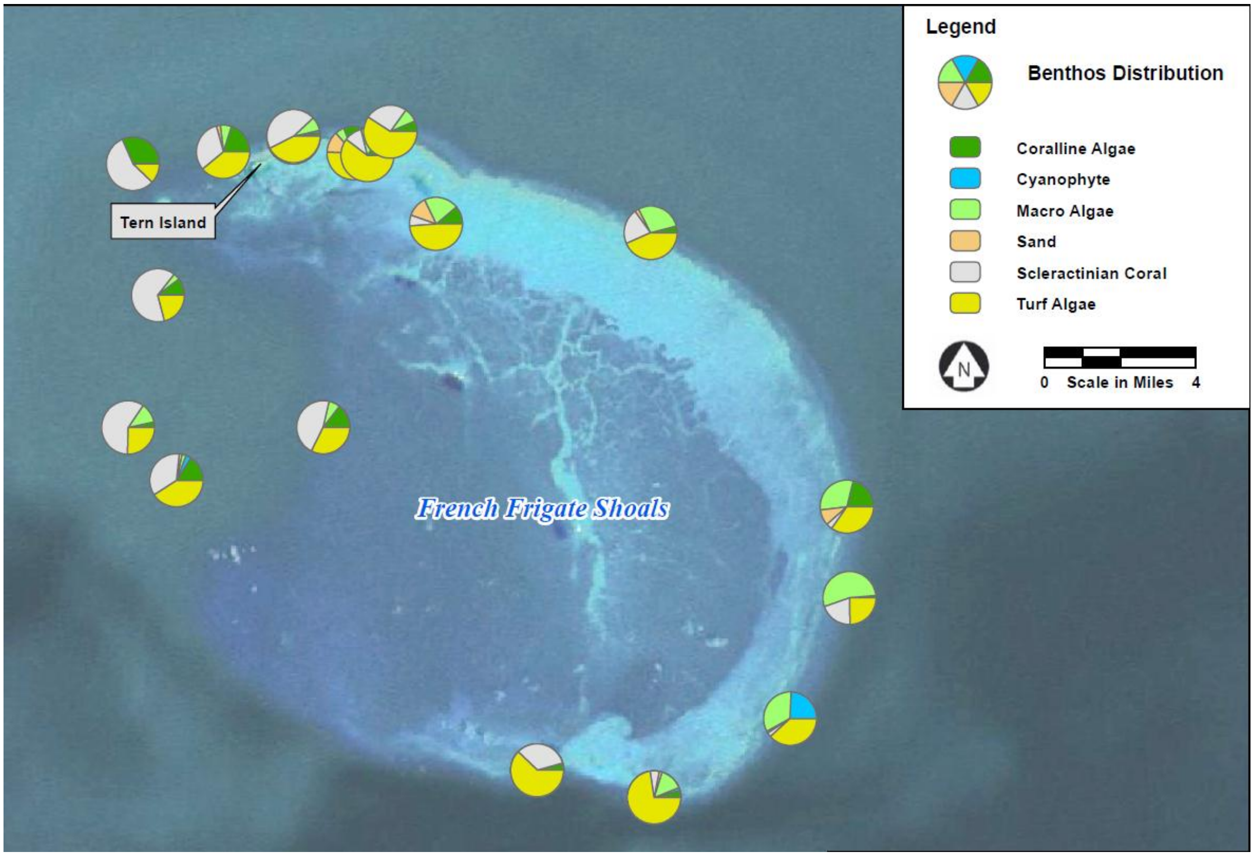


Figure 4-12 Benthos distribution from "as surveyed" form 2006 to 2010

FFS boasts the most diverse island or atoll for corals in Hawai'i. Experts (Grigg, Maragos et al.) suspect that because FFS is the closest atoll to Johnston Atoll, Johnston may be serving as a source for the dispersal of species to Hawai'i. This source theory would explain why FFS has many of the same Acropora species that are found at Johnston and why FFS has higher species richness compared to the other Hawaiian Islands.

FFS has 66 total stony coral species, 27 of which are endemic. FFS has the highest number of endemic corals in the NWHI (36 stony species, 15 of which are endemic) (Maragos et al., 2009).

In 2006, NOAA surveyed 64 sites in the NWHI for quantitative estimates of coral genera and species abundance in the shallow reefs. Relative abundance of corals was assessed by calculating the number of colonies by taxon that occurred within belt transects. The patterns observed in 2006 were indicative of all previous years of study. The results of the survey showed that relative abundance of corals varies among the regions, although *A. cytherea* is an important component of the coral fauna at FFS. Numerous taxa are represented throughout the NWHI at very low levels of abundance, and although there are 57 documented species of stony corals present, many species occur at such low frequencies that they were not encountered within the 64 surveyed transects. Porites, Pocillopora, and Montipora emerge as the dominant genera throughout the NWHI; however, their relative abundance varies by region (Maragos et al., 2009).

Following are the assemblage of coral fauna surveyed in 2006 by NOAA at FFS (Maragos et al., 2009).

Table 4-2 Percentages of Corals in the FFS Assemblage

cytherea 10.7%	*M. incrassata 0.1%*	*P. eydouxi 0.1%*
valida 5.1%	*Pavona duerdeni 2.5%*	*P. ligulata 0.4%*
humilis 0.3%	*Cyphastrea ocellina 7.6%*	*P. meandrina 8.1%*
Montipora capitata2.6%	*Leptastrea purpurea 1.0%*	*Porites brighami 1.1%*
M.patula 2.5%	*Pocillopora damicornis 6.9%*	*Porites lobata 32.2%,*
Porites compressa 15.9%	*Porites evermanni 1.5%,*	*Psammocora nierstrazi 0.1%*
Psammocora stellata 0.1%,	*Palythoa sp. 1.3%*	

The following corals were reported in the NWHI surveys at FFS during 1907 to 2006 as compiled from NOAA research data (Brainard et al., 2011).

Table 4-3 Corals Reported in FFS from 1907-2006

**Coral unidentified, sp.18*	*L. incrustans*	*P. eydouxi*
Acropora cerealis	**L. sp.22 cf. incrustans*	*P. sp.10 cf.laysanesis*
A. gemmifera	*L. mycetoseroides*	*P. ligulata*
A. humilis	**L. cf. papyracea sp19*	*P. meandrina*
A. nasuta	**L.cf.scabra sp17*	*P. molokensis*
A. paniculata	*Pavona duerdeni*	*P. sp.32 cf. verrucosa*
**A.sp.1 (prostrate)*	*P. maldivensis*	*P. sp.33 cf.zelli*
**A. sp.28 cf. retusa*	*P. varians*	**P. sp.11 cf. capitata*
A. valida	**Balanophyllia sp. (pink)*	**P. sp. 15 (paliform lobes)*
**A.sp.29 (table)*	*Cladopsammia eguchii*	*Porites brighami*
**A. sp.30 cf. palmerae*	*Tabastraea coccinea*	*P. compressa*
A.sp. 20 (neoplasia/tumor?)	*Cyphastrea ocellina*	**P. sp.23 (arthritic fingers)*
A.sp.26 cf. loripes	*Leptastrea agassizi*	*P. duerdeni*
Montipora capitata	*L. bewickensis*	*P. evermanni*
M. flabellate	*L. purpurea*	*P. hawaiiensis*
M. patula	*L. pruinosa*	*P. lobata*
**M. sp.4 cf. incrassate*	**L. sp.8 cf. F. hawaiiensis*	**P. sp.21 cf. lobata*
**M. sp.7 (foliaceous)*	**Cycloseris tenuis*	**P. sp. 16 cf. lutea*
M. tuberculosa	**C. vaughani*	**P. sp.27 (columns)*
**M. sp.24 (irregular)*	*Diaseris distorta*	**P. sp.13 cf. solida*
M. verrilli	*Fungia scutaria*	*Psammocora nierstraszi*
Leptoseris hawaiiensis	*Pocillopora damicornis*	*P. stellate*

*: The species is undescribed

Anthropogenic climate change has created a two-pronged global threat to reef-building corals: first, there is mass mortality due to increasingly frequent high temperature events, which cause coral bleaching; second, there are decreased calcification rates due to increasing atmospheric carbon dioxide, which causes ocean acidification.

Hoeke et al. studied the broad-scale probabilities of change in shallow-water stony (reef building) coral cover in the Hawaiian Archipelago for the years 2000 to 2009. They assumed in their calculations a moderate greenhouse gas emissions scenario. Projections were based on ensemble calculations of a growth and mortality model that used sea surface temperature, atmospheric carbon dioxide, observed coral growth rates, and observed mortality linked to mass coral bleaching episodes as inputs. Despite considerable uncertainties, the analysis quantitatively illustrated that a large decline in coral cover is highly likely in the 21st Century; however, there are significant temporal and spatial differences in the outcomes, even under a single climate change scenario (Hoeke et al., 2011).

4.2.1.3 Algae

Although NWHI represents one of the last relatively intact tropical reef ecosystems in the world, the macroalgal community dynamics of the 10 atolls, islands, and reefs situated in the NWHI remain poorly understood. A study published in conjunction with the Northwestern Hawaiian Islands' third Scientific Symposium (Vroom and Page, 2006) was the first to provide distributional maps of common algal species, statistically compare sites from differing habitats and islands based on relative abundance of macroalgae, and look for temporal differences in macroalgal populations. Findings revealed that the abundance of most macroalgal genera was low across the archipelago, but that members of certain green algal genera, including *Halimeda* and *Microdictyon*, can be extremely common and in some cases form dense monotypic meadows on the reef, especially in fore reef areas (*Microdictyon*) and lagoons (*Halimeda*).

Relative abundance of macroalgae across the NWHI chain as a whole remained relatively static for the years surveyed; however, slight changes occurred at Kure and Midway Atolls where coral bleaching events were documented in 2002 and 2004 (Maragos et al., 2009). At FFS, ten stations were sampled in 2006 with seven algal groups present. *Laurencia* was present at all stations and found, on average, in 77% of sample sites. *Halimeda* was present at 90% of the stations and found, on average, in 62% of the sample sites. *Jania* was present at half the stations and found, on average, in 9% of the sample sites (Maragos et al., 2009).

4.2.1.4 Invertebrates

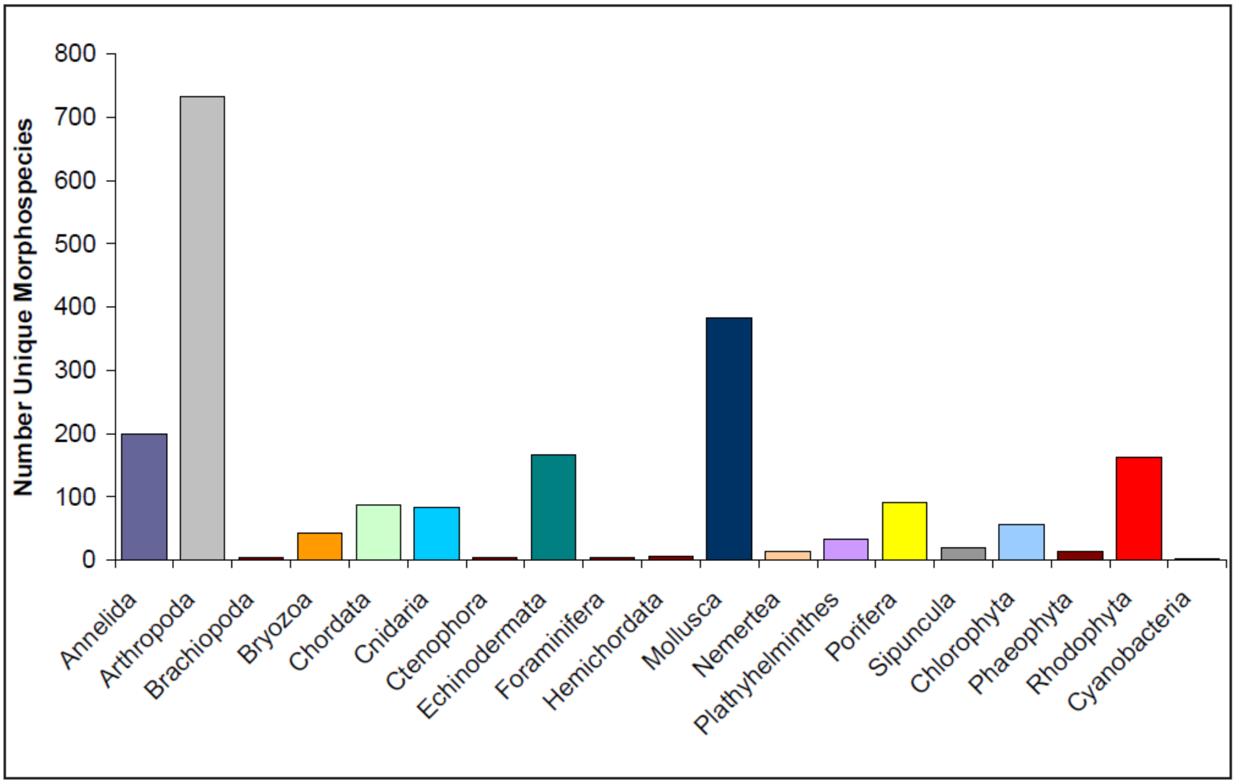
As part of the Census of Coral Reef Ecosystems (CReefs) effort, NOAA's Pacific Islands Fisheries Science Center Coral Reef Ecosystem Division led a multi-institutional team of international taxonomists on a 23-day research expedition in October 2006 to explore the biodiversity of small, understudied, or lesser known invertebrate, algal, and microbial species at FFS. In an effort to maximize the ability to document biodiversity, surveys were conducted at over 50 different sites representing 14 habitat types. Surveys used 12 diverse sampling methods (including baited traps, rubble brushing, rubble extraction, underwater vacuuming with gentle suction, plankton tows, light traps, and sediment and water sampling) specifically designed to minimize habitat impacts while maximizing the number of ecological niches sampled.

During the 3-week event, scientists documented more than 1,000 species at FFS. For comparison, this corresponds to around 20% of the Hawaiian marine invertebrate fauna documented over the past 200 years (Maragos et al., 2009). Collected species were photo-documented for future study. Many species had never been photographed fresh or alive and the survey represented the first documentation of their living color and appearance. DNA samples were also collected to facilitate DNA-based identification of Hawaiian and tropical Pacific invertebrates in the future. Preliminary results of taxonomic identification and molecular analysis suggest 2,300 unique invertebrate species were collected and photographed during the 16 days of sampling (Figure 4-13). From the expedition, well over a hundred new species were potentially identified for FFS. Sponges, corals, anemones, flatworms, segmented worms, hermit crabs, crabs, sea slugs, bivalves, gastropods, octopus, sea cucumbers, sea stars, and sea squirts were observed, of which an estimated 30 to 50 collected specimens are thought to be species new to science (Maragos, et al., 2009). The highest level of diversity at FFS was in the phyla Anthropoda and Mollusca. The highest diversity by habitat type was found at lagoon patch reefs, La Perouse Pinnacle (basalt), back reef, and deep fore reefs (Maragos et al., 2009).

A prime example of the diversity at FFS was the octopus species observed. Of the six specimens of octopus collected, three species may be new to science. Additionally, there were at least 25 species of sea cucumbers documented, three new species, and two new records for Hawaiian fauna.

Whereas this survey found that sponges have relatively high diversity, by contrast the survey found that bryozoans, eulimid gastropods, hermit crabs, echinoderms, ascidians, and other invertebrates had low diversity or were absent (absent species included corallimorph anemones, galatheid squat lobsters, porcellanid crabs, pea crabs, and coral barnacles). Approximately one third of all invertebrate morphospecies collected were either found only once or found only at one site (Maragos et al., 2009).

Recent efforts to quantify the non-coral invertebrate populations in the NWHI included two broad-scale towed-diver surveys conducted in 2004 and 2006 and a survey conducted in 2005. Surveys were focused on collecting information on three target classes of invertebrates: Echinoidea, Holothuroidea, and Asteroidea (sea urchins, sea cucumbers, and sea stars).



Source: Maragos et al., 2009.

Figure 4-13 Unique Invertebrate Species Collected at FFS

Surveys found densities of echinoids and holothuroids to be highest at the northernmost islands and atolls. Sea urchins were the most common invertebrate observed during these surveys, with the atolls of Kure (2004 and 2006) and Midway (2006) reporting the highest densities in the island chain. Sea cucumbers were present at all islands but in low densities, with the exception of the northern atolls. The highest sea cucumber density was recorded at Kure Atoll in 2006.

Data collected during surveys included species level information on the three target classes of invertebrates and followed the general patterns of the towed-diver data. The most common echinoid throughout the NWHI was the burrowing sea urchin, *Echinostrephus sp*., with the highest densities recorded at Midway and Kure Atolls (greater than 12 individuals per square meter). The most common sea cucumber was *Actinopyga obesa*. The most common sea-star was *Linckia multifora* (Maragos et al., 2009).

The CReefs effort included plankton and invertebrate surveys; microplastics (including the ingestion of microplastics) were not part of the survey. However, a study off the coast of Portugal did survey microplastics in zooplankton and identified 61% of the 152 samples as containing microplastics (Frias et al., 2014).

4.2.2 Terrestrial Community

4.2.2.1 Vegetation

The Tanager Expedition recorded the first vegetation survey of Tern Island in June 1923. Five species were recorded: thintail grass (*Lepturus repens*), Hawaiian goosefoot (a shrub) (*Chenopodium oahuense*), and three types of forbs (*Boerhavia repens, Portulaca lutea, and Tribulus cistoides*) (Amerson, 1971). The Navy's reconstruction of Tern Island, however, exterminated all plant life by 1943. The vegetation that was re-established on Tern Island after 1943 was washed away or severely damaged by the wave inundation in 1969 (FWS, 2002).

Today, Tern Island's plant community is composed of common native species and numerous alien species that have been intentionally and accidently introduced. Over the course of Tern's occupation, soil and plants were deliberately brought from Honolulu or were likely transported on equipment brought to the island. Currently the plant life is primarily concentrated around the manmade structures on either side of the compacted runway and more than half of the runway itself. This estimation was based on a visual assessment by FWS staff in 2014.

Tern Island represents approximately 98% of the vegetated land between Laysan Island and Nihoa Island, a distance of over 800 miles. It provides essential vegetated seabird nesting habitats (Reynolds et al., 2013). FWS conducted native species out-plantings in the 2013 field season and conducted numerous years of alien species eradication until it closed the field station in 2013. Table 4-4 documents the most recent vegetation survey conducted on Tern Island by FWS.

Prior to 1980 there were few birds nesting at Tern except the Sooty Tern, which is the island's namesake. This lack of nesting birds was likely because the runway and facilities left only 16 acres available for vegetation, and USCG actively dissuaded birds from nesting to decrease the likelihood of birds damaging aircraft. However, after the USCG turned the island over to FWS, nesting increased dramatically and since 2011 has increased 22% when FWS stopped utilizing the runway and promoted more seabird nesting sites. Nesting was promoted by building shelter boxes, planting native vegetation, and digging ruts adjacent to the runway to promote burrowing (Reynolds et al., 2013; FWS, 2013c).

FWS conducted a vegetation survey in 2002, and documented 18 species, none of which is endemic or endangered. Efforts by FWS led to the eradication of the sandbur (*Cenchrus echinatus*), an aggressive alien species that once was common on the island (FWS, 2002). Since the 2002 survey, the non-native ironwood trees (*Casuarina equisetifolia*), which USCG personnel planted, have also all died (FWS, 1999). United States Geologic Survey (USGS) estimates that allowing the runway to become vegetated would increase the vegetated area on Tern by 22% (Reynolds et al., 2013) (Figure 4-14).

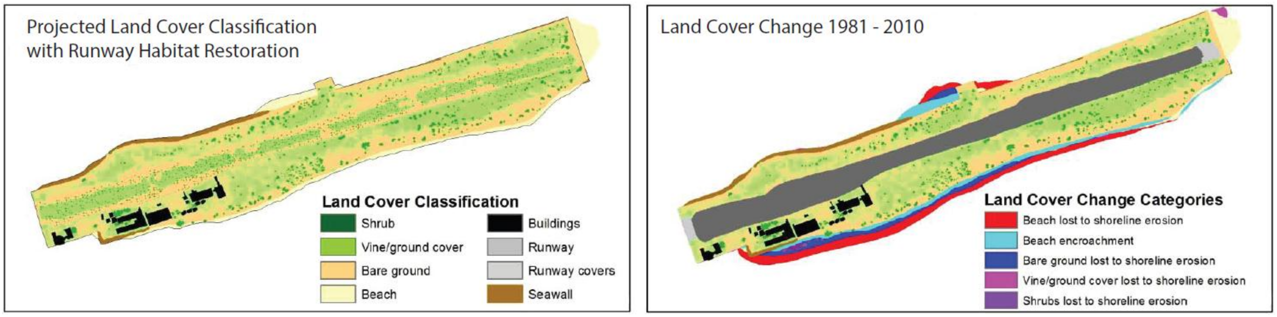


Figure 4-14 Tern Island Land Cover Classification

Notes: (a) land classification, 1981; (b) land cover classification, 2010; (c) land cover change 1981 to 2010; and (d) potential land cover if the runway were decommissioned and seabird nesting habitat created. (Reynolds et al., 2013)

Table 4-4 Common Plant Species in FFS in 2011

Common Name	Scientific Name
Alena	*Boerhavia repens*
Goosefoot	*Chenopodium oahuense*
Beach morning glory	*Ipomoea pes-caprae*
Pacific island thintail	*Lepturus repens*
Beach naupaka	*Scaevola sericea*
Nohu	*Tribulus cistoides*
Ironwood	*Casuarina equisetifolia*
Nettle-leafed goosefoot	*Chenopodium murale*
Coconut tree	*Cocus nucifera*
Indian goosegrass, wiregrass	*Eleusine indica*
Fourspike heliotrope	*Heliotropium procumbens*
Cheeseweed	*Malva parviflora*
Common purslane	*Protulaca oleracae*
Sow thistle	*Sonchus oleraceus*
Salt marsh sand spurry	*Spergularia marina*
Whorled dropseed	*Sporobolus pyramidatus*
Tree heliotrope	*Tournefortia argentea*

(FWS, 2011a)

4.2.2.2 Birds

The seabird population on Tern Island has been increasing since USCG returned management of the island to FWS in 1979. Historically, in order to keep the runway usable, an I-beam was dragged over the runway twice a month. When that practice ceased, the birds started immediately using the runway as habitat. In recent years, FWS has built bird boxes and made burrowing space along the runway to increase the area where birds could nest (Hartzell et al., 2012; FWS, 2013c).

Currently, FFS sees approximately 250,000 breeding seabird pairs annually and more than 500,000 seabirds total (FWS communications). The difference in the number of annual nesters and total nesters exists because not all seabirds nest annually, e.g. Albatross nest every other year. FWS has concluded that the seabird colony on Tern Island as a whole has reached carrying capacity under the current conditions (Hartzell et al., 2012) although some species could expand based on current vegetation conditions on the runway (Reynolds et al., 2013).

Competition for nest sites on islands where suitable land is limited can be intense. On Tern Island there is nearly year round nesting by at least one species of the 18 that inhabit the island. Hawaiian seabirds nest in three ways: above ground in vegetation, on the ground, or below ground such as in a burrow. For ground nesting birds, the preferences can be further divided into those that prefer shade or sun. Black-footed albatross generally prefer to nest on exposed windy beaches, whereas Laysan Albatross prefer to nest close to vegetation. Once a breeding pair has chosen a site, they return to it year after year. This tendency to nest in familiar physical surroundings is known as site fidelity. It is common among many seabirds, especially albatrosses. Gray-backed terns and masked boobies nest on the open ground. Tropicbirds, Christmas shearwaters, sooty terns, brown noddies, and blue-gray noddies nest on the ground but require shade. At Tern Island, Christmas shearwaters nest under shrubs. Great frigatebirds, red-footed boobies, black noddies, and white terns nest on vegetation above ground. Frigatebirds physiologically have difficulty taking off except from a perched position, necessitating a perching nest. Bonin and Tristram's storm petrels, and wedge-tailed shearwaters, having expended considerable effort in digging out their burrows, tend to return to them in following years. The opposite is true for great frigatebirds that invest little time or energy defending a prior territory and will nest almost anywhere the following year (Harrison, 1990).

Nesting activity on the Tern Island runway has increased since 2011 when the use of the runway stopped. Sooty terns, Black-footed albatross, Laysan albatross, Brown noddies, Gray-backed terns, Masked boobies, and red-footed boobies were observed to be nesting on the runway for an estimated total of 1,700 nests in May of 2014 (FWS, 2014b).

Shorebirds are birds that rely on beaches or wetlands for feeding and nesting habitat. They "probe" using their long beaks to poke into the sand for prey or "glean" by scurrying back and forth along the beach, feeding on invertebrates they find on the surface. Seabirds are birds whose normal habitat and food source is the marine environment, including coastal, offshore, or pelagic (ocean) (Sanctuary Integrated Monitoring Network, 2014).

Seabirds can be divided into four groups based on their feeding strategies, which are reflected in their anatomy, physiology, and habitat niche (Figure 4-15):

- Surface feeders feed by alighting on the surface to feed on plankton, fish, squid, or floating carrion (e.g., albatross).
- Plungers plunge to capture prey (e.g., boobies).
- Divers fly down in the water to depths of 10 to 20 meters to catch prey (e.g., shearwaters).
- Scavengers and pirates steal from other birds and force them to regurgitate or give up their food (e.g., frigatebirds).

Threats to seabirds on Tern Island include plastic ingestion, entanglement in marine debris, habitat loss due to erosion and global climate change, entrapment behind the aging sea wall, and chemical contamination such as from lead and PCBs. Due to the fact that seabirds feed over wide ranges and are an upper-trophic level predator, they act as early indicators of pollutants such as plastics in the marine environment. Surface feeding species that feed opportunistically are the most susceptible to ingesting floating marine debris, specifically the albatrosses (order Procellariiformes), and surface feeding species show a greater rate of plastic ingestion. In a 2005 study of plastic ingestion, 100% of the albatross examined contained plastic. A recent study on Tern Island by Hyrenbach et al. found that the Procellariiformes had a significantly higher propensity to consume plastics than seabirds from all other orders and all other feeding habits (Hyrenbach et al., 2014).

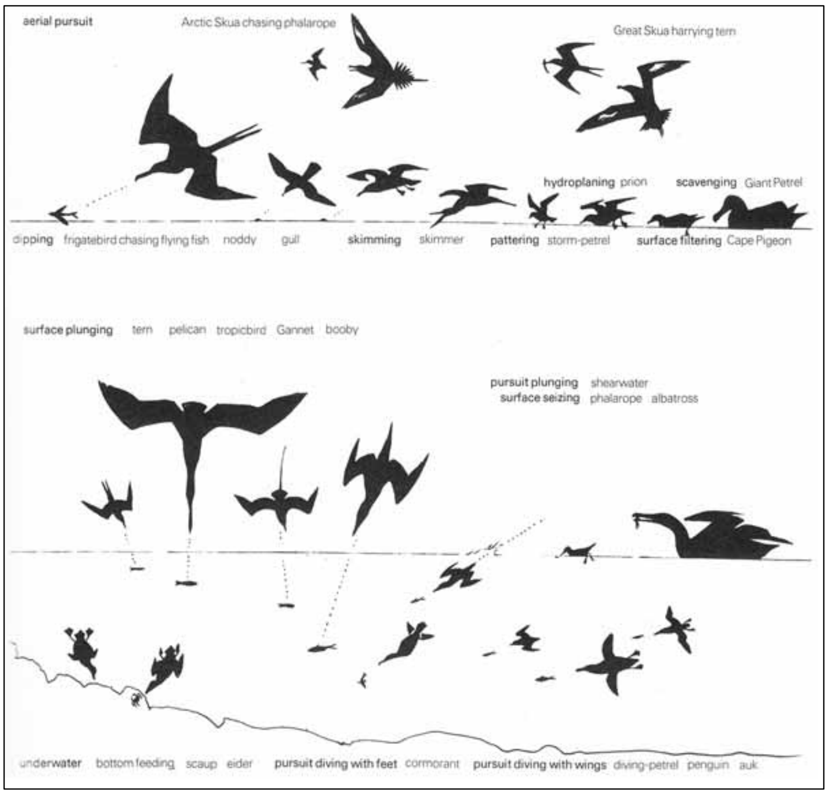


Figure 4-15 Seabird Feeding Strategies (Ashmole, 1971)

The threat to seabirds from plastic ingestion is growing. A 1995 study compared plastic ingestion in the 1970s and the 1980s and documented a higher prevalence and an increase in the number of breeding Alaska seabird species affected by plastic ingestion over time (Hyrenbach et al., 2009). The same trend is evident based on data collected in the NWHI. A study in 1986 and 1987 looking at plastic ingestion in 18 species of seabirds at seven study sites in the Hawaiian Islands and Johnston Atoll found that ingested plastic was absent or uncommon in terns and noddies, and no plastic was found in gray-backed terns or white terns (Sileo et al., 1990). Consistent with the trend of plastic ingestion observed in increasing numbers of Alaskan seabird species, recent studies by FWS have documented plastics in all 18 seabird species found nesting on Tern Island, including the gray-backed terns and white terns (FWS, 2013c). Plastic ingestion by seabirds has been studied at length on Tern Island and will be discussed in detail in Plastics in Seabirds, section 5.4 of this document.

Incidental ingestion of soil by foraging shorebirds was studied by Hui and Beyer, who found that soil can make up as much as 29% of the shorebird diet. The species studied were the Black-bellied Plover and the Willet (Hui and Beyer, 1998). Those species are not known to utilize Tern Island; however, the feeding strategy of the shorebirds that utilize Tern is the same.

During the 1990s, Whale/Skate Island eroded to the point where it was inundated, leaving Tern and East Islands as the most important breeding islands within FFS. Due to Tern Island's relative stability, mature vegetation, and size (approximately 30 acres), the island supports the largest proportion of the atoll's breeding seabirds (FWS, 2002).

Reynolds et al. studied sea level rise and how it would affect the seabird population at FFS. Results of that study suggest that even moderate amounts of sea level rise could have profound effects on the amount of nesting habitat available to seabirds at Tern Island. Specifically, the study projects 12% of FFS (excluding La Peruse Pinnacle) will be inundated with an increase of a one-meter sea level rise and 32% will be inundated with a two-meter sea level rise. Substantial losses in seabird nesting habitat across the low-lying NWHI by 2100 are predicted. Because the seabird colony on Tern Island is at carrying capacity and most of the seabird nesting habitat occurs at the periphery of the island, any sea level rise would be detrimental to the nesting habitat of birds and potentially lethal during storm surge events (Reynolds et al., 2013).

4.2.2.2.1 Nesting Species on Tern

Tern Island is overwintering habitat for a number of migratory shorebirds, including the Pacific Golden Plover (*Pluvialis fulva*), Ruddy Turnstone (*Arenaria interpres*), Sanderling (*Calidris alba*), Wandering Tattler (*Heteroscelus incanus)*, and the Bristle-thighed Curlew (*Numenius tahitensis*).

Vagrant refers to those birds that do not use Tern Island normally or as a migratory stop, but have been blown off course or come there by accident. Occasionally vagrants use Tern Island for short periods of time. These species have been sighted on Tern Island five or more times from 1923 to 2011: Northern Mockingbird (*Mimus polyglottos*), Semipalmated Plover (*Charadrius semipalmatus*), Gulls (all species combined), Short-eared Owl (*Asio flammeus*), Western Sandpiper (*Calidris mauri*), Northern Pintail (*Anas acuta*), Sharp-tailed Sandpiper (*Calidris acuminate*), Least/Little Tern (*Sternula antillarum/albifrons*), Cattle Egret (*Bubulcus ibis*), Black-bellied Plover (*Pluvialis squatarola*), White-tailed Tropicbird (*Phaethon lepturus*), Ruff (*Philomachus pugnax*), Pectoral Sandpiper (*Calidris melanotos*), Red-billed Tropicbird (*Phaethon aethereus*), and Dunlin (Calidris alpine) (Hartzell et al., 2012).

Although the Short-tailed Albatross (*Phoebastria albatrus*) is endangered (FWS, 2011b) and the Bristle-thighed Curlew (*Numenius tahitensis*) is a bird species of concern, neither routinely nests on Tern Island. Short-tailed Albatross rarely visit Tern Island, having been sighted there only four times in the last 25 years; however, they are endangered species under federal and state law, and the world's population is only 1,150 individuals (FWS, 2002). The first confirmed short-tailed chick was hatched in the NWHI at Midway Atoll in 2011 (FWS, 2011b). The Bristle-thighed Curlew is considered to be among the world's rarest shorebirds. Surveys at breeding grounds in Alaska estimate the breeding population to be 7,000 individuals. Bristle-thighed Curlews also do not nest on Tern Island; however, their wintering grounds include sandy atolls in the NWHI. The NWHI are an important wintering area for this species due to the lack of predators that could consume the birds during their vulnerable molting period. Monthly sightings of curlews have been documented on Tern Island by FWS biologists (FWS, 2002; Hartzell et al., 2012).

The Sooty Tern (*Sterna fuscata*) is the namesake of Tern Island. It is the most abundant breeding seabird in the central Pacific and within the NWHI. Sooty Terns have reestablished a colony on Tern Island after being forced out in 1943 during the Navy's reconstruction of the island, and again in 1952 with USCG's construction of the LORAN station (Harrison, 1990). Sooty Terns comprise approximately 75% of the total breeding seabird population on Tern Island (Table 4-5) (FWS, 2002). FFS is now home to approximately 6% of the world's black footed albatross, which is a species of conservation concern (a species that is declining or appears to be in need of concentrated conservation actions). FFS is also the long-term monitoring (greater than 10 years) site of 18 breeding seabird species. Storm petrels did not colonize Tern Island until 1993, but the island now has more than 200 breeding pairs of Bonin, Tristram's and Bulwer's storm petrels (Table 4-6) (Hartzell et al., 2012) Table 4-5 is a summary of the conservation status at FFS from an FWS report (Hartzell et al., 2012).

Figure 4-16 depicts the seabird species on Tern as of 2014 according to their feeding strategies. Both species of albatross typically feed at the surface and are shown in the red box, frigates are in the gold box and they differ because they employ piracy as well as surface feeding to capture prey, the suliformes are in the green box and they employ plunge diving, the birds considered to be "tuna birds" or birds that follow schools of tuna, are shown in the yellow box, the nocturnal petrels are in the purple box, and the neuston or surface-feeders are in the blue box.

4.2.2.2.2 Contamination Studies for Seabirds

Seabirds are a valuable biological indicator of human-related disturbances of marine food webs because they sample oceanic systems over large space and time scales. Albatross have been known to live more than 75 years and shearwaters more than 50 years (Audubon, undated). Thus seabirds can be a valuable ecological indicator of plastic pollution in coastal and pelagic waters.

During the 2012 accumulation and toxicity assessment of PCBs in black-footed albatross from Midway Atoll, UH and FWS collected samples from chicks (black-footed only) and eggs (Laysan and black-footed albatross) found on the atoll and tested them for individual PCB congeners. The goal of the study was to assess the profiles and toxicity of the individual PCB congeners at a natural equilibrium state in various tissues of the samples. Results of the study in the 1-month old chicks from Midway concluded that the major seven congeners, PCBs 99, 118, 138, 153, 170, 180, and 183, accounted for 36 to 78% of the total PCBs in the samples; also the total PCB concentrations in the bird samples were inversely related to the total body weight. In the 4- to 5-month old chick samples, the same seven congeners accounted for only 7 to 26% of the PCBs, with higher amounts of the less chlorinated congeners. The 1-month old chick's total toxic equivalents for all tissues sampled ranged from 130 to 11,000 picograms per gram (pg/g). The authors hypothesized that the high concentratitions in the younger age groups could be accounted for by the age and PCB accumulation of the female producing the egg (Caccamise et al., 2012).

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Table 4-5 Summary of Conservation Status by Species at FFS

Common Name	Scientific Name	Nesting Type	Status	Population
Black-Footed Albatross	*Phoebastria nigripes*	Ground Surface	IUCN near threatened, Bird of Conservation Concern.	Global Population ~60,000 breeding pairs (2005). 5,000 breeding pairs in FFS (2011), 4 to 8% global population
Laysan Albatross	*Phoebastria immutabilis*	Ground Surface 2	IUCN near threatened, Bird of Conservation	Global Population ~630,000 breeding pairs (2005). 3,000 breeding pairs in FFS (2011) <1% global population
Tristram's Storm Petrel	*Oceanodroma tristrami*	Burrow	IUCN near threatened, Bird of high concern.	Global Population Estimated <10,000 breeding pairs (2008). ~100 to 150 breeding pairs in FFS (2011) 1% of global population
Bonin petrel	*Pterodroma hyplodeuca*	Burrow	IUCN Bird of least concern.	Unknown global population, due to unknown status in Japan. 230,000 to 358,000 pairs in the Monument; 15 breeding pairs at FFS (2011)
Short-Tailed Albatross	*Phoebastria albatross*	Grassy steep slopes	Federally and State listed Endangered. IUCN vulnerable.	Global population estimated at 2,400 individuals in 2007. No nesting pairs in FFS
White Tern	*Gygis alba*	Shrubs or Trees	State listed threatened. NAWCP moderate concern. IUCN bird of least concern	Global Population estimated between 150,000 and 1 million. ~50-100 breeding pairs at FFS (2011)
Blue-Gray Noddy	*Procelsterna cerulean saxatilis*	Shrubs or Trees	NAWCP bird of high concern.	Unknown global population. An estimated 10-50 breeding pairs in FFS (2011).
Gray-Backed Tern	*Sterna lunata*	Ground Surface	NAWCP bird of moderate concern. IUCN bird of least concern.	Global Population ~70,000 breeding pairs. 250-500 breeding pairs in FFS (2011). Data suspected to be poor for global estimate.
Christmas Shearwater	*Puffinus nativitatis*	Under Vegetation	NAWCP Bird of high concern. IUCN bird of least concern	Global population ~9,000 (1997) with ~25 breeding pairs in FFS (2011) 3% of global population

Table 4-5 Summary of Conservation Status and General Trend by Species at FFS (Continued)

Common Name	Scientific Name	Nesting Type	Status	Population
Red-Tailed Tropicbird	*Phaethon rubricauda*	Under Vegetation	NAWCP bird of moderate concern. IUCN bird of least concern.	Global population 30,000-40,000 breeding pairs (2009) 400-600 breeding pairs at FFS (2011) 1% of global population

Notes:

IUCN: International Union for Conservation of Nature

NAWCP: North American Waterbird Conservation Plan

Source: Hartzell, 2012; Harrison, 1990; FWS, 2011b

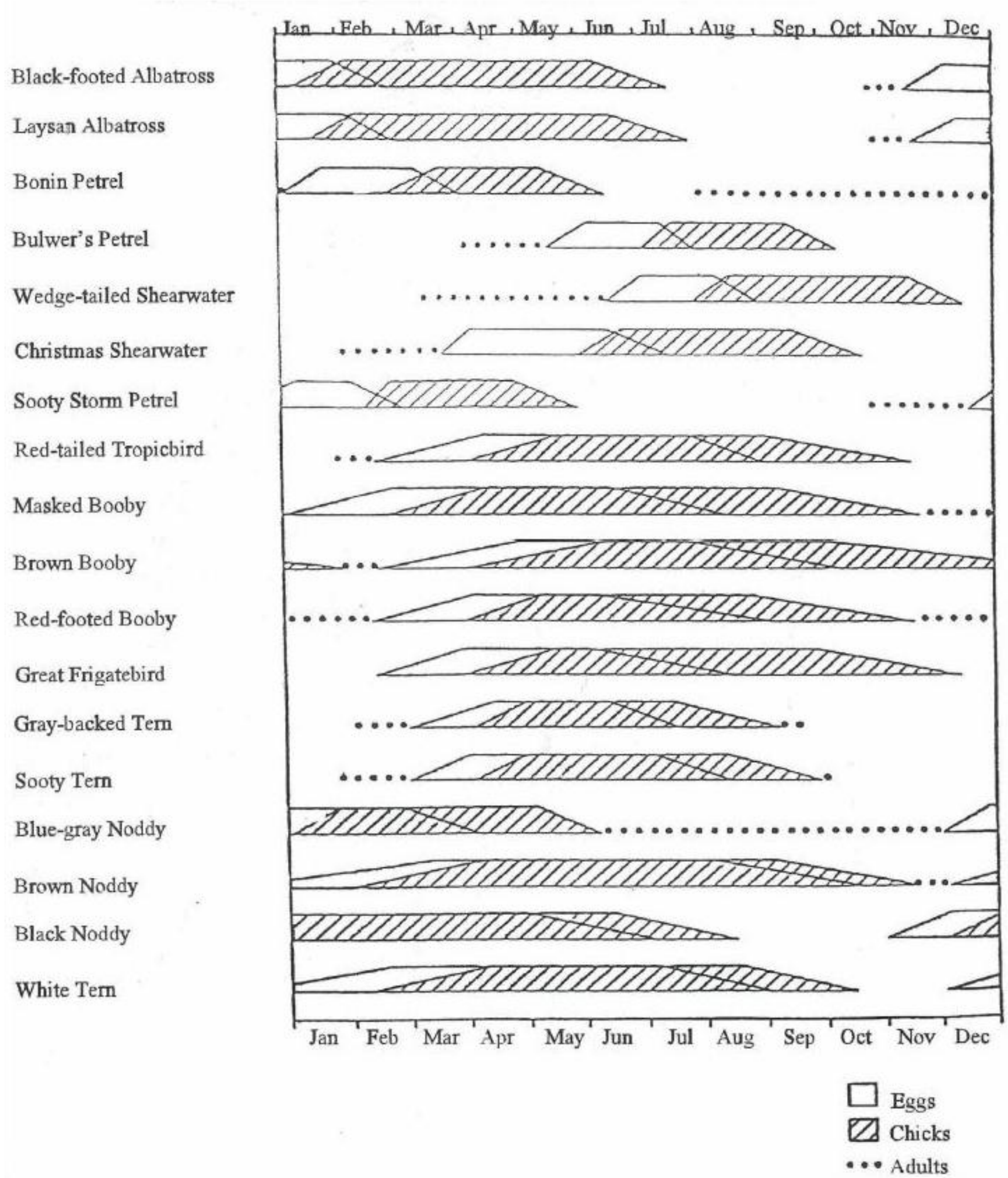
Table 4-6 Minimum Number of Breeding Pairs in 2011, Tern Island and FFS

Species	Total Breeding on Tern	Total Breeding in FFS
Black-Footed Albatross *Diomedea nigripes*	4,965	9,641
Blue-Gray Noddy *Procelsterna cerulea*	-	20
Black Noddy *Anous minutus*	21,255	21,735
Bonin Petrel *Pterodroma hypoleuca*	14	14
Brown Noddy *Anous stolidus*	20,607	21,519
Bulwer's Petrel	67	77
Christmas Shearwater *Puffinus nativitatis*	31	37
Gray-backed Tern *Sterna lunata*	254	265
Great Frigatebird *Fregata minor*	1,402	1,480
Laysan Albatross *Diomedea immutabilis*	1	1
Lesser Frigatebird *Frigata ariel*	1	1
Masked Booby *Sula dactylatra*	330	547
Red-Footed Booby *Sula sula*	2,805	2,848
Red-Tailed Tropicbird *Phaethon rubricauda*	353	389
Sooty Tern *Sterna fuscata*	184,354	184,354
Tristram's Storm Petrel *Oceanodroma tristrami*	199	370
White Tern *Gygis alba*	42	42
Wedge-tailed Shearwater *Puffinus pacificus*	3,493	3,493
Total	243,374	250,671

Source: Hartzell, 2012.

There is never a time of year when nesting birds are not present on Tern Island (Table 4-7). There are times of year when there are fewer nesting birds than at other times (FWS, 2002).

Table 4-7 Typical Seabird Nesting Seasons for the NWHI



Source: FWS, 2002

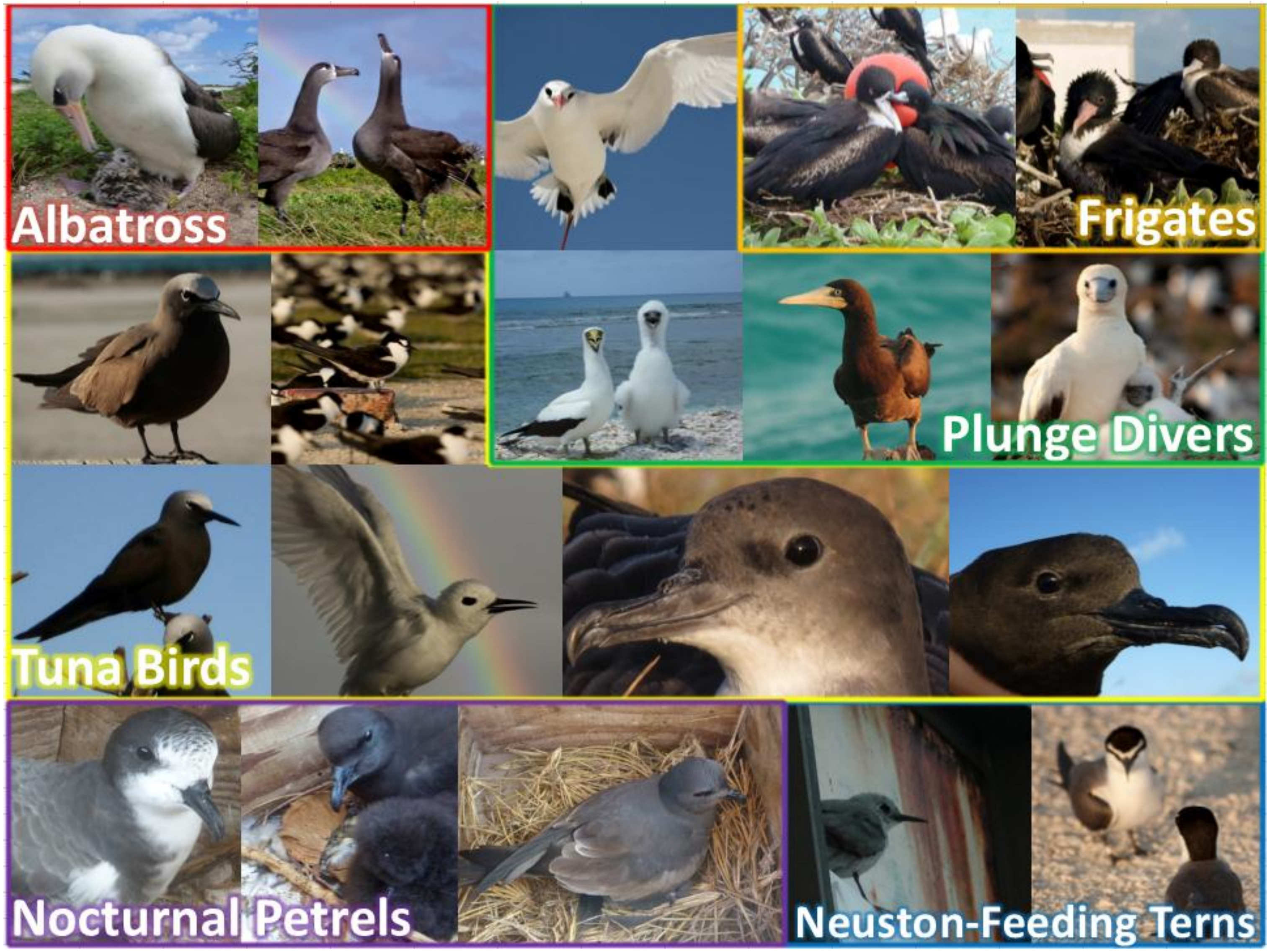


Figure 4-16 Tern Seabird Species by Feeding Guild

Source: Hyrenbach et al., 2014

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Seabirds have significant contaminant exposure through their diets, both from contaminated food in the food web and from ingesting contaminated plastics. In a preen gland oil study of 30 specimens over 13 species, Yamashita et al. (2014) found PCBs ranging from 43 to over 10,000 parts per billion (ppb) in streaked shearwater chicks.

Concentrations of PCBs and dichlorodiphenyltrichloroethane (DDT) were measured in the plasma of chicks and adults and in the eggs of Laysan and black-footed albatrosses from Midway Atoll and Tern Island. Significant differences in PCBs, DDT, and DDE in plasma were detected between species. Concentrations of dichlorodiphenyldichloroethylene (DDE) in the eggs of black-footed albatross were significantly higher than concentrations of DDE in the eggs of Laysan albatross. Similarly, concentrations of PCBs found in black-footed albatross (10 to 448 nanograms per milligram [ng/mg] PCBs) were much higher than concentrations found in the Laysan albatross (12 to 76 ng/mg PCBs). The difference in DDE and PCB concentrations between species may be attributed in part to different diet and feeding strategies (Auman et al., 1997). The Laysan diet consists primarily of squid (68%), the remainder consisting of 9% fish, 9% crustaceans, and 4% other (Awkerman, 2009). Black-footed albatrosses eat mainly flying fish and flying fish eggs (50%), with squid making up 32%, and scavenging human garbage the remainder (Awkerman, 2008).

New research by Lavers and Bond examined the toxic effects of trace metals caused by the ingestion of plastics in flesh-footed shearwaters (*Puffins cameipes*). The study found that the proportion of the shearwater population ingesting plastic increased from 79% in 2005 to 2007 to 90% in 2011. Between 6 and 22% of plastic pieces remained inside fledglings after their stomachs were sampled; therefore, the mass and frequency of plastic ingestion are considered underestimated. The study found body condition is negatively influenced by the amount of ingested plastic, and that the shearwater contaminant load is positively related to the amount of ingested plastic. The study went on to find that the flesh-footed shearwater had the highest percentage of their totally population found to ingest plastics, higher than any marine vertebrate (Lavers, Bond, Hutton, 2014).

4.2.3 Marine Protected Species

The Monument is habitat for many rare and protected species. The Monument is the critical habitat for the listed federally endangered Hawaiian monk seal (*Monachus schauinslandi*). Although marine mammals such as cetaceans, sea turtles, and pinnipeds use the resource, this section will focus mainly on the Hawaiian monk seal and Hawaiian green sea turtles because the other marine mammals that use FFS are not well documented. For the purpose of this TSD, marine mammal surveys of the NWHI will be discussed with the assumption that those animals use FFS.

4.2.3.1 Cetaceans

Twenty-four species of cetaceans have been sighted in the Hawaiian Islands Exclusive Economic Zone. During the 2002 NOAA marine mammal survey, 23 species of cetaceans were observed and identified to the species level (Barlow et al., 2004). Five of the 23 species are on the federal Endangered Species list: the humpback whale (*Megaptera novaeangliae*), false killer whale (*Pseudorca crassidens*), sperm whale (*Physter macrocephalus*), fin whale (*Balaenoptera physalus*), and sei whale (*Balaenoptera borealis*). All of the species mentioned have been observed within the Monument boundaries (Barlow et al., 2004).

The Papahānaumokuākea Associated Cetacean Ecology Survey took place from May 7 to June 5, 2013. The survey resulted in 88 ship-based visual sightings of at least 14 cetacean species. There is a potential that more than 14 species were observed, due to eight unidentified groups or individuals (e.g., unidentified small whale, unidentified medium dolphin). Researches acoustically detected 120 cetacean groups. The survey combined visual and acoustic survey methods. Several of the species stay in the NWHI year round (e.g., spinner dolphins, false killer whales) while others are only there seasonally, such as the humpback whale, which is known to migrate from Alaska to use the area for breeding. The following species were identified during the 2013 survey (NOAA, 2013c). The ~ symbol denotes a federally endangered species.

Table 4-8 Cetaceans in the NWHI

Spotted Dolphin (*Stenella attenuata*)	Striped dolphin (*Stenella coeruleoalba*)	Spinner dolphin (*Stenella longirostris*)	Rough-toothed dolphin (*Steno bredanensis*)	Bottlenose dolphin (*Tursiops truncates*)	~False killer whale (*Pseudorca crassidens*)	Pilot whale (*Globicephala macrorhynchus)*
~Killer whale (*Orcinus orca*)	~Sperm whale (*Physter macrocephalus*)	Dwarf sperm whale (*Kogia sima*)	Cuvier's beaked whale (*Ziphius cavirostris*)	~Humpback whale (*Megaptera novaeangliae*)	~Sei or Byrde's whale (*Baleanoptera borealis and Balaenoptera edeni*)	Unidentified Mesoplodon

During the 2013 cetacean study, the following species were visually identified in waters surrounding FFS: bottlenose dolphins, unidentified medium dolphins, pilot whales, spinner dolphins, and an unidentified beaked whale.

4.2.3.2 Hawaiian Monk Seal

The Hawaiian monk seal is part of the genus Monachus, which is a wide ranging pinniped found in several different geographic areas around the world. The genus includes the Mediterranean monk seal *(Monachus monachus*), the Caribbean monk seal (*Monachus tropicalis*), and the Hawaiian monk seal. The Mediterranean and the Hawaiian monk seal are endangered, and the Caribbean monk seal is presumed to be extinct within the last 50 years (Maragos, et al., 2009).

The commercial harvest of seals decimated the population of Hawaiian monk seals by the early 1900s. In 1976, the Hawaiian monk seal was classified as Endangered under the ESA (Baker et al., 2010). Despite a very aggressive management effort, the seal population has declined by an estimated 60% of what it was in the 1950s (NMFS, 2007). Their current population estimates are around 1,212 individual seals, the majority of which live in the NWHI (NOAA, 2012). Due to its rapidly declining and small population, the Hawaiian monk seal is the focus of extensive conservation efforts. The average rate of monk seal abundance during 2004-2013 was declining at a rate of 3.4% per year. The decline appeared to be slowing or ceasing from 2007 to 2011; however, an estimated 10% decline in total abundance was documented from 2012 to 2013. Estimates from 2012 and 2013 were likely low due to a lower than average field effort (NMFS. 2007; PIFSC, 2014).

In 2013, the number of pups born at the six main NWHI reached a record low for the second consecutive year since data collection began in the 1980s; the total (103 pups), is 8 pups fewer than were born in 2012 (111) (PIFSC, 2014). Poor juvenile survival has been the primary driver of the NWHI Hawaiian monk seal population decline.

Human disturbance at FFS caused by the Navy and USCG depressed the monk seal population. Following the departure of these agencies from FFS, the population increased dramatically into the late 1980's, and then subsequently dropped. In 1986, the mean count at FFS (excluding pups) was 284, approximately 6 to 8 times higher than it had been in the late 1950s. The total of mean non-pup beach counts in the NWHI subpopulations in 2010 was 71% lower than in 1958. The annual number of births dropped from a high of 127 in 1988, to at approximately 32 in 2013. Decreased survival rates of immature animals, including a decline in survival from birth to weaning, has been documented at FFS which, based on 2013 estimates, hosts the second largest monk seal sub-population. Survival from weaning to age 2 years also declined from almost 90% in the mid-1980s to as low as 8% in 1997. Current survival rates are approximately 50% for juveniles from weaning to 1 year and approximately 65% for juveniles from 1 to 2 years at FFS (PIFSC, 2014). This paucity of young seals means that the sub-population will decline further in coming years because there will be fewer new females reaching maturity (NMFS, 2007).

4.2.3.2.1 Foraging Habitat

Monk seals' primary habitat is the marine environment, where they spend approximately two-thirds of their time. The monk seal population is characterized as a metapopulation or as spatially subdivided, with semi-isolated subpopulations distributed along the chain (Antonelis, et al., 2006). In general, monk seal aquatic behaviors include thermoregulatory cooling, resting, playing, mating, and foraging (Antonelis et al., 2006).

FFS were established as Hawaiian monk seal critical habitat in 1988. Critical habitat refers to areas that contain habitat features that are essential for the survival and recovery of the species and may require special management considerations or protections. Current critical habitat for the Hawaiian monk seal includes all beach areas; sand spits; and islets, including all beach crest vegetation to its deepest extent inland; lagoon waters; inner reef waters; and ocean waters out to a depth of 20 fathoms (NOAA, undated).

Their range generally consists of the islands, banks, and corridors within the Monument, although individual animals may be found beyond this extensive area on occasion, sometimes farther than

50 nautical miles (92.6 kilometers) from shore (NOAA; FWS; HDLNR, 2008; Johanos et al., 2013) (Figure 4-17). Most foraging occurs near the sea floor, where they search for food on marine terraces of atolls. Hawaiian monk seal feeding has been observed in reef caves that may also be used for resting and refuge from predators (Stewart et al., 2006).

The diet of Hawaiian monk seals has been studied using cameras affixed to the animals and through examination of fecal and regurgitate samples. In the total number of prey recovered and identified in all samples during the fecal and scat studies, teleosts (ray-finned fishes) represented the largest component (78.6%), followed by cephalopods (15.7%) and crustaceans (5.7%). Overall, the teleost and cephalopod prey consumed by Hawaiian monk seals represent a mixture of diurnally and nocturnally active species. The seals were found to shift their diet ontogenetically: as juveniles, feeding on small, slow-moving species of teleosts and cephalopods; and as adults, gradually shifting to larger diurnal or nocturnal prey. These findings indicate that Hawaiian monk seals are opportunistic predators that feed on a wide variety of available prey (Goodman-Lowe, 1998; Parrish et al., 2005). Foraging data indicate that FFS seals feed on benthic and demersal fish species; therefore, their foraging is limited to relatively shallow areas of the (<600 m) archipelago (Parrish and Abernathy, 2006).

Foraging interactions between monk seals and large predatory fish such as reef sharks and jacks have been documented in the crittercam or seal-mounted video research. Rock-flipping is a method of feeding that monk seals use to catch prey and videos show jacks obtaining prey items flushed from cover by monk seals at FFS. The high density of predatory fish may impact the foraging success of monk seals at FFS (Parrish et al., 2008).

Lobster fishing off the banks of FFS (permitted until 2000 when it was banned) was thought to have decreased prey availability for monk seals (NMFS, 2007), however recent studies show only a small percentage of their diet is made up of crustaceans.

Decreased prey availability is thought to be a major factor contributing to the exceptionally high proportion of juvenile and subadult seals that were observed to be emaciated at FFS in 1991; it is also believed to be the major contributing factor to low fecundity at FFS. Pups and immature seals born at FFS in the early 1990s tended to be smaller than seals of the same age at Laysan Island, and smaller size at weaning was correlated with lower survival rate (NMFS, 2007). However, there have been no studies comparing the prey species on FFS to Laysan during this period. Early survival has generally improved slightly since 1999; however, survival rates of pups and juveniles continue to be well below their historic rates (NMFS, 2007).

New research suggests that climate variability may impact the monk seal demography. Periods of growth and decline in four NWHI subpopulations were associated with positive and negative PDO events with approximately a 2-year lag. Monk seal abundance trajectories corresponded to the climactic variability with potential for increased prey species during El Nino-like conditions (Baker et al., 2012).

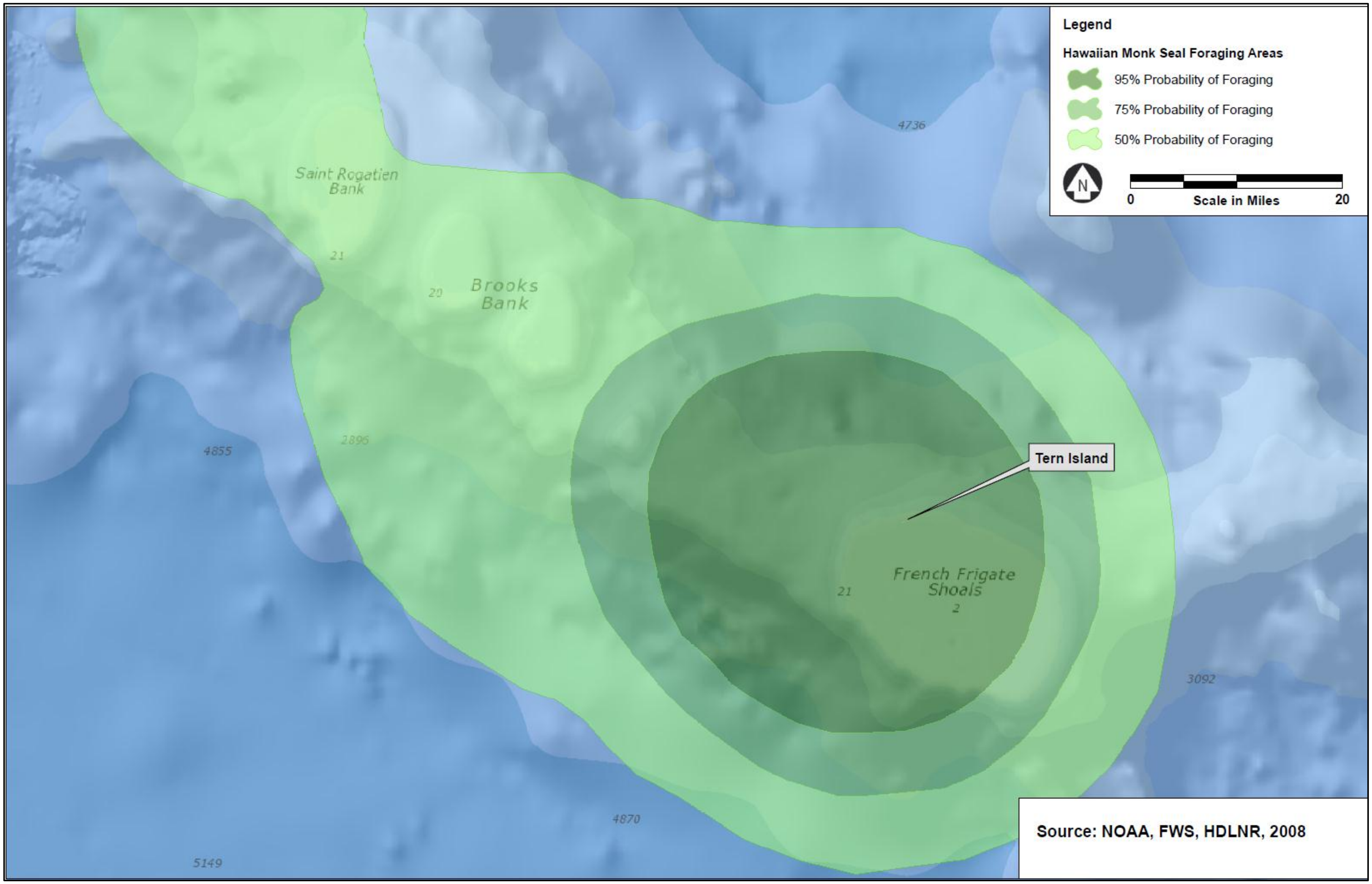

Figure 4-17 French Frigate Shoals Hawaiian Monk Seal Foraging Area

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4.2.3.2.2 Pupping Information

Reproductive success of the Hawaiian monk seal population has declined since the mid-20th century. FFS (including Tern Island) has the second-largest Hawaiian monk seal breeding site and breeding subpopulation, followed by Pearl and Hermes Atoll, and Lisianski Island (NOAA, 2012).

Pup production varies by island and year, but over the last 2 decades, approximately 200 Hawaiian monk seal pups have been born annually systemwide. Monk seal females usually give birth for the first time between the ages of 5 and 10. Subpopulations on FFS, Laysan and Lisianski reach sexual maturity at substantially different ages. Maturation occurs approximately 1 to 4 years earlier at Laysan than at the other two sites. In pinnipeds, the onset of sexual maturity usually coincides with the attainment of some percentage of final body size, suggesting that the observed delay at both FFS and Lisianski may be indicative of poorer nutritional conditions for immature seals at these sites (Antonelis et al., 2006).

An imbalance in the age/sex structure of some subpopulations is another aspect of monk seal demography that is a cause of concern. A succession of poor cohort survival at some sites (including at FFS) has led to a pronounced age structure imbalance in which young adult seals are severely underrepresented. At FFS, the low survival rate of young seals means that there will be few new females reaching reproductive maturity. Thus, the annual pup production is expected to drop, and the subpopulation will continue its downward trend (Antonelis et al., 2006; PIFSC, 2014).

4.2.3.2.3 Known and Suspected Stressors

Past and present sources of anthropogenic impacts to Hawaiian monk seals include hunting (during the 1800's and early 1900s), habitat disturbances (e.g., military operations beginning in WWII), entanglement in marine debris, fishing interactions (Antonelis et al., 2006), entrapment in structures with compromised integrity (e.g., corroding seawalls) (Figure 4-18), and intentional killings in the MHI (including a case in 2009 in which a pregnant female and fetus were shot) (Mooallem, 2013).

Poor juvenile survival rates and variability in the relationship between weaning size and survival suggest that prey availability is likely limiting recovery of the NWHI monk seals (Baker and Thompson, 2007; Baker 2008). In the NWHI, the abundance of predatory fish (jacks and sharks) and their interaction with monk seals during foraging activities has been documented to possibly decrease monk seal prey consumption by up to 30%. The competition for prey is higher in the NWHI where apex predators are abundant when compared to the MHI where those apex species are less frequently observed (Parrish et al., 2008).

From 1982 to 2003, 238 Hawaiian monk seal entanglements were documented in the NWHI, of which 162 were disentangled and freed, 61 escaped or freed themselves, 8 were found dead, and 7 met an unknown fate (NOAA, FWS, HDLNR, 2008). Due to the sheer size of the Monument there are likely undocumented entanglement and entrapment events; thus, this number presumably is low. Additionally, pups at FFS have a unique imminent threat of mortality due to a population of Galapagos sharks that preys on them (PIFSC, 2014). The corroded condition of the seawall surrounding Tern Island presents an entrapment and potential mortality hazard as does the presence of sink holes and anthropogenic debris.

Primary natural factors affecting monk seal recovery include predation by sharks, aggression by adult male monk seals, and reduction of habitat and prey associated with environmental change (Antonelis et al., 2006).

Recent trends indicate that food limitation may be a primary control in population growth. This is reinforced by indications of relatively poor body condition in various juvenile age seals. Other factors affecting monk seal recovery are infectious diseases, bio-toxins, and contaminants (Antonelis et al., 2006).

The main terrestrial habitat requirements include haul-out areas for pupping, nursing, molting, and resting. These are primarily sandy beaches, but virtually all substrates are used at various islands. The loss of this habitat is a priority issue of concern in the NWHI, especially habitat loss caused by environmental factors such as storms and sea level rise that could further exacerbate the problem. The only recent coastal construction has been the repair of the seawall protecting Tern Island's small runway and buildings and construction of a small boat ramp at FFS in 2004. This construction was needed to halt the erosion of the island and to eliminate the risk of injury and death to endangered Hawaiian monk seals (NOAA, FWS, HDLNR, 2008).

Figure 4-18 Hawaiian Monk Seal Trapped in Debris on Tern

The seawall around Tern Island is aging, badly corroded, and currently represents an entrapment hazard to monk seals. The Hawaiian monk seal recovery program began research at FFS in 1982. Entrapments were documented and entrapped seals were recovered, transported to the beach, and released. FWS assisted in the recovery program; however, FWS field station closed in 2012, resulting in a current inability to detect or respond to wildlife entrapments. NMFS sent a monk seal team to FFS in the summer of 2014 to continue monitoring the population. The future success of this effort is dependent on annual federal funding; thus, the long-term viability of a seal camp at Tern is uncertain. NMFS expects that the seal camp will be present on Tern for at least the upcoming two to three years. A total of 13 seals were observed in 14 entrapments during the years 2004 to 2013 (Table 4-9) (Johanos, 2014). All seals were subsequently captured, transported, and released onto the beach (Johanos, 2014).

Table 4-9 Monk Seal Entrapments in Artificial Structures at Tern Island, FFS 2004 though 2013

Date	Seal ID	Size	Sex	Structure	Outcome
2004 (n=4):					
8/02	YI13	Weaned pup	Female	Runway	Released
8/07	YI10	Weaned pup	Female	Runway	Released
9/16	YI32	Weaned pup	Female	Runway	Released
11/06	YI33	Weaned pup	Male	Runway	Released
2005 (n=2):					
7/17	YV02	Weaned pup	Male	Runway	Released
8/06	YV12	Weaned pup	Male	Tennis Court	Released
2006 (n=0):	-	-	-	-	-
2007 (n=0):	-	-	-	-	-
2008 (n=0):	-	-	-	-	-
2009 (n=3):					
7/25	YA08	Weaned pup	Female	Seawall	Released
7/29	YA02	Weaned pup	Male	Runway	Released
7/31	YA10	Weaned pup	Male	Runway	Released
2010 (n=0):	-	-	-	-	-
2011 (n=1):					
8/14	YW03	Subadult	Female	Seawall	Released
2012 (n=0):	-	-	-	-	-
2013 (n=4):					
8/09	Y08N	Weaned pup	Male	Seawall	Released
9/11	Y06N	Weaned pup	Male	Seawall	Released
9/11	Y08N	Weaned pup	Male	Seawall	Released
9/11	Y12N	Weaned pup	Female	Seawall	Released

4.2.3.2.4 Contamination Studies

During USCG control of Tern Island, an area on the north side of the island across from the barracks was used as a general dump and for burning garbage and trash. Waves, rust, and erosion slowly destroyed the northern seawall, and it was breached in late 1980, exposing the dump.

Wastes consisted of scrap metal, cable, wire, batteries, and electronic equipment such as capacitors and transformers containing PCBs and other contaminants.

This area was open to the lagoon and was washed by tides and storms (NOAA, FWS, HDLNR, 2008). The affected media included seawater, beach sand, sediment, and soil. The Hawaiian monk seals are potentially exposed to PCBs and other contaminants via direct contact, direct ingestion, and ingestion of prey items (USCG, 2000). Elevated PCB levels in sediment samples from Tern Island lend support to the presence of PCB sources on and around Tern Island (Miao et al., 2000a).

In order to assess contaminant levels in the Hawaiian monk seals, whole blood and blubber samples were collected in 1999 from 46 free-ranging Hawaiian monk seals at FFS and were analyzed for eight dioxin-like PCBs as well as six other PCB congeners, DDE, and DDT metabolites, and all types of organochlorines (OC). Organochlorines are defined as a class of compounds, including DDT and PCBs among others, that contain carbon, chlorine and hydrogen and do not break down easily, meaning that they persist in the environment and in the bodies of animals long after their use, (FWS definition). Average levels of the total PCBs in blood samples from Hawaiian monk seal adult male, juvenile and reproductive female groups were 4,800, 4,000, and 3,000 ng/g lipid weight, respectively. Average levels of total PCBs in blubber were 3,200, 1,300, and 1,200 ng/g, respectively (Willcox et al., 2004).

The various levels of OC concentrations may be influenced by diet, lipid content, and turnover, foraging behavior, sex, age, body mass, and body condition. OCs are lipophilic, meaning that they accumulate in fatty tissues such as blubber and milk (Lopez, 2012), and tend to accumulate in lipid-rich tissues of aquatic organisms. OC levels are influenced by biological factors such as age and lipid turnover caused by lactation and feeding status. The lack of statistical difference between male and female juveniles indicates that before sexual maturity there was no difference in PCB and DDT accumulation. There was also no significant difference in OC levels between the juveniles as a lumped group and the non-parous females. The levels of OCs were lower in adult females compared to juveniles or adult males, evidently owing to the transfer of these lipophilic compounds to pups by pregnant and lactating females (Ylitalo et al, 2008). PCBs are associated with reproductive disorders in seals (Willcox et al., 2004).

Ylitalo et al., analyzed 158 monk seals in the NWHIs for OCs in blubber and blood. The results of the study were similar to Willcox in that the PCBs and DDE concentrations in blubber generally increased with age until seals were sexually mature then continued to increase in age with males past puberty. Average levels of PCBs were significantly higher in adult male and juvenile males from Midway Atoll than the same age class at the other colonies studied.

There was a significant correlation between the body condition and the total PCBs in blood. High PCB levels correlated with low body fat or emaciation. It is possible that emaciated seals have higher lipid turnover than healthy seals. The seals from FFS were thin to emaciated and were in the physiologic state of gluconeogenesis, indicating that they were utilizing their stored energy reserves or never built up a blubber layer. Utilization of lipids also indicates a possible increase in circulating contaminants (as opposed to storing them in lipid tissues) (Willcox et al., 2004).

Although the concentrations of OCs measured in Hawaiian monk seals were generally equal to or lower than those reported for other pinniped species in the North Pacific Ocean, they were high enough in a few seals to potentially affect their health (Ylitalo et al., 2008). The toxicity data to evaluate the significance of tissue concentrations in marine mammals have only recently been developed and for only a small number of potential contaminants (USCG, 2000).

4.2.3.3 Sea Turtles Other than the Hawaiian Green Sea Turtle

Loggerhead, hawksbill, and leatherback turtles because utilize Monument waters as foraging, developmental or migratory habitats (Benson et al., 2011; Kobayashi et al., 2008; Van Houtan et al., 2012). Olive ridley turtles have never been observed or tracked within the Monument. The loggerhead, hawksbill, leatherback, and olive ridley turtles are all protected under the ESA.

4.2.3.4 Green Sea Turtle

Green turtles (*Chelonia mydas (L.*) are long-lived, slow growing, marine reptiles found throughout the tropical and subtropical oceans with distinctive genetic populations structured within oceanic basins (NMFS, FWS, 1998). Green turtles are listed as federally threatened under the ESA throughout its Pacific Range, except for the endangered population nesting on the Pacific coast of Mexico.

The Hawaiian green turtle population was subjected to extensive human exploitation from turtle and egg harvesting at foraging and nesting grounds, and nesting habitat destruction as a result of development and WWII impacts (Balazs and Chaloupka, 2004; Kittering et al., 2013). Since the enactment of state and federal ESA protections in 1974 and 1978, respectively, the Hawaiian green turtle population is demonstrating encouraging signs of population recovery as indicated by a steady long-term increase in the number of nesting females at FFS as well as increases in the number of green turtles residing in foraging pastures of the MHI (Balazs and Chaloupka, 2004; Balazs and Chaloupka, 2006; Chaloupka et al., 2008a).

Figure 4-19 Basking Hawaiian Green Turtles at FFS

The green turtle in Hawai‘i is a genetically distinct stock that occurs throughout the geographically disparate foraging ground populations within the 132 islands that make up the Hawaiian

Archipelago (Dutton et al., 2008). The stock is derived primarily from the nesting population at FFS (Figure 4-19) photo credit: FWS staff.

After hatching from a shell buried in sand, newborn sea turtles have to dig out of the pit in which their mother laid them and race to the ocean as fast as physically possible to escape the predator-rich shore. After this emergence event, little is known about their existence until they return years later to coastal waters as larger juveniles. This period is known as the “lost years” (Mansfield et al., 2014). Historically, the long-term tracking of small, fast-growing turtles in the open ocean during their ‘lost years’ was logistically or technically impossible. However, new research on neonate loggerhead sea turtles published in the Proceedings of the Royal Society of Biological Sciences shed some light into those lost years. Satellite-tagged loggerheads (sized 11 to 18 cm straight carapace length, and age 3.5 to 9 months old) chose a habitat of floating mats of sargassum, a species of seaweed, to remain offshore in oceanic waters away from the dangers of predator-rich Continental Shelf waters. The mats of sargassum drift passively with ocean currents and attract other small sea creatures. Not only does the sargassum provide food and concealment from predators, it also acts as a thermoregulatory tool to support survival. Temperatures relayed from the satellite transmitters showed that the sargassum mats were an average of 4 to 6°C warmer than the surrounding sea surface temperatures, a situation that serves to promote food consumption and body growth. In a broader evolutionary context, it makes sense that the species would want to grow as large as possible as fast as possible to reduce the assemblage of predators capable of consuming them (Mansfield et al., 2014). Whereas the Mansfield study cannot be directly correlated to green turtles, it does provide a hypothesis of how they may spend their lost years.

After green turtles reach a straight carapace length of approximately 35 cm, the juveniles recruit to neritic or near shore habitat, where they will spend the remainder of their life growing into a sub-adult and to adulthood. At the point of neritic recruitment, the green turtle shifts from an omnivorous diet to an herbivorous one. Upon reaching sexual maturity, which occurs anywhere between 20 to 50 years, males and females congregate at the breeding grounds. Females will lay eggs every 2 to 3 years; however, males may mate every year with females off shore. Female green turtles in Hawai‘i have been tagged with satellite tags and have traveled as far as 800 miles one way to their nesting beaches at FFS from foraging habitats in the MHI (Rice and Balazs, 2008). Nesting female turtles return to the same beach where they were hatched, also called a natal beach (Meylan et al., 1990). Gestation is 7 to 10 weeks, after which time females will pull themselves up the beach onto dry sand and use their flippers to excavate a pit in which to lay their clutch (or nest), consisting of 100 to 120 eggs. Hawaiian green turtle females will lay an average of four nests per breeding season (Tiwari et al., 2010). After depositing the eggs, the female will cover them with sand and return to the ocean. Hatching typically occurs at night after approximately 60 days of incubation. The temperature of the sand during incubation, and therefore the temperature of the eggs, influences the sex of the hatchlings (NMFS, FWS, 1998).

Green turtles were first recorded at FFS by personnel aboard the *Fenimore Cooper* in 1859. The Japanese-owned schooner *Ada,* reported the collection of approximately 350 turtles for shells and turtle oil from FFS (Amerson, 1971). Subsequent reports in 1914 and 1923 document observation of green turtles and turtle eggs at FFS as well as reported turtle slaughter at FFS (Amerson, 1971). Amerson summarized observations of basking and nest attempts of green turtles in the *Atoll Research Bulletin* spanning 1859 through 1969.

Green sea turtles are the only species of marine turtle to exhibit basking behavior when not nesting. DOI, NOAA, and the Smithsonian Institute reported basking behavior from the 1920s through the late 1960s at FFS, including Tern, Trig, Whale/Skate, Round, East, Gin, Little Gin and Disappearing Islands. The highest number of turtles basking during that time period occurred on East Island (86 turtles) in 1966. Basking also occurs throughout the Hawaiian Archipelago (NOAA, 2014d; Balazs and Parker 2011).

Data have been collected on the number of basking green sea turtles on all islands of FFS during the nesting season annually from 1973 through 2012 (Spring, 2013). During a turtle survey in May 2014 193 basking sea turtles were counted on Tern Island (FWS, 2014b).

4.2.3.4.1 Foraging Habitat

Understanding the foraging habits and habitats of threatened species is integral to their conservation because diet is intimately linked with growth rate, maturity, and reproductive output. Understanding foraging habitat use can provide valuable information on population and threats to survival. Immature green turtles appear at inshore foraging habitats when their straight carapace length is approximately 35 cm and weight is 6 kg. At this point in their development, their diet shifts from the omnivorous planktivory of an immature pelagic turtle to that of the herbivorous inshore mature turtle. The inshore feeding habits of Hawaiian green turtles show high site fidelity and foraging ground-specific growth rates (Arthur and Balazs, 2008). Because the turtles in Hawai‘i are all from the same genetic stock, it is likely that the availability or quality of food at each foraging ground explains the differences in growth rate (Balazs and Chaloupka, 2004).

Green turtles spend most of their time feeding or resting underwater, although they do haul out and rest on beaches as well (basking). Foraging behavior of green turtles in Hawai‘i is characterized by numerous short dives in shallow water (less than 3 m) with short surface intervals (less than 5 seconds). Resting periods are characterized by longer dives (greater than 20 minutes) in deeper water (Rice et al., 1998).

Diet is related to growth rate and the time it takes for turtles to reach maturity. Diet quality or food availability, as controlled by environmental conditions, has been correlated with variability in nesting in the years leading up to breeding (Arthur and Balazs, 2008).

The diet of a post-pelagic green turtle consists predominately of seagrass, macroalgae, and often small amounts of animal material. Turtles have displayed some level of selectivity; however, items found in their diet are primarily associated with the local availability. Dietary studies of green turtles in algal-dominant systems indicate that turtles feed predominantly on *Rhodophyta* or red algae, although *Chlorophyta* and *Phaeophyta*, green and brown algae, respectively, are also consumed. A study conducted in Australia on an algal-based coral reef community, (Forbes, 1996) discovered that green turtles preferred certain species and avoided others. Preferred species included *Gelidiella sp.* and *Sargassum sp.*, whereas *Halimeda sp.* and *Chlorodesmis sp.* were avoided. In a study of the Hawaiian Islands in an algal-based coral reef system, the green turtles fed on seagrass and algae. The majority of the green turtle diet consisted of only nine of the total 400 species of algae present in the Hawaiian Archipelago, red algae, such as *Acanthophora specifera,* was the most prevalent (Arthur and Balazs, 2008).

Juvenile turtles at Midway Atoll have been observed feeding on a number of algae species found there. Juvenile turtles regularly fed on algae such as *Spyridia filamentosa* and *Centroceras clavulatum*. The seagrass *Halophila hawaiiana* is regularly a source of forage. Reports of foraging on *Codium cuneatum* by subadults were made during a 25-year study period (Arthur and Balazs, 2008). Recent research in the Rio de la Plata region showed juvenile green turtles are exposed to high concentrations of plastic debris in their foraging habitat, and when exposure occurred a high frequency of plastic ingestion was correlated. The same oceanic processes that cause prey species to converge in fronts likely include plastic debris (Carman et al., 2014).

4.2.3.4.2 Nesting Information

More than 95% of green turtle nesting occurs at FFS, with over 50% of nesting occurring on East Island (Kittering et al., 2013). Tagging studies have shown that nesting-island site fidelity is very high within the Hawaiian rookery. Balazs and Chaloupka found that the number of green turtles nesting at East Island varied from under 100 to more than 500 nesting female turtles each year from 1973 to 2004 (Figure 4-20), with nesting trends increasing annually at approximately 5.7% per year (Balazs and Chaloupka, 2006). More recently, between 400 and 500 females nest annually at East Island (Figure 4-20). The increase in the nesting population may be attributed, in part, to protections afforded since listing the species as threatened under the ESA in 1978, which prohibited the harvest of turtles and their eggs. Additionally, human impacts on the nesting turtles and their nesting habitat were reduced dramatically on Tern and East Islands when the U.S. Navy and USCG ceased their respective operations (NOAA, FWS, HDLNR, 2008). Despite the increasing nesting trend at the East Island index nesting beach, 80% of historical nesting populations that once occurred throughout the Hawaiian Archipelago have been extirpated, or heavily reduced compared with current estimates. Today more than 90% of green turtle nesting in Hawai‘i occurs at a single site, FFS (Kittering et al., 2013), which is vulnerable to sea level rise (Baker et al., 2006).

Monitoring nesting activity is the easiest and likely best way to assess sea turtle population nesting trends, but surveys with less than 10 years of data are inadequate because turtles are thought to have a life span of 60 years or more and females can skip several nesting seasons due to nutritional constraints (Bjorndal, 1997; NOAA, 2014d). Thus, long-term data sets are needed for population nesting trend estimates that are useful in understanding population status. FWS and NOAA have collected decades of data for green turtles nesting at East Island, FFS spanning 1973 to 2012 (Balazs and Chaloupka, 2004; Spring, 2013).

In December 2012, a microburst storm damaged barracks on the permanent field station at Tern Island and FWS decided to close the permanent field station in 2013. Therefore, 2013 was the first year in 40 years that nesting surveys were not conducted on East Island (Spring, 2013).

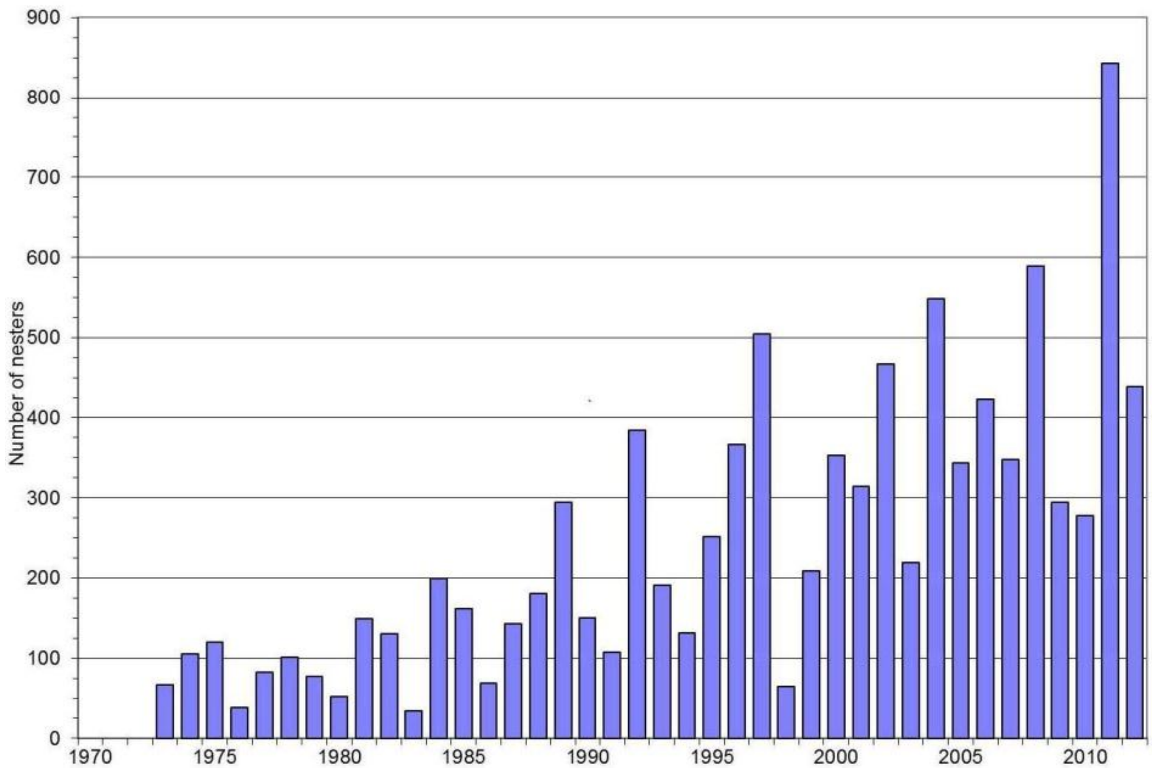

Figure 4-20 Estimated Number of Nesting Green Turtles on East Island, FFS, 1973-2012 (adapted from Spring, 2013)

4.2.3.4.3 Known and Suspected Stressors

Large species of sharks such as the Galapagos shark (*Carcharhinus galapagensis*) and the tiger shark (*Galeocerdo cuvier*) are well-known natural predators to Hawaiian green sea turtles. Dale et al. (2010) studied the top reef predators in the shallow waters of the Monument and concluded that large sharks are a significant source of predation on the Hawaiian green sea turtle in the Monument, especially due to the prominent nesting beaches in FFS (Dale et al., 2010).

The principal cause of historical decline of the green turtle in Hawai‘i has been the long-term over-harvest of turtles and eggs. Harvesting is currently prohibited under the ESA and is no longer considered a significant threat to turtles in Hawai‘i. Current anthropogenic threats to green turtles include human disturbance, disease (e.g., fibropapillomatosis), habitat loss and degradation, and incidental capture or entanglement in fishing gear. Turtles can become entangled in gillnets, hook-and-line, and trap/pot fishing gear. Turtles interacting with these types of fishing gear may drown or suffer serious injury from flipper amputation by lines or ropes. In addition to entangling turtles, longline gear can hook turtles in the face, esophagus, or flippers (NOAA, 2014d). NMFS works to minimize the number of turtle interactions in the Hawai‘i-based shallow-set and deep-set longline fisheries. Green turtles rarely interact with longline fishing gear because longline gear is typically set in locations of pelagic waters which sub-adult and adult turtles don’t normally inhabit; leatherback and loggerhead turtles have the highest likelihood of being caught in these fisheries (NMFS, 2012).

Marine debris is a worldwide problem for turtles. During the juvenile pelagic period of development, turtles may ingest or become entangled in marine debris. The debris could be anything from tar balls, plastic bags, and plastic pellets to balloons and ghost fishing gear that the juvenile turtles encounter while feeding or migrating (NOAA, 2014d).

Habitat degradation from coastal runoff, construction, dredging, aquaculture, underwater noise, and boat traffic can negatively impact turtles and nearshore habitats. Fuel, oil, and sewage spills into areas frequented by turtles are another known stressor. Turtles swimming or feeding near heavy boat and vessel traffic are at risk of vessel strikes, which can result in serious propeller injuries and turtle morality (NOAA, 2014d).

A worldwide threat to green turtles is fibropapillomatosis (FP), which is a pandemic tumor-forming disease commonly associated with the herpes virus (Jacobson et al., 1991, Quackenbush et al., 1998; Herbst et al., 1999). A debilitating disease that causes multiple connective tissue tumors on or in the eyes, mouth, nasal passages, skin, carapace, plastron, and visceral organs. In Hawai‘i, the prevalence of FP increased in the 1970s peaking in the 1990s (Chaloupka et al., 2009). Most locations where FP is studied in Hawai‘i have seen a recent decline in FP (Van Houtan et al., 2010).

Following recruitment from the pelagic (oceanic) habitat to neritic (shallow marine) habitats throughout the Hawaiian Archipelago, juvenile turtles may contract the disease (Balazs, 1991; Balazs et al., 1998, 2000; Murakawa et al., 2000). The disease is often considered to be the primary cause of mortality for many green turtles that strand in the Hawaiian Archipelago (Aguirre, 1998; Chaloupka et al., 2008b). FP is most prevalent among immature green turtles that reside in coastal habitats around the southeastern part of the island chain. Although there are no reliable estimates of depressed reproductive rates or mortality resulting from the disease for any sea turtle population, growth rates are significantly affected for turtles with advanced FP (Chaloupka and Balazs, 2005). Whereas the disease appears to have regressed over time in Hawai‘i (Chaloupka et al., 2009), it persists in the population and its occurrence shows spatial variability (Van Houtan et al., 2010). Van Houtan et al. (2010) theorize a connection between FP and the State’s land use, waste-water management practices, and invasive macroalgae, suggesting a tight correlation exists between invasive algae and proliferation of FP (Van Houtan et al., 2010). It was hypothesized for decades that environmental pollutants may contribute to FP; however, recent research by Keller et al. found that POPs are not a major cofactor in causing the onset of FP (Keller et. al., 2014).

Climate change may have a significant influence on marine turtle populations. As a species that is closely tied to temperature regimes, a changing climate may skew sex ratios (Fuentes et al., 2009; Pike, 2013) or change the timing of breeding and nesting (Chaloupka et al., 2008a; Van Houtan, 2010). Additionally, although island systems have dynamic geomorphology, they have a potentially greater risk of nesting beach loss due to rising sea levels, including at FFS (Baker et al., 2006). Therefore climatic changes may inter-react with other population impacts to further exacerbate population threats.

Current Threats at FFS

Favorable nesting habitat is critical for sea turtle reproduction and is central to the survival of sea turtle populations. The protection and restoration of terrestrial habitats is high priority as per the U.S. Green Turtle Recovery Plan (NMFS and FWS, 1998). The anthropogenic induced threats at FFS must be mitigated and addressed to ensure continued recovery of federally threatened green turtles in Hawai‘i that utilize FFS habitats for basking and nesting. Unique threats to green turtles at FFS include entanglement hazards from debris, entrapment behind the eroding sea wall at Tern Island (increased mortality of trapped turtles) and loss of nesting habitat due to beach erosion coupled with sea level rise, . Natural predation by seabirds, crabs, fish or sharks also occurs. Hatchlings are often found disoriented and wandering along the runway in their attempt to reach the ocean; during times where NOAA or FWS have camps on Tern Island, biologists collect and release hatchlings daily.

Large black PVC pipes that are located along the shoreline currently pose a threat to hatchlings. While adult females can crawl over the large pipes to lay a clutch, the hatchlingsare unable to crawl back over the pipes and becoming trapped as they attempt to travel to the ocean (Spring, 2013). The pipes are scheduled to be removed during the 2014 NMFS monk seal field season.Once all of the PVC pipes are removed from the shoreline, they will no longer pose a threat to sea turtles.

4.2.3.4.4 Contamination Studies

Industrial pollutants are known to be widely distributed in global ecosystems from both terrestrial sources and from aerial deposition (Thompson et al., 1974). Marine turtles are susceptible to waterborne chemical contamination because they spend the majority of their life in the ocean.

PCBs in green turtle eggs were first studied in 1974 where 10 eggs from Ascension Island were analyzed (Thompson, et al., 1974). Results of that study found multiple PCBs, dichlorodiphenyldichloroethane (DDD), DDE, and DDT present in the eggs. The average concentrations of total PCBs were 45 to 58 nanograms per gram (ng/g) dry weight and 73 to 665 ng/g in the liver and adipose tissues, respectively (Thompson et al., 1974).

PCBs have been studied in turtles from Hawai‘i, especially in regard to their role in the etiology of FP. In current work, Keller et al. (2014) collected samples from 12 Hawaiian green sea turtles with FP varying from no tumors to heavily tumored. Turtle blood from 53 individuals was screened for 164 POPs, including PCBs and OC pesticides. Preliminary results did not show a correlation between contaminant concentration and tumor growth. Research has not supported the hypothesis that PCBs are the cause of FP (Keller et al., 2014).

The level of POPs in the Hawaiian green turtle plasma was an order of magnitude lower than levels found in other populations of green sea turtles around the world and two orders of magnitude lower than loggerhead turtles from the southeastern U.S. coast (Keller et al., 2012). Interestingly, the study found the presence of hydroxylated and phenolic compounds in higher concentrations than total PCBs. The hydroxylated and phenolic compounds originate from metabolism of parent pollutants such as PCBs or are synthesized by other marine organisms like algae or sponges (Keller et al., 2014).

Keller et al. (2012) studied the plastic emulsifiers perfluorochemicals (PFCs), pesticides, and PCBs in the blood plasma of five sea turtle species of differing trophic levels found off the southeastern U.S. (Keller et al., 2012). The research linked loggerhead immune system changes to a variety of contaminants. As the levels of chlordane and mirex (two U.S.-banned pesticides) increased, the production of immune cells decreased. Similarly, as PCBs and DDT increased, the production of immune cells decreased. Similarly, as PCBs and DDT increased, immune cells decreased. The mean concentrations of the PFC perfluorooctane sulfonate (the predominant PFC) increased with the trophic level of the turtle, with green sea turtles having the least (2.41 ng/g) and Kemp's ridley (eat mainly fish) having the most (15.7 ng/g) (Keller et al., 2012). This would suggest that when green turtles are omnivorous (juvenile), there is a greater risk for ingestion of PFC-contaminated food sources. The estimated margins of safety were calculated in this study and in all five species, a risk of potential adverse health effects via immunosuppression was found (Keller et al., 2012).

A study of PCBs in green turtle eggs was attempted by FWS as part of a UH study in FFS (Lorenz, 2002). Egg specimens were collected and documented by FWS; however, due to an extended power outage in the UH laboratories, the specimens were not viable and PCB analysis was not conducted (FWS, 2014a).

4.3 SUMMARY OF ENVIRONMENTAL CONTAMINATION

4.3.1 Introduction

A variety of types of environmental contamination is present on Tern Island as a result of human interaction with the environment. The environmental contaminants include dioxins/furans, lead, heavy metals, hydrocarbons, polycyclic aromatic hydrocarbons (PAHs), PCBs, and pesticides (DDD, DDE, and DDT). Exposure to these contaminants can have negative impacts on wildlife and the marine ecosystem. Discharges of pollutants may be terrestrial or waterborne.

Waterborne discharges include direct and indirect discharges of pollutants such as chemicals into the aquatic environment. Discharges may be directly released into marine waters, or may be carried by surface water, groundwater, wave action, or coastal runoff. There are factors influencing waterborne discharges such as surface and groundwater flow, storms and hurricanes, and seawater flow. The waterborne discharges can be either point source or non-point source runoff. Regardless of the source, the discharge impacts the surrounding reef ecosystem.

Changes in the landscape such as erosion can affect the rates and distribution of terrestrial pollutant discharge into coastal waters. Inputs of toxic chemicals and impacted sediments into the reef environment can affect the survival and growth of reef species, including fish, marine mammals, coral, and other invertebrates (EPA, 2012).

4.3.2 Summary of Contamination, Sampling, and Cleanup Efforts

Table 4-10 outlines the historical users of Tern Island, the investigations that have occurred on the island, and the cleanup activities.

4.3.2.1 Navy and USCG Use

The Navy used Tern Island as an airfield and a re-fueling stop from 1942 to 1946. The Navy installed 21 USTs, ASTs, and barracks when it modified the natural island to create a Naval Air Facility to support the war effort. The USTs were located along the northern edge of the runway, spaced about 205 ft apart, along the majority of the island (Figure 4-21). They were installed in pairs, with the exception of one single tank (Environmental Technologies International [ETI], 1992). Twenty of the tanks held a combined volume of 100,000 gallons of aviation fuel and one tank held 6,000 gallons of diesel fuel (URS, 1999). There are no records of releases from these tanks while they were used by the Navy. The USTs were abandoned in-place when the Navy ceased operations. The Navy decommissioned its facility in 1946.

Land mines were depicted in an undated figure from Navy files assumed to be from WWII. On December 23, 1943, an unidentified mine covered with growth drifted ashore at Tern Island. A mine disposal officer promptly disarmed it (Amerson, 2012). Another incident of a mine washing ashore on East Island was documented in 1948. The mine was detonated on East Island (Amerson, 2012). No unexploded ordnance has been discovered since 1948.

USCG started utilizing FFS in 1944, and in 1952 built the LORAN station on Tern Island. The LORAN station was powered by fuel oil stored in eight ASTs. USCG renovated six of the Navy’s USTs to hold fuel oil, increasing Tern Island’s fuel oil storage capacity from 16,000 to 46,000 gallons (URS, 1999).

From 1960 to 1963, the Navy installed and operated components of the PMR facility, including a 50,000-gallon neoprene fuel tank. While renovating the Navy's facilities in 1964, USCG demolished the Navy's power generation facility. The FWS 2002 Environmental Assessment (EA) states that on two separate occasions, USCG demolished and buried equipment (including transformers and batteries) at on-site “landfills.” It also states that waste materials were believed to have been used as fill between the old deteriorated bulkheads and newer repaired sections of pilings (FWS, 2002).

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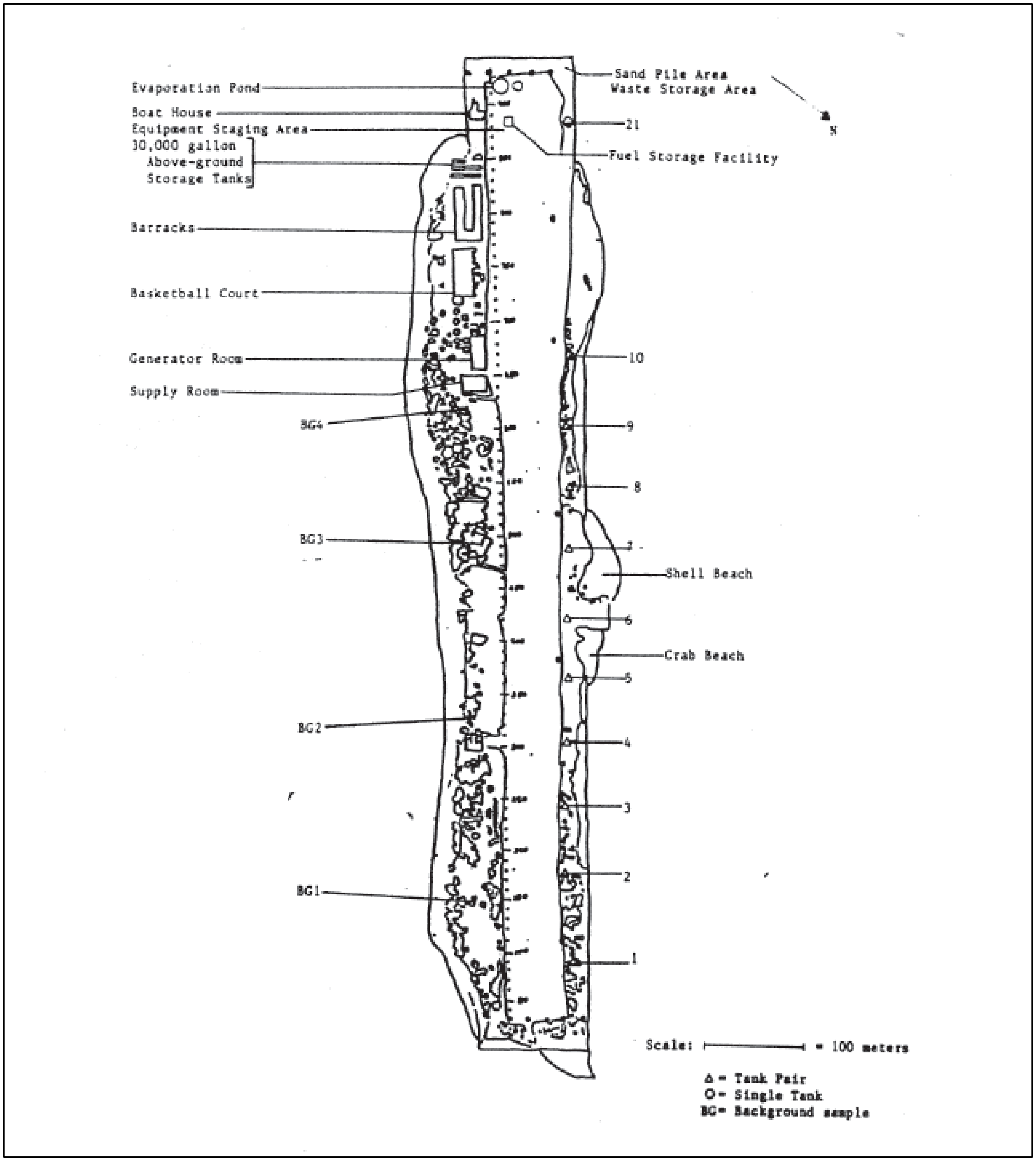

Figure 4-21 Sample Locations from 1992 UST Closure

Source: URS, 1999

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Some of this debris has been subsequently exposed by corrosion of the bulkhead, erosion of fill material, and storm activity (FWS, 2002; URS, 1999). Military activities on the island mainly involved constructing and operating an air field, powering and operating electrical equipment, constructing buildings, and performing repairs of the island's facilities. These activities resulted in the introduction of hazardous materials into the environment at Tern Island. USCG ceased using Tern Island in 1979, at which time FWS assumed management of the island.

4.3.2.2 FWS Management

FWS managed Tern Island from 1979 to 2013 as a field research station. During that time, FWS maintained the seawall; conducted seabird research, collaborated with turtle research, facilitated monk seal research; conducted contamination sampling; cultivated native vegetation; and modernized the facilities (Manta Corp., 1979; FWS, 2002). In 1982, FWS allowed NOAA to use Tern Island as a monk seal research camp, and NOAA continues to hold summer seal camps at Tern Island (NOAA, 2014e).

Lead paint chips from the woodshop on Tern Island were presumed to have been killing albatross chicks in a NMFS Monthly Activity Report dated June 1990 (FWS, 1990). FWS field personnel removed the paint chips from the area and covered the wall with metal siding (FWS, 1992). In November 1991, a fence was built around the woodshop to prevent the albatross from nesting in the area that contained lead paint chips. The fence was taken down in January 1992 because it proved to be an entrapment hazard to the birds and did not stop nesting. Later in 1992, the area measuring 25 by 15 meters located just east of the woodshop was covered with 8,300 pounds of sand (FWS, 1992).

FWS conducted an asbestos remediation in the early 2000s, during which paint was also removed from cinder block walls that could have been lead-based paint (FWS, year unknown-photo log of activities on Tern Island). FWS conducted a follow-up asbestos removal after the microburst storm in 2012. There was not sufficient materials to contain all of the asbestos containing materials safely and those materials are still present on Tern Island in the Barracks (FWS, 2013a)

NOAA and FWS used the trash burn pit to dispose of combustible trash (URS, 1999) until 2001, when FWS stopped the practice. A burn barrel has been occasionally used since 2001 to dispose of paper, cardboard, and food waste (FWS, 2014a).

FWS conducted a UST removal in 2004 and excavated hydrocarbon-contaminated soil below one UST. The contaminated soil was wrapped in filter fabric and re-buried on Tern Island in an unknown location.

4.3.2.3 1992 21 UST Removal by USACE

In July 1991, a survey of UST contents was conducted by ETI (contracted by the U.S. Army Corps of Engineers [USACE]) as part of the DERP FUDS. The FUDS Program cleans up environmental contamination at properties formerly owned, leased, possessed, or used by the military services

(Army, Navy, Air Force, or other Defense agencies). The Army is the Department of Defense executive agent for FUDS, and the U.S. Army Corps of Engineers is responsible for carrying out the program. The FUDS program is part of the DERP and cleans up properties in accordance CERCLA and the NCP.

The tanks were located in pairs along the northern side of the runway, along a major portion of the island (Figure 4-21). ETI found that 5,000 to 6,500 gallons of fuel, 15,200 to 16,000 gallons of intruded sea water, and 5,500 gallons of sand remained in the tanks.

The intruded sea water and sand in the tanks indicated leaks in nearly all of the tanks. These findings also showed that fuel was left in the tanks after the conclusion of the Navy and USCG activities.

In 1992, ETI completed tank closures for the 21 USTs. The tanks were cleaned and the tank appurtenances were all cut and plugged with concrete. They were abandoned in place to maintain the island's structural integrity. Water generated during cleaning of the tanks was either discharged onto the ground or transferred to an evaporator unit for disposal. Recovered water/fuel mixture, fuel product, and sludge was pumped into drums and transported to Honolulu for recycling and disposal (URS, 1999; ETI, 1992). Four types of samples were collected during this effort. Initial samples were collected from exposed tank fillpipes to determine the contents of the tanks. Samples were then collected from inside the tanks during closure activities. The contents of an on-site 30,000-gallon AST were then sampled. Finally, 11 excavations were made near the tank pairs so that the soil could be analyzed for contamination and the tanks could be abandoned.

Lead was detected in tank sludge at concentrations as high as 3.44 milligrams per liter (mg/L), and fuel product was found below some of the tanks demonstrating that the tanks were a source for hydrocarbons and lead in the environment at Tern Island. ETI found that one of the USTs located near the northwest side of the island had a 2-ft hole in it, and the ocean had washed out the entire contents of the tank (URS, 1999; ETI, 1992). The results from these analyses can be found in Table 4-11. Lead was detected in soil at concentrations ranging from 15.7 to 89.1 milligrams per kilogram (mg/kg). Most of the soil samples near the USTs were determined to be below the detection limit for total petroleum hydrocarbons (TPH). However, near tank pairs 7 and 9, TPH concentrations in soil were detected at 130 mg/kg and 1,490 mg/kg, respectively. These values are attributed to small holes in the tank walls (ETI, 1992).

The following inventory of petroleum hydrocarbons was removed from the island (URS, 1999; ETI, 1992):

- 3,615 gallons of diesel fuel in forty-three 55-gallon drums, two 500-gallon tanks, and two 250-gallon tanks;
- 660 gallons of petroleum sludge in twelve 55-gallon drums;
- 990 pounds of petroleum contaminated debris in nine 55-gallon drums; and
  2,420 gallons of diesel/water mixture in forty-four 55-gallon drums.

4.3.2.4 1997 AST Closure

The EA produced by FWS in 2002 mentions that FWS removed the LORAN ASTs in December 1997. No records of this removal could be located.

4.3.2.5 1997 Geophysical Investigation

In 1997, Woodward-Clyde Federal Services (WCFS) on behalf of USCG completed a geophysical investigation of the northern side of the island in an attempt to locate the on-site “landfills.” As part of the study, a baseline transect was set up north of the landing strip in the northwest corner of the island and an investigation area was set up corresponding to that transect. The area of the investigation spanned almost 3,000 ft. in the east-west direction (the length of the runway) and from 30 to 140 ft. in the north-south direction. The results of the survey found that approximately 20% of the north side of the island had subsurface metal debris (URS, 1999).

4.3.2.6 1997 Subsurface Soil Sampling USCG

USCG personnel conducted a subsurface sampling investigation of Tern Island in September 1997. This study used the same base transect line (located north of the runway) created for the WCFS survey in 1997 so that any locations with detections could be spatially related to new detections (Figure 4-22). The event consisted of using portable hand-held augering equipment to collect soil samples from depths of 3 to 5 ft bgs. These samples were taken from areas that had been determined to have subsurface anomalies during the WCFS survey. A total of 37 soil samples were collected and analyzed for total PCBs, lead, chromium, cadmium, and mercury. No PCBs were detected in the soils above the detection limit of 2 mg/kg (URS, 1999). One sample showed elevated lead concentrations of 939 mg/kg. Average lead values were determined to be approximately 23.4 mg/kg in soil at Tern Island (URS, 1999).

Average Tern Island cadmium and chromium levels were determined to be approximately 2.1 and 11.6 mg/kg in soil, respectively. Current EPA regional screening levels for cadmium in the diet and chromium VI in soils are 7 mg/kg and 0.293 mg/kg, respectively. There is no current EPA screening level for total chromium in soil.

4.3.2.7 1998 FWS Biota and Sediment PCBs and Metals in Marine Species

In March 1998, FWS collected sediment and biota samples that were submitted to UH for analyses of PCBs and metals. Average concentrations of total PCBs ranged from 0.154 mg/kg to 0.274 mg/kg in the sediments (Miao et al., 2000a). Lead concentrations in sediment were 22 mg/kg to 44 mg/kg in samples collected from Tern and 20 mg/kg from the reference site La Perouse.

Coral (*Porites lobata*), fish (*Stegastes fasciolatus*), and crab (*Grapsus tenuicrustatus*) samples were collected from the waters off the northwest and northeast corners of the Tern Island seawall. Reference samples were collected from Trig and La Perouse Islands, also part of the FFS. Average concentrations of total PCBs ranged from 0.120 to 0.267 mg/kg in the corals, from 0.387 to 4.5 mg/kg in the crabs, and 1.34 to 46 mg/kg, dry weight, in the fishes. Average concentrations of lead was 12 mg/kg in corals, 16 mg/kg in fish and 22.5 in crabs from Tern location. The authors concluded that high concentrations in marine species indicated there were PCB source(s) in FFS, especially Tern Island. The sediment samples collected from Tern Island had higher concentrations of heavy metals than sediments collected from the reference site, La Perouse Pinnacle (Table 4-11) (Miao et al., 2000a). The concentrations of arsenic and cadmium were more than double in the crab samples from Tern than in the sediment samples from Tern (Table 4-11). The sediment and coral were predominated by lower chlorinated PCB congeners, whereas the fish and crab bioaccumulated mainly higher chlorinated congeners (Miao et al., 2000a).

4.3.2.8 1998 US Navy Reserve HAZMAT SCUBA Cleanup

In October and November 1998, U.S. Navy Reserve Hazardous Materials (HAZMAT) mobile diving and salvage unit self-contained underwater breathing apparatus (SCUBA) divers observed two transformers during their dives. The first, located 20 ft south of the northwest corner of the island, was observed to be empty with the side missing.

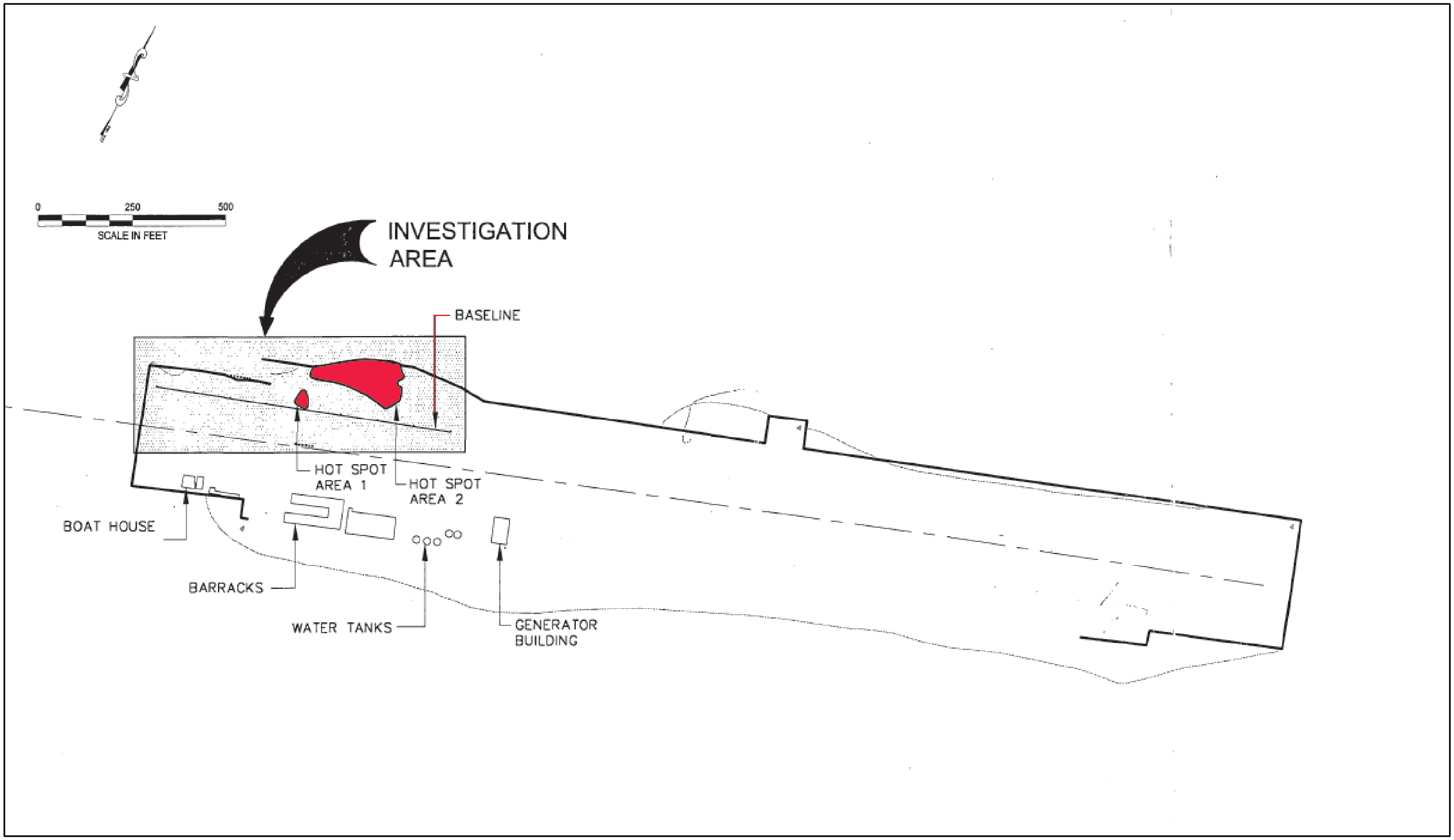

Figure 4-22 USCG Investigation Location for 1999 EI of Tern Island

Source: URS, 1999

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The second, located 100 ft west of the corner of the seawall, was observed to have ruptured sides. These transformers were removed, along with over 30 lead-acid batteries and other HAZMAT during a clean-up of the nearshore waters (Figure 4-23). Correspondence between USCG Civil Engineering Unit and the U.S. Navy Reserve unit provides a summary of the removal of over 2,000 pounds of hazardous waste from Tern Island in late 1998. The summary chronicles the unsuccessful efforts of the Navy Reserve Dive/HAZMAT mobile diving and salvage unit SCUBA divers to relocate two large scale batteries (900 to 1,500 pound size) (Navy, 1998).

4.3.2.8.1 1999 USCG Environmental Investigation of Tern Island

An Environmental Investigation (EI), which was conducted by URS Greiner Woodward Clyde (URSGWC) on behalf of USCG in October and November 1998, assessed the level and extent of lead and PCB soil contamination resulting from discarded batteries and electrical equipment observed on the island. The base transect line for this investigation matched the baseline established during the 1997 geophysical investigation immediately north of the runway on the northwestern portion of the island. The suspected impacted sites detected during the previous investigations were excavated in an attempt to assess the subsurface conditions.

In total, 11 trenches were excavated to a depth of at least 4 ft bgs. Surface soil samples were collected from areas where batteries and electrical components were observed. In the southeastern portion of Tern Island, hand-held metal detectors were used to survey new areas located between 1,200 ft and 2,800 ft east of the origin and between 180 ft and 260 ft south of the baseline. Seven test pits were excavated in areas of major detections (URS, 1999). Surface soil samples were also collected from these test pits if contamination was observed. Most of the subsurface debris was found in trenches dug in an area identified as Hotspot Area 2 (Chase, 2002; URS, 1999) (Figure 4-22).

Two areas of significant surface lead and PCB contamination were identified during the investigation and were designated Hotspot Area 1 and Hotspot Area 2 (Figure 4-22). Hotspot Area 1 extended from the baseline to about 50 ft north of the baseline and southeast of the break in the northern seawall. Hotspot Area 2 was located from the baseline to about 150 ft north of the baseline directly behind the northern seawall to the east of the break. Contamination in the extreme northern part of this area was estimated to extend to 4 or more ft bgs (URS, 1999; USCG, 2000).

Fifty-seven surface soil samples were collected for laboratory analysis, and an additional 91 field samples were collected for X-ray fluorescence (XRF) analysis. A subset of 33 XRF samples was analyzed by the laboratory. Analyses yielded lead concentrations in soil ranging from non-detect to 2,800 mg/kg and non-detect to 3,700 mg/kg for the field (XRF) and laboratory samples, respectively. The majority of the surface lead detections correlated with subsurface contamination locations. Field PCB analysis was performed on 68 of the 91 samples. Laboratory analyses for total PCBs were performed on 33 of the 91 field samples. PCB concentrations ranged from below detection to 126 mg/kg in the field and from below detection to 2,300 mg/kg in the laboratory. Sixty-eight of the 91 soil samples were field sampled for PCBs (URS, 1999) (Figure 4-22).

The report concluded that PCB concentrations were highest in the two hotspot areas, and concentrations decreased with depth. Based on contoured data, it was estimated that roughly 1,170 cubic yards of soil contained PCB concentrations of between 1 and 3 mg/kg, 500 cubic yards had PCB levels between 3 and 10 mg/kg, and 150 cubic yards contained PCB levels greater than 10 mg/kg. The total mass of PCBs present in the investigation area was estimated to be approximately 11.8 kg (URS, 1999).

The only metal, in addition to lead, analyzed during this study was arsenic. Arsenic was detected at concentrations ranging from below detection to 50 mg/kg in soil (URS, 1999).

During this investigation, five Hawaiian monk seal scat samples were collected and analyzed in the field for PCBs. Three of the five scat samples contained detectable levels of PCBs with measured concentrations ranging from 0.02 to 0.36 mg/kg of PCB as Aroclor 1254 (URS, 1999).

4.3.2.9 1999 USCG Environmental Investigation of Former LORAN Station

In 1997, URSGWC, on behalf of USCG, performed a more comprehensive EI to refine the lateral and vertical extent of lead- and PCB-contaminated soils in the northwestern portion of Tern Island. Two fine (7.5-ft by 15-ft) grids were set up in the Hotspot Areas 1 and 2 discovered in the URSGWS survey. A coarse (15-ft by 30-ft) grid was established from the western end of Tern Island to a point 810 ft east along the WCFS baseline, including all of the land north of the runway.

A total of 346 soil samples were collected, including 278 surface soil (0 to 6 inches bgs) and 68 subsurface soil (6 to 48 inches bgs) samples. The majority of the samples were collected from the areas identified as hotspots in the previous investigation (Figure 4-24). One subsurface sample was collected from what was considered a background location. PCBs were detected in 260 of the 278 surface samples and in 44 of the 68 subsurface samples (Figure 4-24). Detected concentrations in surface soils ranged from 0.011 to 92 mg/kg and in subsurface soils from 0.0099 to 24 mg/kg. PCBs were not detected in the background sample. The majority of the onshore soil PCB patterns closely matched the Aroclor 1254 standard pattern, but some evidence of weathering was interpreted in the patterns, meaning the less chlorinated PCB congeners were typically present in lower concentrations relative to the more highly chlorinated congeners as compared to the reference standards for Aroclor 1254 (URS, 1999; USCG, 2000).

Lead was detected in 277 surface soil samples, ranging from 0.33 to 26,000 mg/kg. Lead was detected in 53 subsurface samples ranging from 0.19 to 680 mg/kg. The majority of the samples submitted to the laboratory were collected from Hotspot Areas 1 and 2.

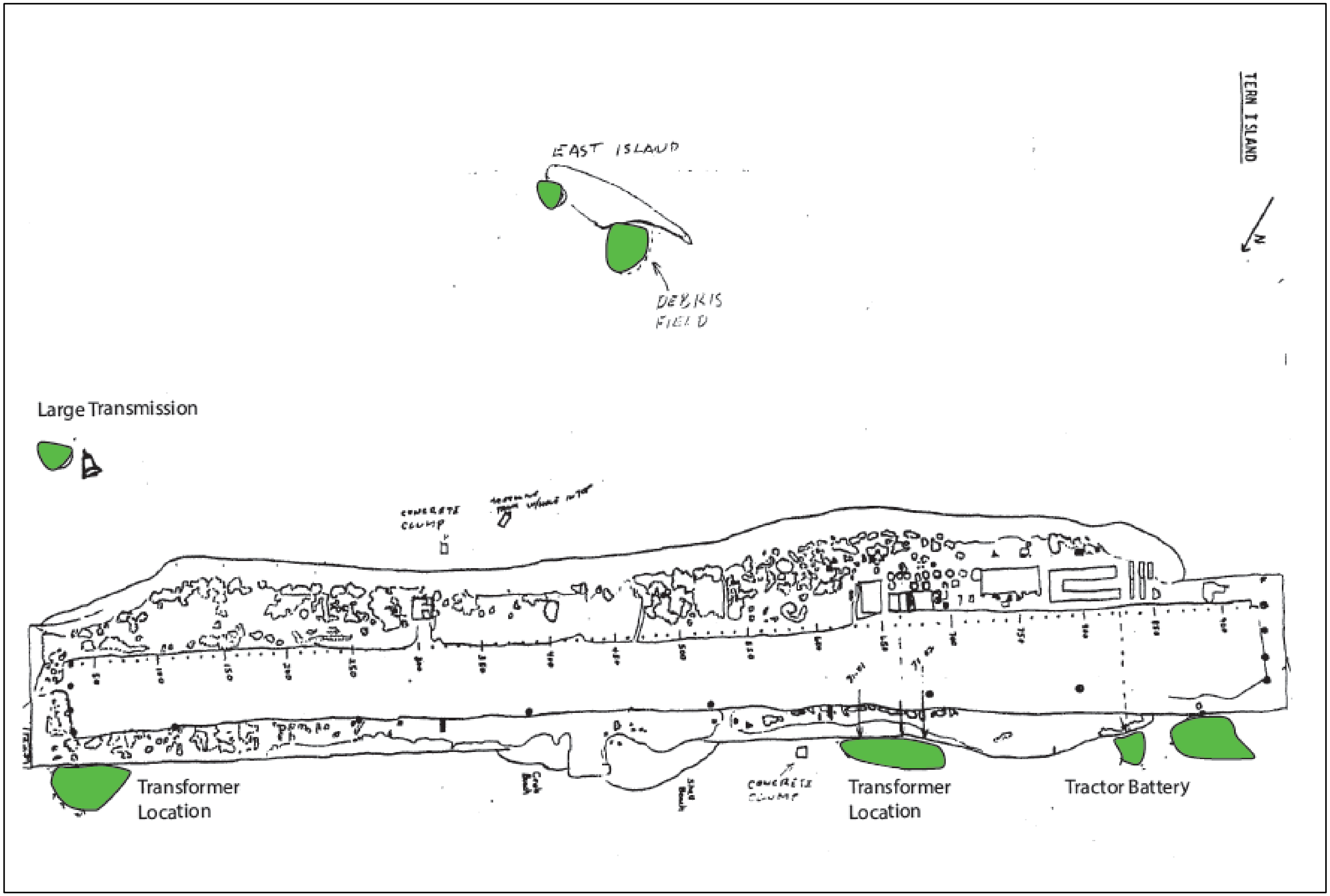

Figure 4-23 HAZMAT Investigation-Cleanup Locations, 1998

Source: Navy, 1998

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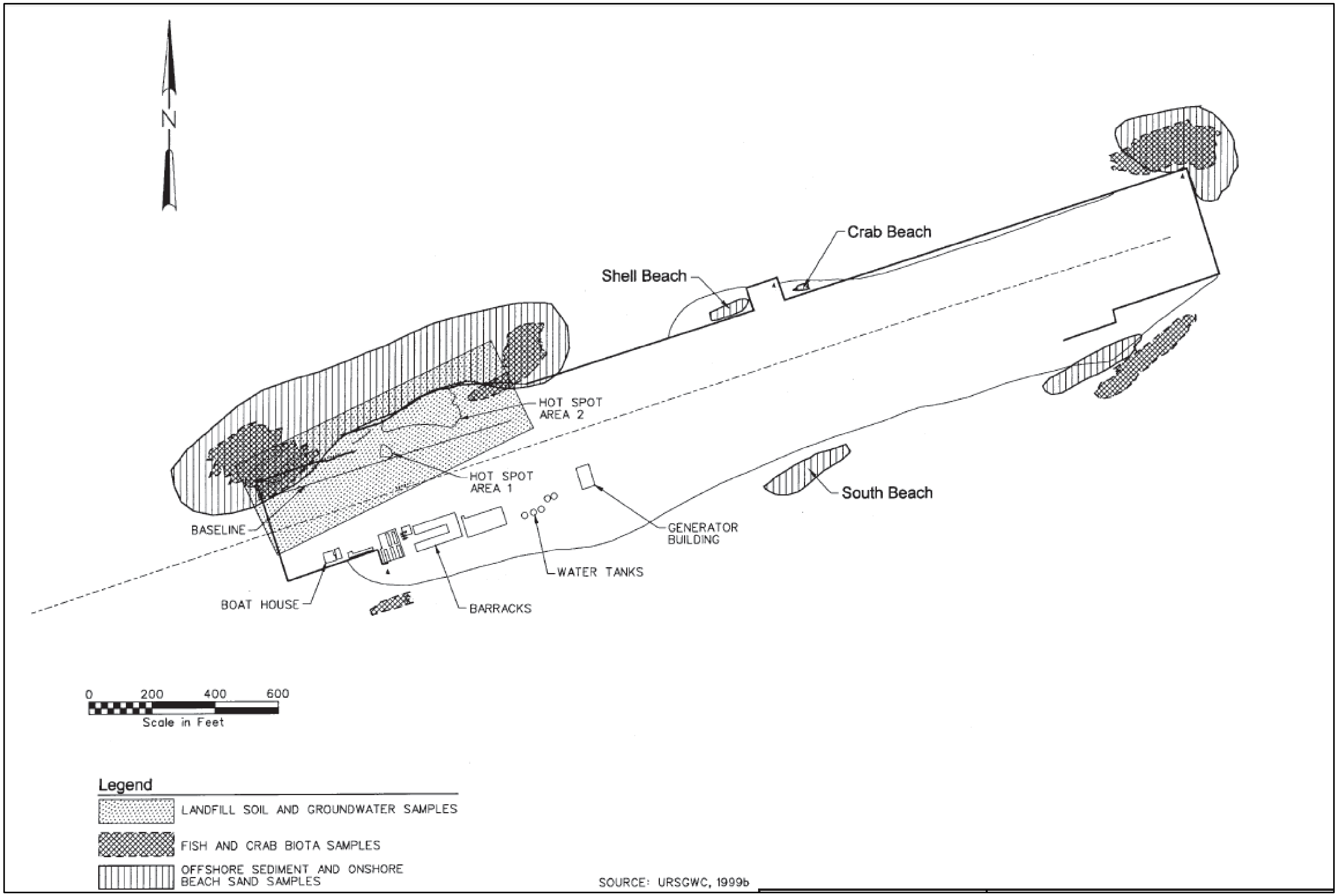

Figure 4-24 Soil, Groundwater, Sediment and Biota Sampling Areas 1999 EI Former LORAN Station

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Seven soil samples were analyzed for TPH-Diesel. The TPH samples were collected in subsurface locations that field personnel identified as having an organic odor. TPH-Diesel was detected in five of the seven samples at concentrations ranging from 11 to 660 mg/kg (URS, 1999).

A total of 28 marine sediment samples were collected from three offshore locations: off the landfill, the northwest, and the northeast sides of Tern Island (Figure 4-24). At each location, sediments from 0 to 6 inches bgs were collected. In addition, six onshore beach sediment samples were collected from two locations along the southern shore of the island and from a single site located along the northern shore of the island. The samples were near-surface and subsurface, and they were located to represent contaminant levels that may be encountered by monk seals and sea turtles during their nesting and hauling out activities. Four background sediment samples were collected from offshore sediments on Gin and Little Gin Islands, which are located approximately 9.5 and 11 miles southeast of Tern Island, respectively (Figure 1-1). Thirteen of the offshore sediment samples, the six onshore beach sediment samples, and the four background sediment samples were analyzed for 28 PCB congeners. The other 15 offshore sediment samples were analyzed for total PCBs. The highest sediment PCB concentrations were detected in sediment samples collected offshore from the landfill area (sum of congeners range of non-detect to 2.7 mg/kg and total PCB range of 0.007 to 0.640 mg/kg). Concentrations were lower off the northwestern (sum of congeners range of below the detection limit to 0.104 mg/kg and total PCB range of 0.008 to 0.260 mg/kg) and northeastern corners (total PCBs range of below the detection limit to 0.0092 mg/kg) of the island. PCBs were not detected in the three beach sand samples collected at Shell Beach and Crab Beach, but were detected in three of six beach sand samples collected from areas of South Beach known to be used by monk seals as resting areas and by green sea turtles for egg laying. All three of these sand samples had sum of PCB congener concentrations of 0.012 mg/kg (URS, 1999; USCG, 2000). Lead was detected in 22 sediment samples at concentrations ranging from 0.0001 to 0.1111 mg/kg (URS, 1999).

Thirty-two (32) marine biota tissue samples were collected from the area directly offshore from the landfill and from the northeastern, northwestern, southeastern, and southwestern corners of Tern Island (Figure 4-25). A total of 20 background samples were also collected from Gin and Little Gin Islands. A total of 21 fish were collected from Tern Island and analyzed, including 10 goatfish (*Mullidae spp.*) and 11 manini (*Acanthurus triostegus* or common striped reef surgeonfish). Additionally, 11 land crabs were collected from Tern Island. Sixteen fish and four land crabs of similar size were collected from background areas.

Biota samples were analyzed for 28 PCB congeners by EPA Method 8270. The highest PCB concentrations were detected in biota collected from areas directly offshore of the landfill area. PCB concentrations up to 16.4 mg/kg were detected in goatfish, manini, and land crab collected from this area.

PCB concentrations up to 0.705 mg/kg were detected in all three types of biota samples collected from the northwestern corner of Tern Island. PCB concentrations up to 0.466 mg/kg were detected in all three types of biota samples collected from the northeastern corner of Tern Island. No PCBs were detected in the biota samples collected from the background locations on Gin and Little Gin Islands. The study concluded that there was clear evidence of bioaccumulation in the aquatic food chain that resulted in high concentrations of lipophilic contaminants such as PCBs in organisms that occupy high trophic levels (URS, 1999; USCG, 2000).

Groundwater samples were collected from six boreholes and excavations in Hotspot Area 2 by drilling or hand digging to depths ranging from 2 to 5 ft. bgs. Six samples were collected in a grab fashion, using either direct grab methods or disposable bailers. Three water samples were analyzed for TPH-Diesel because field personnel either smelled an organic odor or observed a hydrocarbon sheen. All three samples contained TPH ranging from 11,000 to 240,000 microgram per Liter (µg/L) (URS, 1999). An additional sample was collected from a background location on Tern Island. Three of the six groundwater samples, as well as the background sample, were analyzed for PCBs by EPA Method 8081/8082. PCBs were detected in the background sample at a concentration of 0.41 µg/L and in the Hot-Spot Area 2 samples at concentrations ranging from 1.2 to 10 µg/L. Lead was detected in five of the samples collected at concentrations ranging from 12 to 430 µg/L (URS, 1999). The report concluded that elevated concentrations of hydrocarbons present in soils have facilitated migration of PCBs bound to soil into the shallow underlying groundwater system (URS, 1999; USCG, 2000). The exact locations of the groundwater samples were not included in the report; however, the vicinity is shown in Figure 4-24.

In addition, seawater samples were collected from two offshore sites surrounding Tern Island. One seawater sample was collected just offshore of the main landfill area. The other sample was collected approximately 150 ft offshore of the southeast corner of the island. The seawater samples were collected by divers from approximately 3 ft beneath the sea surface. The seawater samples were analyzed for trace PCBs by Modified EPA Method 8290. Total PCBs detected in these samples were 0.00445 and 0.000665 µg/L (URS, 1999).

Transformers are a source of PCB-containing liquid and batteries are a source of lead contamination. Electrical equipment and power generation equipment may have contained levels of heavy metals as well. Lead sources at Tern Island came primarily from lead-based paint, leaded fuel storage, and the use and/or disposal of lead-acid batteries for electrical equipment. Releases of lead from fuel storage and batteries occurred at Tern Island according to this investigation (URS, 1999).

4.3.2.10 1999 FWS Marine Sediment and Tissue Analysis

In May 1999, FWS collected biota and sediment samples from the waters off the barge location and the northeast and northwest corners of the Tern Island seawall.

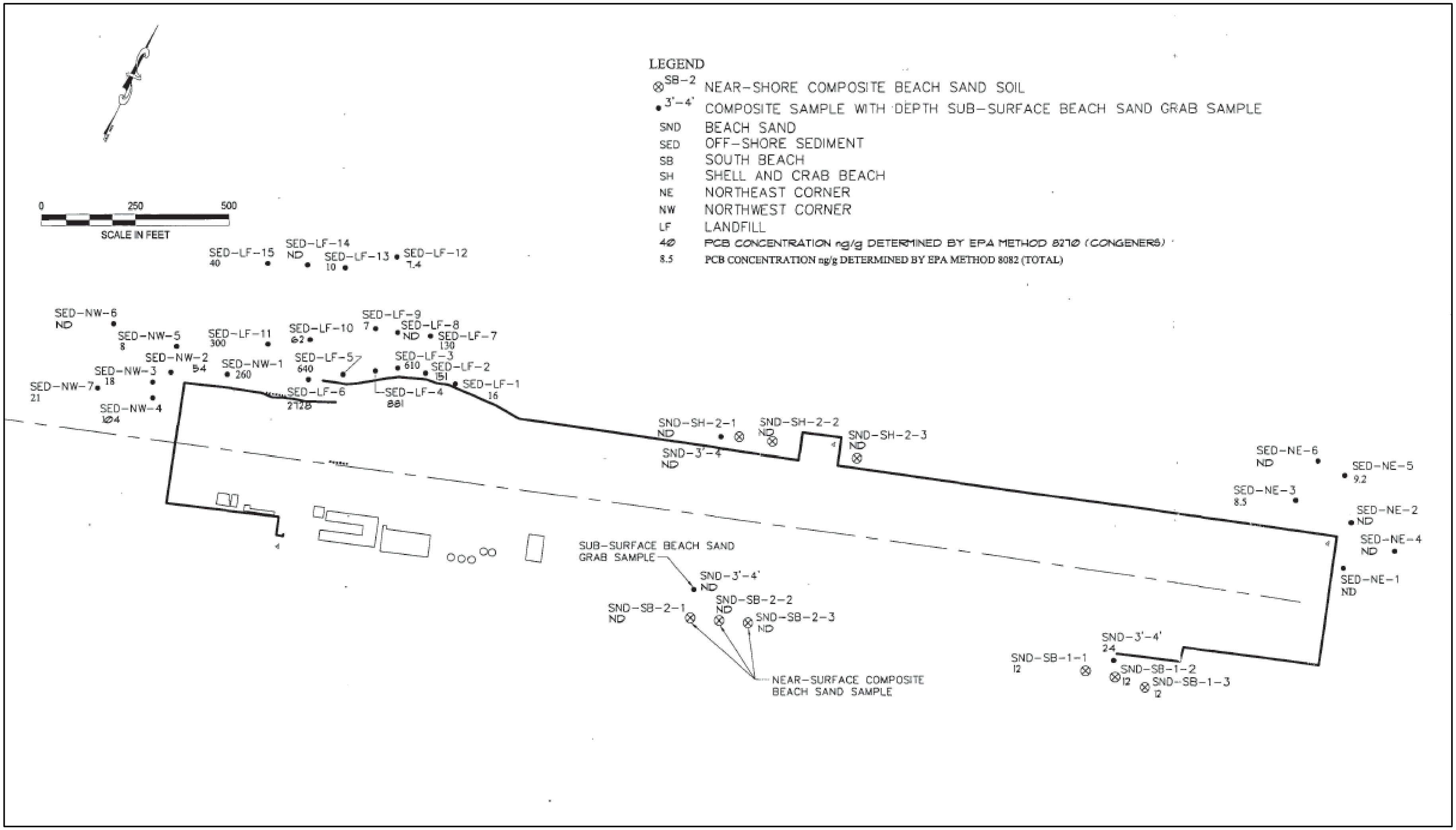

Figure 4-25 Approximate Location of Sediment Samples Collected for 1999 EI of Former LORAN Station

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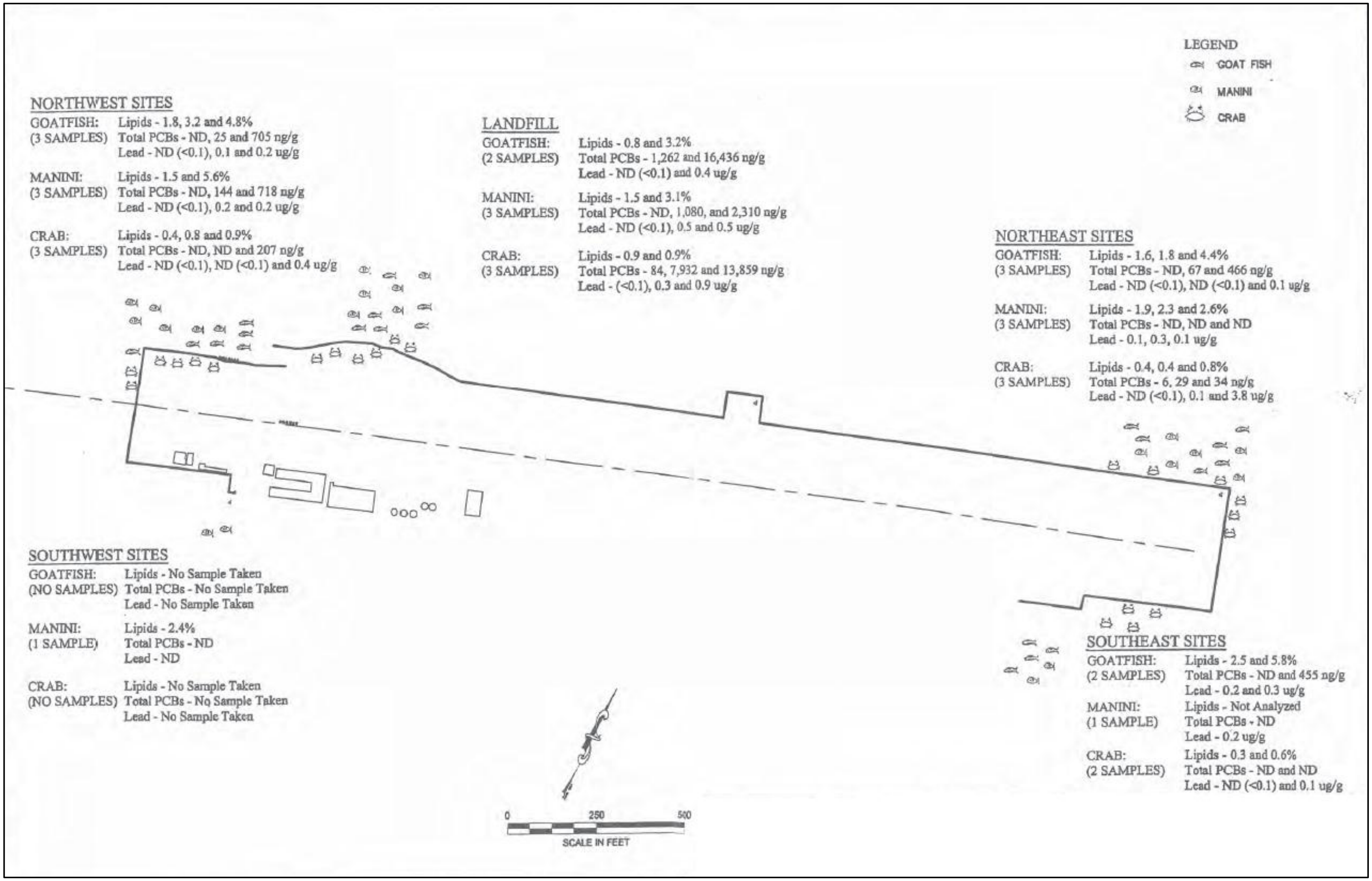

Figure 4-26 Approximate Location of Biota Samples Collected for 1999 EI of Former LORAN Station

The barge location is off-shore of the central part of the island between the northeast and northwest corners (Figure 4-27). Reference samples were collected from Disappearing Island, located in the FFS approximately 16 miles from Tern Island. PCBs were analyzed in samples of sediment; coral (*Porites evermanni*); fish *(Stegastes fasciolatus, Neoniphon sammara, Acanthurus triostegus and Mulloidichthys anicolensis*); crab (*Grapsus tenuicrustatus*); lobster (*Panulirus marginatus*); and eel (*Conger cinereus, Gymnothorax flavimarginatus, G. undulatus and G. meleagris*) (Miao, 2000b; Miao 2001).

In general, high trophic species such as eels were found to highly bioaccumulate PCBs. The total average PCB concentrations were as high as 96.470 and 28.546 mg/kg dry weight in eels and damselfish, respectively, from Tern Island. The study concluded that the high average concentrations of the sum of PCBs in different food chain levels suggest pollution sources around Tern Island (0.274, 0.273, 0.119 mg/kg) and possibly around Disappearing Island (0.085 mg/kg) (Miao, 2000b).

In order to assess OC levels in Hawaiian monk seals, whole blood and blubber samples were collected from 46 free-ranging Hawaiian monk seals at FFS and were analyzed for eight dioxin-like PCBs, six other PCB congeners, DDT, and DDT metabolites. Average levels of PCBs in blood samples from adult male, juvenile, and reproductive female groups were 4.8, 4.0, and 03.0 mg/kg lipid weight, respectively. Average levels of total PCBs in blubber were 3.2, 1.3, and 1.2 mg/kg, respectively (Willcox, et al., 2004).

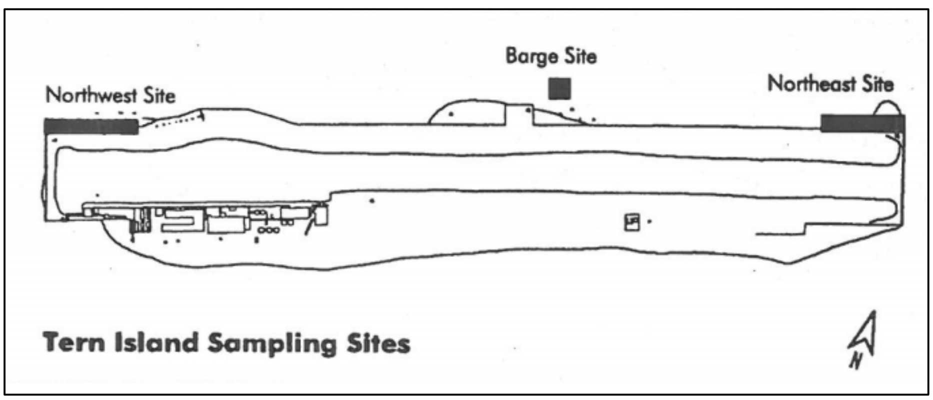

Figure 4-27 Sampling Locations for PCBs and Metals

On behalf of FWS, UH conducted a study of OCs in marine organisms, sand, and sediments that were collected from Tern Island and other Islands of the Hawaiian Islands National Wildlife Refuge. One of the objectives of the study was to determine the extent of PCBs in Hawaiian green sea turtle samples from Tern Island. Turtle blood and egg samples, as well as sand samples from nesting sites, were collected and analyzed for PCBs and OC pesticides. Concentrations of total PCBs in turtle blood ranged from below the detection limit to 7.7ppb in the nine individuals tested. Concentrations of total PCBs in nest sands ranged from 0.02 to 42.7 ppb in the 18 nests that were tested (Lorenz, 2002).

Miao et al. found relatively high levels of selenium in sediment at FFS. Moderate concentrations of arsenic, cadmium, and lead were found in sediment in this study. Chromium was detected in low levels. These values were compared to other known marine environments (Table 4-11) (Miao et al., 2001). Lead concentrations ranged from 0.01 to 0.044 mg/kg. The average concentrations of cadmium, chromium, copper, lead, mercury, selenium, and zinc were higher in sediments from Tern than from Disappearing Island; however, arsenic concentrations were similar. Comparing Tern and Disappearing Island sediment metals with the Pacific coast, Atlantic coast, Gulf of Mexico of the U.S., and Southern California coasts, the sediment from Tern and Disappearing Islands contained high levels of selenium (7 to 55 fold), and moderate to low concentrations of the other metals mentioned in this study.

4.3.2.11 2002 USCG Voluntary Remediation and Verification Report

Chase Environmental Group, Inc. (Chase) was contracted by USCG to conduct a cleanup of the landfills. USCG, in cooperation with EPA and FWS, agreed to the Toxic Substances Control Act (TSCA) PCB cleanup level of 2 mg/kg. USCG coordinated with FWS to complete the work, which began in September 2001. Construction debris, soils, transformers, and batteries located during previous site investigations were removed from the island using an excavator. Portions of batteries and capacitors were removed from several locations in the landfill. The Bulky Dump is located in the northwest area of the island, just west of the landfill. Several electrical devices, such as capacitors and transformers, were found here and removed during remediation of the landfill. The remainder of the Bulky Dump was not remediated during the landfill cleanup. One drum of batteries, five drums of capacitors, and eight drums of soil were disposed of as hazardous waste. A total of 1,690 cubic yards of soil was profiled, manifested, shipped off-island, and disposed as non-hazardous waste at the Columbia Ridge Landfill in Oregon. The Oregon landfill required soil to be less than 50 parts per million (ppm) of PCBs to be accepted as non-hazardous.

The Remediation Verification Report generated by Chase has conflicting data about the amount of wastes removed from the site (CH2MHill, 2002; Chase, 2002). The sampling methods used in the Remediation Verification sampling were not those that were accepted in the Sampling and Analysis Plan (Chase, 2002). The cleanup was considered incomplete by FWS and EPA for multiple reasons, including omission of excavation in the Bulky Dump, along the northern sea wall, and in the burn pit where Shearwater birds had burrows and FWS would not allow Chase to excavate (Chase, 2002) due to the USCG not obtaining a Migratory Bird Treaty Act permit pursuant to 50 CFR parts 13 and 21. In addition, the clean-up goal of 2 mg/kg was not achieved in all areas partly because USCG had not obtained necessary USACE Section 10 and Section 404 permits to excavate and backfill in this area. EPA stated that further action is necessary because the cleanup left unacceptable levels of PCBs on Tern Island (EPA, 2003) (Figure 4-28).

Although hazardous materials were removed from Tern Island as part of this cleanup, further cleanup and characterization is required because there are still levels of PCBs as high as 22.3 mg/kg present in the soil on Tern Island (Chase, 2002). The Marine Mammal Commission sent a letter to USCG stating that further cleanup was necessary and the Hawaiian monk seal was threatened by the remaining contamination (MMC, 2003). In a response to the Marine Mammal Commission (MMC), USCG stated it would undertake no further cleanup effort on Tern Island (USCG, undated).

4.3.2.12 2004 UST Closure by FWS

FWS contracted GeoEngineers for the closure of two USTs discovered in the northwest corner of the island (location was not available). UST1 was excavated along with several cubic yards of petroleum-contaminated soil. UST2 was not excavated other than to expose the top of the tank. Approximately 500 gallons of a diesel fuel and water mixture were pumped from UST1 into 55-gallon drums.

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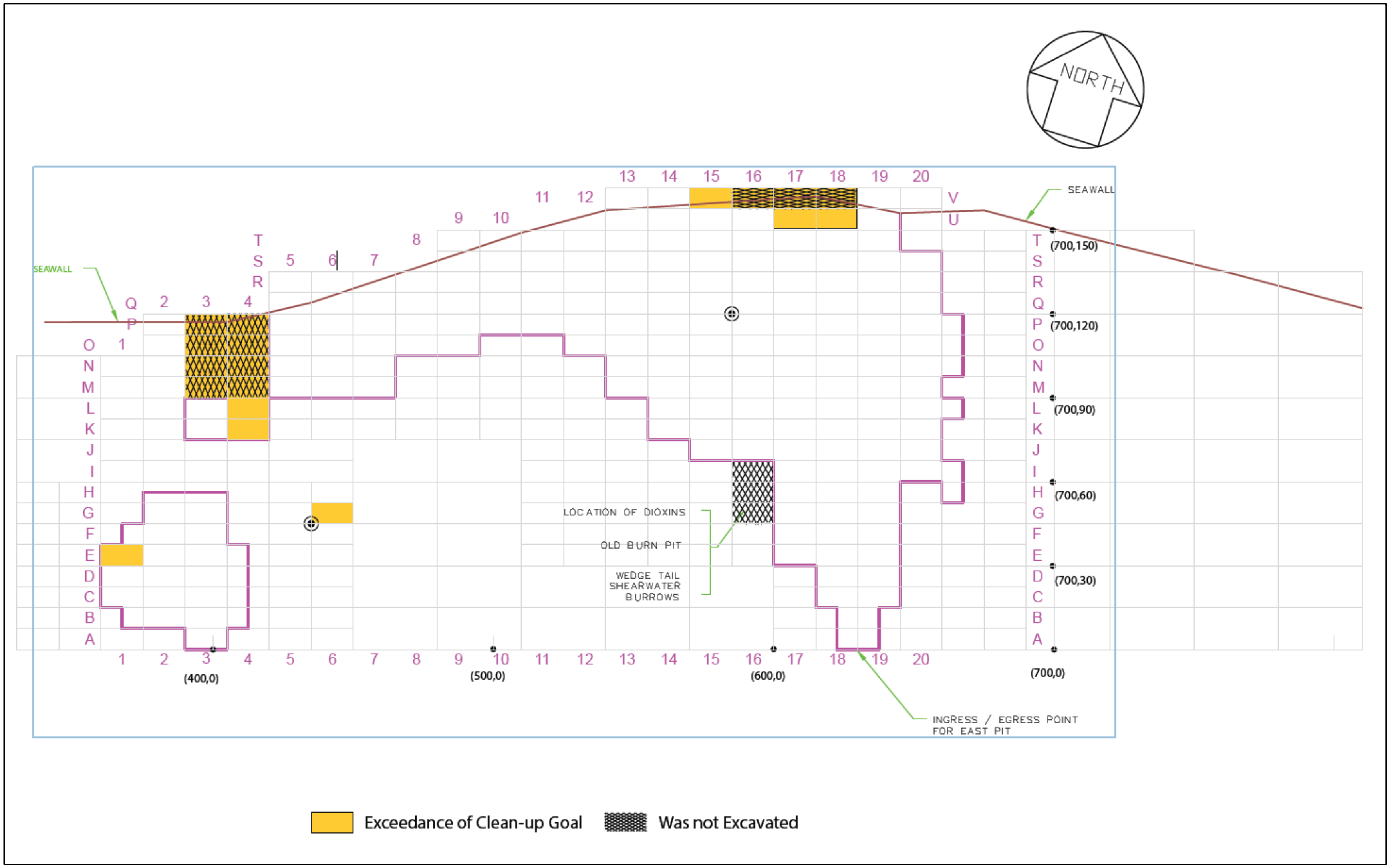

Figure 4-28 PCB Sampling Locations from 2002 PCB Cleanup

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After 220 gallons were pumped from UST2, it was determined that sea water was infiltrating the tank and the fuel floating on the water was staying at the same level. The fuel was removed from UST2 and it was filled with sand and buried in place. UST1 was removed and recycled; however, removal and off-island disposal of UST2 were considered by FWS to be impractical (GeoEngineers, 2004).

The soil contaminated by UST1 was wrapped in sheeting and reburied within a trench next to the area from which it had been removed. There is currently no delineation of the contaminated soil on maps or record of what was done with the soil in documents (FWS, 2014a).

Three soil samples were taken as part of the UST closure and contained detections of PCBs, TPH-Diesel, TPH-Gasoline, lead, and chromium. There was also one detection of naphthalene, a PAH, at 0.26 mg/kg; however, that value is not included in Table 4-11 (GeoEngineers, 2004).

4.3.3 Remaining Contamination

In addition to the areas identified in Figure 4-28 that remained after the USCG remediation event in 2002, two new waste disposal areas have been identified as a result of wave action and erosion. Electronic and metallic wastes have been exposed at the southeast corner of the island and the area in the northeast corner labeled double seawall in Figure 4-29. There are also two areas suspected of containing buried waste in the southeast corner of the island. Lead based paint was used by the Navy and/or USCG and is believed to remain on buildings. The woodshop was identified in 1990 as the source of lead based paint chips that potentially caused droop wing and chick mortality (FWS, 1990). The remediation effort by FWS to address the paint chips (placed 8,300 lbs of sand on and around the area) is no longer visible and it is presumed that lead-based paint chips are still present (FWS, 2014a).

The previously mentioned asbestos containing material is currently left in place in the old FWS barracks building after the microburst storm in 2012 (FWS, 2013a). The hydrocarbon contaminated soil from the 2004 UST removal was buried in an unknown location and no documentation of removal was found (GeoEngineers, 2004; FWS, 2014a).

Offshore wastes, such as the previously mentioned two large (900 to 1,500 pound sized) lead batteries and materials identified around East Island that were not relocated during the 1998 HAZMAT mobile diving and salvage unit SCUBA cleanup event, are assumed to be buried in sand.

4.3.4 Contaminant Hazards

4.3.4.1 PCBs

PCBs belong to a broad family of manmade organic chemicals known as chlorinated hydrocarbons. PCBs were domestically manufactured from 1929 until their manufacture was banned in 1979. They have a range of toxicity and vary in consistency from thin, light-colored liquids to yellow or black waxy solids. Due to their non-flammability, chemical stability, high boiling point, and electrical insulating properties, PCBs were used in hundreds of industrial and commercial applications, including electrical, heat transfer, and hydraulic equipment; as plasticizers in paints, plastics, and rubber products; in pigments, dyes, and carbonless copy paper; and for many other industrial applications. Products that may contain PCBs include transformers and capacitors as well as other electrical equipment, including voltage regulators, switches, reclosers, bushings, and electromagnets. The PCBs used in these products were chemical mixtures made up of a variety of individual chlorinated biphenyl components, known as congeners. Most commercial PCB mixtures are known in the U.S. by their industrial trade names. The most common trade name is Aroclor (Agency for Toxic Substances and Disease Registry (ATSDR), 2000; EPA, 2014b).

With few exceptions, PCBs were manufactured as a mixture of various PCB congeners, through progressive chlorination of batches of biphenyl until a certain target percentage of chlorine by weight was achieved. Commercial mixtures with higher percentages of chlorine contained higher proportions of the more heavily chlorinated congeners, but all congeners could be expected to be present at some level in all mixtures. Aroclor is a PCB mixture produced from approximately 1930 to 1979. There are many types of Aroclors, and each has a distinguishing four-digit suffix number that indicates the degree of chlorination. The first two digits generally refer to the number of carbon atoms in the phenyl rings (for PCBs this is 12), and the last two digits indicate the percentage of chlorine by mass in the mixture. For example, the name Aroclor 1254 means that the mixture contains approximately 54% chlorine by weight (ATSDR, 2000; EPA, 2014b).

Once in the environment, PCBs do not readily break down and therefore may remain for very long periods of time. They can easily cycle between air, water, and soil. In air, PCBs can be carried long distances and have been found in snow and sea water in areas far away from where they were released into the environment, such as in the Arctic. As a consequence, PCBs are found all over the world. In general, the lighter the type of PCBs, the further they may be transported from the source of contamination. In water, PCBs may be transported by currents, attach to bottom sediment or particles in the water, and evaporate into air. Heavier PCBs are more likely to settle into sediments whereas lighter PCBs are more likely to evaporate to air. Sediments that contain PCBs can also release the PCBs into the surrounding water. PCBs adhere strongly to soil and will not usually be carried deep into the soil with rainwater.

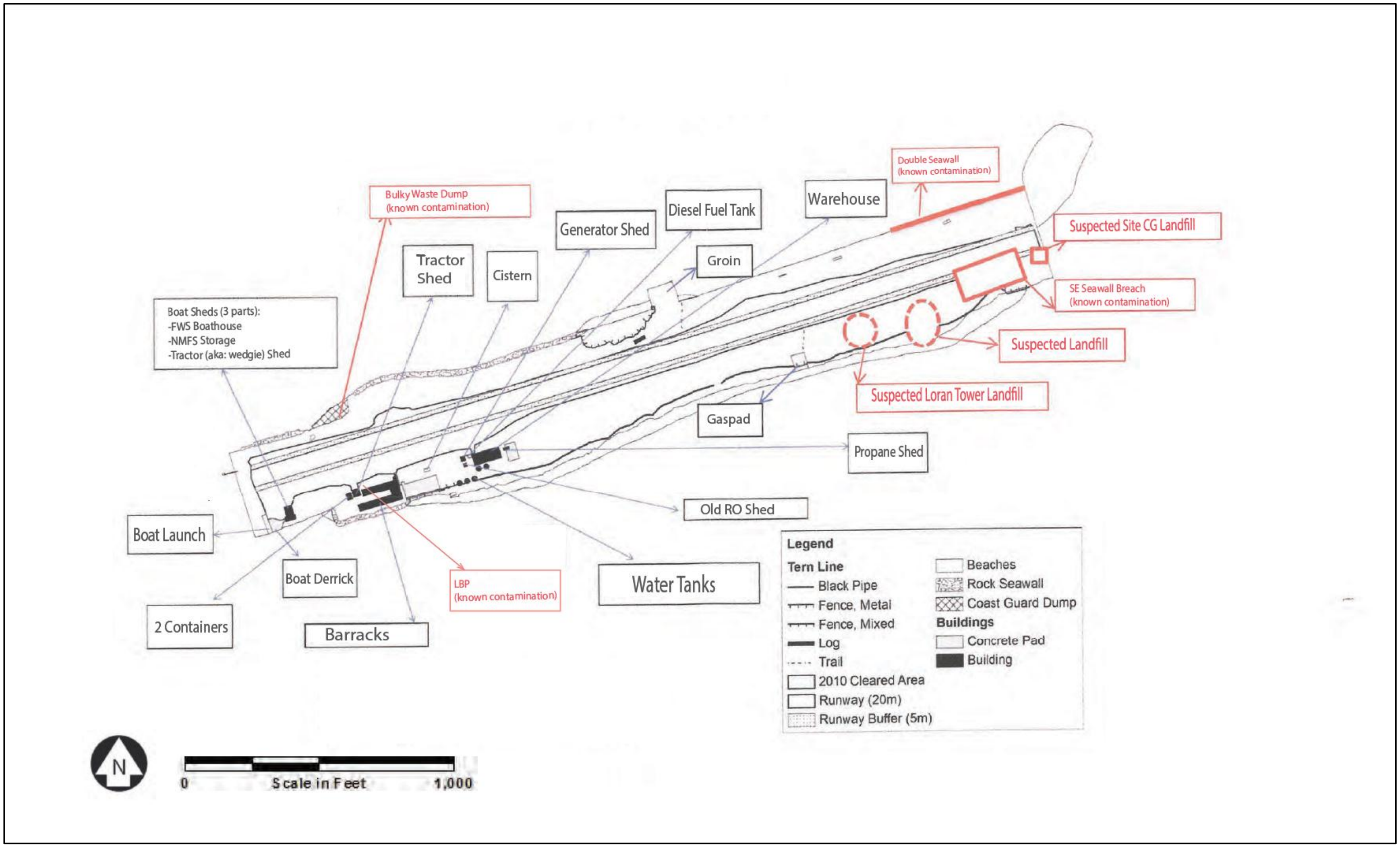

Figure 4-29 Remaining Contamination and Site Features 2012

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They do not readily break down in soil and may stay in the soil for months or years. Generally, the more chlorine atoms that the PCBs contain, the more slowly they break down (ATSDR, 2000; EPA, 2014b).

PCBs are hydrophobic in nature, meaning they repel water and are not water soluble. PCBs have also been shown to prefer adsorption to material with organic content, such as soil when released in water (EPA, 2014b). These characteristics are of note because hydrophobic PCBs in the water column will sorb to and hyperaccumulate on marine plastics, which are made from organic content, as opposed to staying in free phase in seawater.

PCBs are taken up into the bodies of small organisms and fish in water, then by other animals that eat these aquatic organisms as food. PCBs especially accumulate in fish and marine mammals such as seals and whales, reaching levels that may be many orders of magnitude higher than in water. PCBs have been demonstrated to cause cancer as well as produce a variety of other adverse health effects on the immune system, reproductive system, nervous system, and endocrine system (ATSDR, 2000; EPA, 2014b).

4.3.4.2 Hydrocarbons

TPH is a general term used to describe molecular chains made up of carbons and hydrogens. Petroleum hydrocarbons are compounds with a very high energy density, which makes them very useful as fuels. They are widely used all over the world. Some have been more extensively studied than others. The smaller compounds in TPH, like benzene, toluene, ethylbenzene, and xylene (BTEX), are known to cause negative health effects in humans, attacking the central nervous system and sometimes causing death. The International Agency for Research on Cancer (IARC) has shown that benzene causes cancer in humans. Benzene has been given a Group 1 carcinogen designation (ATSDR, 1999b). Very little is known about the toxicity of many of the remaining compounds that make up TPH.

Animal studies have shown that TPH can cause a variety of harmful health effects. Exposure to TPH can include negative health effects in systems like the lungs, central nervous system, kidney, reproductive system, liver, and in developing fetuses if TPH is ingested or inhaled (ATSDR, 1999b). Compounds like PAHs can also have negative effects and can be persistent in the environment. Although individual PAHs vary in behavior, most do not break down easily in water (EPA, 2008).

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Table 4-10 Timeline of Use and Investigations of Tern Island

Year and Agency	Investigation/Use	PCBs	Lead	Hydrocarbons	Heavy Metals	Dioxins	DDT
1942-1946 U.S. Navy	The Navy built a U.S. Naval Air Facility on Tern Island. Built USTs ASTs and Barracks.	S	S	S	S	S	
1946-1970s Commercial fishermen utilized Tern	Commercial fishermen utilized the airstrip to send fish back to Honolulu. Commercial fishing use of the airstrip declined when the waters were considered "fished out".	*	*	*	*	*	
1944-1979 USCG	From 1944 to 1952, the USCG built and operated the LORAN Station on East Island in FFS. Later in 1952 the USCG built and operated a LORAN Station on Tern Island. The LORAN Station was decommissioned in 1979.	S	S	S	S	S	
1960-1963 U.S. Navy	A Pacific Missile Range Facility was operated on Tern Island.	*	S	S	S	S	
1967-1972 U.S. Atomic Energy Commission	U.S. Atomic Energy Commission monitoring station was in operation.		S	S	S	S	
1979-2013 FWS	FWS utilized Tern as a field camp for research of endangered species and avian populations.		S			S	
1982-Current NOAA	Hawaiian monk seal research camps have occupied Tern for the summer months since 1982.		◊				
1982 NOAA	June 1982 Volume IV of The Cooperative Observer Pacific Region documents a National Weather Service facility that transmits weather data by satellite. Construction date unknown.	*	*	*	*	*	
1991 USACE contracted ETI	UST Tank Survey of 21 tanks as part of the Defense Environmental Restoration Program (DERP)		X	X	X		
1992 USACE contracted ETI	UST Tank Closure of 21 tanks as part of the DERP		◊	◊			
1992 FWS	Lead-based Paint Cleanup: An Activity Report documented construction of a fence in an attempt to keep chicks away from the paint chips. The fence proved to be ineffective and approximately 8,300 lbs of sand was used to cover the area.						
1997-December FWS	AST removal: There is little documentation and no sampling data to accompany this event.		◊	◊	◊		
1997 USCG	Geophysical Investigation to find buried landfills	X	X		X		
1997 USCG	Subsurface soil Sampling Investigation: Follow-up to the Geophysical Survey	X	X		X		
1998 Navy	Navy Reserve HAZMAT MDSU Cleanup, funded by USCG Civil Engineering Unit: Divers remove two transformers and 30 lead acid batteries, although large scale batteries (900-1500 lbs) that were observed were not relocated for removal.	◊	◊				
March 1999 USCG	Environmental Investigation of Tern Island: Established Hot Spots 1 and 2.	X	X		X		
1998 FWS	FWS and UH Sediment and Biota Analysis (Miao et al., 2000a)	X	X		X		
1999 USCG	Environmental Investigation of former LORAN Station on Tern Island FFS-Follow-up to Environmental Investigation of Tern Island to fill in data gaps left by previous investigation.	X	X	X		X	X
May 1999-2001	FWS Marine Sediment and Tissue Study; Miao et al. 2000b, 2001 metals and PCB published papers.	X	X		X		X
2000 USCG	Ecological Risk Assessment.						
2001-2002 USCG	USCG Cleanup of former landfill areas on Tern. Remediation Verification Report was generated after the cleanup event.	◊, X	◊				
2002 FWS	EA for the Reconstruction for the Shore Protection for Tern Island.						
2001-2002 UH, Lorenz et al.	Study of Organochlorines in Marine Organisms, Sand, and Sediment.	X					X
2001 UH	Study: Distribution of PCBs in marine species from MMF, North Pacific Ocean, Miao et al.	X					
2004 GeoEngineers contracted by FWS	Two USTs closed One left in place and one shipped off-island for recycling.	X	X, ◊	X, ◊	X, ◊		
2004 Willcox et al.	OC levels in Monk Seals in French Frigate Shoals.	X				X	X
2008 Ylitalo et al.	OC levels in Monk Seals in the NWHI.	X					

S-Potential Source of Contaminant.

◊-Clean-up Action.

X-The investigation sampled for the listed contaminant.

*-Insufficient documentation to determine whether use was a source of contamination.

Table 4-11 Sediment Sampling Results

Sampling Event	Matrix	Total Samples	PCBs	Lead	Arsenic	Cadmium	Chromium	Copper	Selenium	TPH (D or R)	Dioxins/Furans(ppt)	DDT/DDD/DDE (ng/g)	BTEX	Total Organic Carbon
1992 UST Closure Published in 1993														
	Subsurface	11		15.7 mg/kg to 89.1 mg/kg	0.32 mg/kg to 0.43 mg/kg	2.1 mg/kg to 4.6 mg/kg	12.8 mg/kg to 20.0 mg/kg			R-ND to 1,490 mg/kg			ND to 0.007 mg/kg Benzene ND to 0.069 mg/kg Toluene ND to 0.041 mg/kg Ethylbenzene ND to 0.083 mg/kg Total Xylenes	
	Subsurface Background	4		15.6 mg/kg to 56.3 mg/kg	0.53 mg/kg to 1 mg/kg	3.1 mg/kg to 4.3 mg/kg	15.6 mg/kg to 17.2 mg/kg			R- ND to 25 mg/kg			ND Benzene, Ethylbenzene and Xylenes ND-0.005 mg/kg Toluene	
1997 USCG Subsurface Soil														
	Subsurface	37	<2 mg/kg	Average 23.4 mg/kg		Average 2.1 mg/kg	Average 11.6 mg/kg							
1999 URSGWC USCG Environmental Investigation on Tern Island														
	Surface Soil 57 samples Subsurface 34 samples	57	ND to 126 mg/kg in field ND to 2,300 mg/kg in Lab	ND-2,800 mg/kg in field and ND to 3,700 mg/kg in Lab	ND to 50 mg/kg									
1999 Environmental Investigation of Former LORAN Station														
	Surface Soil-278 samples Subsurface Soil- 65 samples	346	0.0099 mg/kg to 92 mg/kg in Lab	0.19 mg/kg to 26,000 mg/kg								2.2 ng/g to 539 ng/g		
	Sediment Reference (La Perouse)	1	ND								D-1.8 ppt F-0.6 ppt			
	Soil-Grab	10								D- 11 mg/kg to 660 mg/kg	ND to 506 ppt			9,600 mg/kg to 56,000 mg/kg
	Marine Sediment	28	ND to 2.728 mg/kg by congener analysis	0.0007 mg/kg to 0.111 mg/kg								ND to DDT-5.2 ng/g DDD-20.0 ng/g DDE- 13.0 ng/g		0.11 to 0.21 percent

Table 4-1 Sediment Sampling Results (Continued)

Sampling Event	Matrix	Total Samples	PCBs	Lead	Arsenic	Cadmium	Chromium	Copper	Selenium	TPH (D or R)	Dioxins/Furans(ppt)	DDT/DDD/DDE (ng/g)	BTEX	Total Organic Carbon
	Marine Sediment Reference (Gin and Little Gin)	4	ND	0.0001 to 0.0002 mg/kg										
	Beach Sand	6	ND to 0.024 mg/kg	0.001 to 0.0016 mg/kg								DDT-8.7 ng/g DDD-31.1 ng/g DDE-1.5 ng/g		0.11 to 0.16 percent
1998 PCBs and Metals in Marine Species from FFS, North Pacific Ocean Dry Weight (Miao et al., 2000a),														
	Marine Sediment	2	0.273 mg/kg and 0.274 mg/kg	22 mg/kg to 44 mg/kg	23 mg/kg to 24 mg/kg	1.3 mg/kg			21 mg/kg to 23 mg/kg					
	Sediment Reference (La Perouse)	1	0.154 mg/kg	20 mg/kg	24 mg/kg	1.0 mg/kg			16 mg/kg					
May 1999 Distribution of PCBs in marine species from MMF, North Pacific Ocean, (Miao et al., 2000b), Dry Weight and Comparative Concentrations of Metals in Marine Species from FFS, (Miao et al., 2001)														
	Marine Sediment	3	0.119 mg/kg to 0.274 mg/kg	0.013 mg/kg to 0.044 mg/kg	0.023 mg/kg-0.028 mg/kg	0.0004 mg/kg to 0.0013 mg/kg	0.0122 mg/kg	0.0368 mg/kg	0.021 mg/kg to 0.023 mg/kg					
	Sediment Reference (Disappearing Island)	1	0.085 mg/kg t	0.0105 mg/kg	0.0248 mg/kg	ND	0.008 mg/kg	0.0078 mg/kg	0.0175 mg/kg					
2002 Chase Remediation Verification Report for USCG														
	Sediment	835	ND to 54 mg/kg											
2002 Study of Organochlorines in Marine Organisms, Sand, and Sediments by UH, Lorenz														
	Turtle Nest Sand	18	0.00002 mg/kg to 0.0427 mg/kg											
2004 UST Closure by GeoEngineers Contracted by FWS														
	Soil	3	0.2 to 0.97 mg/kg	8.6 to 11 mg/kg			5.6 mg/kg to 6.8 mg/kg			D: 420 mg/kg to 42,000mg/kg Gasoline: 1.07 mg/kg			ND	

Lab: results were obtained by laboratory analysis of the constituent
Field: results were obtained by a field analysis method (i.e. XRF)
ND: results were below the detection limit
TPH-D: TPH-Diesel Range
TPH-R: Total Recoverable Petroleum Hydrocarbons
Lab: results were obtained by laboratory analysis of the constituent
Field: results were obtained by a field analysis method (i.e. XRF)
ND: results were below the detection limit
TPH-D: TPH-Diesel Range
TPH-R: Total Recoverable Petroleum Hydrocarbons

Table 4-12 Water Sampling Results

Sampling Event	Matrix	Total Samples	PCBs (µg/L)	Lead (µg/L)	Concentration of TPH (D or R)
1999 Environmental Investigation of Former LORAN Station					
	Groundwater	6	1.2 µg/L to 10 µg/L	12 µg/L to 430 µg/L	D-11,000 µg/L to 240,000 µg/L
	Off-shore Seawater	2	0.000665 µg/L to 0.00449 µg/L	ND	

Table 4-13 Biota Sampling Results

Sampling Event	Matrix	Total Samples	PCBs	Lead	Arsenic	Cadmium	Chromium	Copper	Selenium	Zinc	DDT/DDE/DDD	PAHs
1999 –URSGWC contracted by USCG Environmental Investigation on Tern Island;												
	Monk Seal Scat	5	ND to 0.36 mg/kg									
1999 Environmental Investigation of Former LORAN Station												
	Fish	18	ND to 16.436 mg/kg	ND to 0.0002 mg/kg							ND	ND
	Reference Fish (Gin and Little Gin)	16	ND	ND to 0.0178 mg/kg							ND	ND
	Crab	11	ND mg/kg to 13.859 mg/kg	ND to 0.0038 mg/kg							DDT-27.9 ppb DDD-50.9 ppb	ND
	Reference Crab (Gin and Little Gin)	4	ND	0.0007 mg/kg to 0.0133 mg/kg							ND	ND
1998 Distribution of PCBs in marine species from MMF, North Pacific Ocean, (Miao et al., 2000a)												
	Corals	2	0.237 mg/kg to 0.267 mg/kg	12 mg/kg	13 mg/kg to 14 mg/kg	0.5 mg/kg to 0.6 mg/kg			9 mg/kg			
	Coral Reference (Trig and La Perouse)	2	0.120 mg/kg to 0.181 mg/kg	13 mg/kg to 11 mg/kg	15 mg/kg	0.8 mg/kg to 0.4 mg/kg			6 mg/kg to 10 mg/kg			
	Fish	2	1.3 mg/kg 46.00 mg/kg	16 mg/kg	13 mg/kg	1.1 mg/kg to 1.7 mg/kg			16 mg/kg to 19 mg/kg			
	Fish Reference (Trig Island)	1	2.66 mg/kg	13 mg/kg	16 mg/kg	0.8 mg/kg			13 mg/kg			
	Crab	2	0.387 mg/kg, 4.5 mg/kg	17 mg/kg to 28 mg/kg	49 mg/kg to 51 mg/kg	2.8 mg/kg to 3.6 mg/kg			14 mg/kg to 20 mg/kg			
1999 Distribution of PCBs in marine species from MMF, North Pacific Ocean, (Miao et al., 2000b), Dry Weight and Comparative Concentrations of Metals in Marine Species from FFS, (Miao et al., 2001)												
	Coral	2	0.019 mg/kg to 0.021 mg/kg	0.009 mg/kg to 0.0093 mg/kg	0.0187 mg/kg	0.0001 mg/kg	0.0017 mg/kg to 0.002 mg/kg	0.0053 mg/kg	0.0103 mg/kg to	0.0017 mg/kg to 0.0043 mg/kg		

Table 4-13 Biota Sampling Results (Continued)

Sampling Event	Matrix	Total Samples	PCBs	Lead	Arsenic	Cadmium	Chromium	Copper	Selenium	Zinc	DDT/DDE/DDD	PAHs
	Reference Coral (Disappearing)	1	0.006 mg/kg	0.0097 mg/kg	0.0187 mg/kg	ND	0.0027 mg/kg	0.0053 mg/kg	0.013 mg/kg			
	Reference Coral (Oahu)			0.0004 mg/kg	0.012 mg/kg	ND	0.001 mg/kg	0.008 mg/kg	0.0077 mg/kg	0.0023 mg/kg		
	Eel	4	0.403 mg/kg to 96.470 mg/kg	0.006 mg/kg to 0.0095 mg/kg	0.024 mg/kg to 0.296 mg/kg	0.001 mg/kg to 0.0153 mg/kg	0.003 mg/kg to 0.006 mg/kg	0.004 mg/kg to 0.062 mg/kg	0.018 mg/kg to 0.025 mg/kg	0.079 mg/kg to 0.132 mg/kg		
	Reference Eel (Disappearing Island)	1	0.331 mg/kg	0.008 mg/kg	0.0395 mg/kg	0.0028 mg/kg	0.006 mg/kg	0.035 mg/kg	0.0245 mg/kg	0.141 mg/kg		
	Fish	4	0.245 mg/kg to 28.546 mg/kg	0.0093 mg/kg to 0.031 mg/kg	0.0235 mg/kg to 0.0315 mg/kg	0.0012 mg/kg to 0.0017 mg/kg	0.0078 mg/kg to 0.024 mg/kg	0.014 mg/kg to 0.125 mg/kg	0.0223 mg/kg to 0.0275 mg/kg	0.084 mg/kg to 0.189 mg/kg		
	Reference Fish (Disappearing Island)	4	0.331 mg/kg to 0.604 mg/kg	0.013 mg/kg to 0.020 mg/kg	0.024 mg/kg to 0.121 mg/kg	0.0027 to 0.0063 mg/kg	0.0075 mg/kg to 0.0115 mg/kg	0.019 mg/kg to 0.119 mg/kg	0.0215 mg/kg to 0.0278 mg/kg	0.118 mg/kg to 0.273 mg/kg		
	Crab/Lobster	2	0.452 mg/kg to 19.460 mg/kg	0.011 mg/kg to 0.0565 mg/kg	0.0577 mg/kg to 0.116 mg/kg	0.0029 mg/kg to 0.006 mg/kg	0.005 mg/kg to 0.0468 mg/kg	0.110 mg/kg to 0.343 mg/kg	0.0257 mg/kg to 0.0301 mg/kg	0.129 mg/kg to 0.301 mg/kg		
	Reference Crab (Oahu)	1		0.0002 mg/kg	0.0274 mg/kg0	0.0019 mg/kg	0.0014 mg/kg	0.0497 mg/kg	0.0083 mg/kg			
2002 Study of Organochlorines in Marine Organisms, Sand, and Sediments by UH, Lorenz												
	Turtle Blood	9	ND to 0.0077 mg/kg									
	Turtle Eggs	Collected but not analyzed										
2004 Willcox et al. Study on Organochlorides in Hawaiian Monk Seals												
	Monk Seal	48	0.730 to 14 mg/kg in blood 0.150 to 8.9 mg/kg in blubber								DDT-ND to 8.1 mg/kg In blubber	
2008 Ylitalo et al. Study on Organochlorides in Hawaiian Monk Seals												
	Monk Seal (158 Blood and 78 Blubber)	158	1.8 to 6.3 mg/kg in blood 0.480 to 8.8 mg/kg in blubber								DDE-0.270 to 1.5 mg/kg in blubber	

J: Estimate- analytical result is below method reporting limit.
ND: results were below the detection limit

J: Estimate- analytical result is below method reporting limit.
ND: results were below the detection limit

PAHs are persistent and have been shown to be harmful to marine environments. PAHs have carcinogenic and mutagenic potentials (EPA, 2008). TPH contamination can also cause a variety of negative effects to the metabolic, behavioral, reproductive, and immune systems in marine organisms that can be manifested in the decline of entire populations and communities of animals (Capuzzo, 1985).

4.3.4.3 Heavy Metals

Heavy metals are naturally occurring materials that can be found all over the Earth at varying background levels. Metals are typically very persistent and water soluble in nature. They can be bioaccumulated by humans and animals, increasing in concentration in tissues in an additive fashion, as further contaminants are encountered. In humans, metals usually enter the body through ingestion and inhalation. Fish accumulate metals from the water they live in and the food they eat. Marine mammals, sea birds, and other predators can accumulate high levels of metals from the fish they eat (Martin, Griswold, 2009). Generally higher levels of metals found in tissues of lower trophic level animals (fish) correlate to higher metal levels in higher order species' tissue (monk seals and sea birds) (Jakimska et al., 2011).

Arsenic is a heavy metal that can be found naturally in soils and the environment. In the U.S. arsenic is mainly used for industrial purposes by the wood treatment industry (90%). Arsenic can cause a wide range of symptoms in humans, including negative health effects on the immune system, abnormal heart rhythm and other cardiovascular effects, damage to blood vessels, neurologic effects, and death (Martin, Griswold, 2009). Arsenic is a known human carcinogen and may cause cancers of the bladder, kidney, liver, lung, prostate, and skin. Arsenic-contaminated drinking water is the most common route of exposure to humans (ATSDR, 2007).

Cadmium is a known human carcinogen. It can cause digestive problems, lung and kidney disease, and fragile bones. It is mainly used in electroplating, fertilizers, batteries, and plastics (Martin, Griswold, 2009). The main exposure pathways into the body are through smoking and food consumption (ATSDR, 2012a).

Chromium is a naturally occurring metal and is an essential dietary nutrient. Chromium is also one of the most widely used industrial metals. Compounds are used in industries such as pigment production, chrome plating, stainless steel welding, and leather tanning. General public and environmental exposure is mainly through inhalation of contaminated air or ingestion of food or drinking water containing chromium. Dermal contact is more common with worker exposure. Chromium can cause the following symptoms in humans: breathing problems, ulcers, and skin irritation. Long-term exposure can lead to damage of the liver, kidney, nerve tissue, and circulatory system, and can lead to cancer (ATSDR, 2012b, Martin, Griswold, 2009).

Lead is an extremely toxic heavy metal that is naturally present in the Earth's crust. It can be found in organic and inorganic forms, and it causes adverse health effects in all human organ functions. It is a soft ductile metal with high density. Lead has many industrial applications and it has been used by humans for thousands of years. Pertinent applications of lead in modern times include use as a fuel and paint additive to improve product performance. However, the dangerous health effects on humans and the environment have led to its restricted or discontinued use in many products (ATSDR, 2010).

Lead in the human body can affect many areas. First, it affects the nervous system. Its acute effects on the human body can cause convulsions, stupor, ataxia, and even death. Lead can affect organ operation, development, reproduction, and a wide range of other biological processes in humans (ATSDR, 2010). Lead can cause a variety of negative health effects in birds. Common negative health effects observed in birds as a result of lead exposure include gastrointestinal effects, weight loss, anemia, and a drooped posture. Albatross nesting near paint chips on Tern Island in 1990 exhibited droop-wing attributed to lead based paint chips. Lead can cause changes in behavior and circulatory and biochemical function and a host of other ill effects in birds (Fisher et al, 2006).

Lead is very soluble in water (ATSDR, 2010). This means that once released into a marine environment (Tern Island), it can be transported easily in water and become environmentally accessible to the fragile marine environment.

Mercury is another heavy and possibly carcinogenic metal found in nature. It is very toxic and can cause nervous system, brain, kidney, and reproductive damage in humans (Martin, Griswold, 2009). It is used in gold mining and electronics manufacturing and is a byproduct of coal-fired power plants. Exposure to humans is mainly through the consumption of fish that have mercury in their tissues, such as tuna, although inhalation and absorption are also pathways of exposure. Methylmercury bioaccumulates up the food chain so that the apex predators have the highest levels of mercury in their tissues (ATSDR, 1999a).

Selenium is naturally occurring in rocks and soil. Selenium commonly enters the air through burning coal or oil and is used in metal industries and paint manufacturing. Humans are commonly exposed to selenium through consuming contaminated food or water sources. Dermal exposure causes rashes. Consumption of selenium can cause neurological effects and deformed nail development. Ingestion of large amounts of selenium causes adverse reproductive effects in animals and is life threatening to humans. Selenium sulfide is the one form of selenium that is not a probable human carcinogen (ATSDR, 2003).

In nature these heavy metals can cause negative health effects in fish, sea birds, and marine mammals such as monk seals and whales. Animals at the top of the food chain (apex predators) are far more likely to have higher metal concentrations in their tissues due to the way heavy metals bioaccumulate and biomagnify (i.e., the increase in concentration of a pollutant from one link in a food chain to another) up the food chain. The negative health effects of metal accumulation in marine animals are extremely varied and difficult to study. The species, size, age, sex and many other variables affect how an animal will respond to metals in the environment. Metals also often react to form other molecules that can have varying levels of toxicity. Ill effects have been shown to cause tissue damage, lower uptake of oxygen in fish, liver toxicity, nervous system damage, reproductive and immune system damage, and other negative health effects (Krishna et al., 2003). Low levels of heavy metals are present in building supplies such as treated wood and paints.

4.3.4.4 Dioxins and Furans

Dioxins are naturally occurring in the environment as a result of forest fires. Anthropogenic introductions to the environment include incineration of municipal solid waste, incineration of medical waste, secondary copper smelting, coal-fired power plants, residential wood burning, the paper making process, and backyard burning of household wastes. Dioxins are widely distributed throughout the environment in low concentrations, are persistent, and bioaccumulate in animals and humans. Most people have detectable levels of dioxins in their tissues that have accumulated over a lifetime in the low parts per trillion. At body burden levels 10 times or less the average background exposure, adverse non-cancer health effects have been observed in both animals and, to a limited extent, humans. Effects observed from exposure to elevated levels of dioxins include hormone disruption, alterations in fetal development, reduced reproduction capacity, and immunosuppression (EPA, 2011a).

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5 PLASTICS IN THE MARINE ENVIRONMENT

There is a growing concern about the hazards plastic pollution poses to the marine environment. Plastics pose both physical (e.g., entanglement, gastrointestinal blockage, reef destruction) and chemical (e.g., bioaccumulation of the chemical ingredients of plastic or toxic chemicals sorbed to plastics) threats to wildlife and the marine ecosystem. Although plastics in the remote gyre accumulation areas of the world garner the most media attention, they are not the only waterbodies containing plastics. Plastic pollution is now found in most marine and terrestrial habitats, including the deep sea, Great Lakes, coral reefs, beaches, rivers, and estuaries.

In the Marine Debris Research, Prevention, and Reduction Act, the U.S. Congress defined the term "marine debris" to mean any persistent solid material that is manufactured or processed and directly or indirectly, intentionally or unintentionally, disposed of or abandoned into the marine environment or the Great Lakes (33 U.S.C. § 1956(3)). It is estimated that about 80% of marine debris originates as land-based trash and the remaining 20% is attributed to at-sea intentional or accidental disposal or loss of goods and waste (EPA, 2011b). This breakdown can vary depending on such factors as location of various landmasses, population densities, and behavior of currents in surrounding marine waters. Marine debris impacts the marine ecosystem directly, through ingestion, entanglement, and alteration of the ecosystem, and indirectly, by contributing to the movement of invasive species. Significant economic impacts occur when marine debris impairs tourism, the fishing industry, and navigation. The portion of marine debris comprised of plastic is of particular concern due to its longevity in the marine environment, the physical and chemical hazards it presents to marine and bird life, and the fact that it is frequently mistaken as food by wildlife (Engler, 2012).

Although nearly every type of commercial plastic is present in marine debris, floating marine debris is dominated by polyethylene and polypropylene because of their high production volumes, their broad utility, and their buoyancy (Colton et al., 1974; Ng and Obbard, 2006; Rios et al., 2007). Low-density polyethylene or linear low-density polyethylene is commonly used to make plastic bags or six-pack rings; polypropylene is commonly used to make reusable food containers or beverage bottle caps.

In contrast to other organic and inorganic marine debris, plastics and synthetic materials are typically persistent in the environment while maintaining their bioavailability. Plastic objects typically fragment into progressively smaller and more numerous particles without substantial chemical degradation (Barnes et al., 2009). It is currently unknown how long traditional plastics persist in the environment, but degradation rates may be as slow as just a few percent of carbon loss over a decade (Andrady, 2011). The physical breakdown of plastics is likely to decrease in the deep sea and non-surface polar environments (Barnes et al., 2009; Roy et al., 2011; Cooper and Corcoran, 2010) where weathering conditions are less of a factor.

Although much of the marine debris research focuses on floating plastic debris, it is important to recognize that only approximately half of all plastic is positively buoyant, i.e., it floats (EPA 1992).

Buoyancy is dependent on the density of the material and the presence of entrapped air (Andrady, 2011). After some amount of time in the ocean, floating plastic debris may become sufficiently fouled with biological growth that the density becomes greater than seawater, and it sinks (Ye, Andrady, 1991). The presence of plastics has been documented throughout the water column, including on the seafloor of nearly every ocean and sea (Ballent at al., 2013, Maximenko et al., 2012).

The majority of the plastic debris items documented and recorded seen washing up onto Tern Island fall into the realm of macroplastic; however, 90% of the plastics in the pelagic marine environment are microplastics (less than 5 mm in diameter) (Eriksen et al., 2013; Browne et al., 2010; Thompson et al., 2004). Microplastics arise from the fragmentation of larger pieces as they weather from the effects of ultraviolet rays, and wind and wave action. Recent information on the use of tiny plastic abrasives (commonly called microbeads or nanobeads), especially in personal care products and home cleaning products, and synthetic fabrics shedding during laundering has shown the prevalence of nanoparticle size (micron-sized) plastics as being pervasive in some water bodies. (Eriksen et al., 2013). The plastics may not be removed as part of the wastewater treatment facility process and may pass through largely unchanged. These nanoparticle plastics, as well as other microplastics, are available for ingestion by a wide range of animals in the aquatic food web.

The introduction of plastics into the marine food web is well documented (Ryan et al., 2009; Rochman et al., 2014). The tendency for plastics to act as a sink for persistent, bioaccumulative, and toxic (PBTs) substances, i.e., contaminants such as DDT and PCBs will preferentially adsorb to the surface of the plastic in the water, is also well documented (Engler, 2012; Teuten, 2007; Teuten et al., 2009). Additionally, the fact that plastics are by nature organic, originating from oil, make plastics a natural sorbent for hydrophobic PBTs (Engler, 2012). Roughly half of all plastics are positively buoyant, which allows them to be transported great distances by ocean currents. Plastic consumption by marine organisms, along with their tendency to sorb toxic and persistent substances and their ability to be transported great distances, poses a significant risk to human health and the environment (EPA, 2011b). Frias et al. (2010) suggest that the entire food web may be impacted because of the pervasive nature of plastic and its widely accepted use. Plastics are a transport vector not only for PBTs to enter into the food web, but also for metals. Lavers et al. found a correlation between the mass of plastics ingested and the amount of trace metals (chromium and silver) present in fledgling flesh-footed shearwaters (Lavers et al., 2014).

From September 2001 to September 2006, EPA funded the Ocean Conservancy to conduct beach monitoring for marine debris nationwide, including in the Hawaiian Islands. This study established that Hawaiʻi on average receives a greater assortment of types of marine debris than the rest of the nation. Unlike the mainland, where generally 80% of marine debris comes from a land-based source, in Hawaiʻi ocean-based items comprise over 40% of debris (i.e., fishing line, rope, and nets) (National Marine Debris Monitoring Program, 2007). The Ocean Conservancy study did not include microplastics in its analysis. Long-term trend analysis of plastic abundance has been determined by studying plankton samples that have been collected regularly since the 1960s.

Global trends suggest that accumulations are increasing in aquatic habitats (Thompson et al., 2004), consistent with trends in plastic production.

5.1 PERSISTENT BIOACCUMLATIVE AND TOXIC SUBSTANCES AND PLASTICS

PBTs pose a risk to the marine environment because they resist degradation, persisting for years or even decades. PBTs are toxic to humans and marine organisms and have been shown to accumulate at various trophic levels. Even at low concentrations, PBTs can be insidious in the environment due to their ability to biomagnify up the food web, leading to toxic effects at higher trophic levels even though ambient concentrations are well below toxic thresholds. The subset of PBTs known as POPs are especially persistent, bioaccumulative, and toxic (such as DDT, dioxins, and PCBs) (Engler, 2012).

Generally PBTs have very low water solubility or are hydrophobic. For this reason, when in the marine environment, they tend to partition to sediment or concentrate at the sea surface (Hardy et al., 1990; Hardy et al., 1992) and not dissolve into solution. When PBTs encounter plastic debris, they tend to preferentially sorb to the debris.

Different pollutants sorb to different types of plastics in varying concentrations depending on the concentration of the PBT in seawater and the amount of plastic particle surface area available to sorb to. Plastics on the seafloor may sorb PBTs from the sediments (Graham, Thompson, 2009; Rios et al., 2007), in addition to sorbing them from the seawater. Concentration of PBTs such as PCBs and DDE on plastic particles have been shown to be orders of magnitude greater than concentrations of the same PBTs found in the surrounding water. This concept of hyperconcentration will be discussed further in Section 5.1.1.

Overall, the potential for PBTs to sorb to plastic debris is complex because their behavior in the environment will vary; however, they are more likely than not to preferentially sorb to plastic debris. The particular affinity to sorb will depend on the PBT and type of plastic: polyethylene sorbs PCBs more readily than polypropylene does (Endo et al., 2005). The longer plastic is in the water, the more weathered and fragmented it becomes (Teuten et al., 2007). With increased fragmentation comes higher relative surface area, thereby increasing the relative concentration of sorbed PBTs (a process referred to as hyperconcentration of contaminants) (Engler, 2012).

While sorbed on floating plastic debris, PBTs may be transported significant distances (Zarfl, Matthies, 2010). A country may ban a particular PBT, but still encounter the banned PBT through the food supply due to sorbing of the PBT to plastic debris in the ocean and subsequent entry into the food web.

In general, the types and concentrations of PBTs on plastic may be an indicator of a nearby source (Kaminuma et. al., 2000). For example, because of the historical production and use patterns, debris near the industrial coasts of the U.S. and Japan has higher concentrations of sorbed PCBs than debris in other less industrialized locations (Eriksson, Burton, 2009; Ebbesmeyer, Scigliano, 2009; Zarfl, Matthies, 2010). Sorbed PCB concentrations will vary with the local concentrations of PCBs in the water and the time the plastic is in the water. It may take months for the PCBs to equilibrate between the water and the plastic (Mato et al., 2001; Müller et al., 2001). Floating and stranded plastics have been found with sorbed PCB concentrations ranging from 4 to 5000 ppb (Carpenter et al., 1972; Colabuono et al., 2010; Endo et al., 2005; Frias et al., 2010; Mato et al., 2001; Ogata et al., 2009; Rios et al., 2007). In a further experiment, virgin resin pellets were shown to adsorb contaminants from seawater within a 6-day exposure period. Although adsorption was constant, maximal concentrations were not reached in this time, indicating adsorption is not a rapid or linear process (Mato et al., 2001).

Plastics tend to have a high affinity for the sorption of hydrophobic compounds (PAHs, PCBs, DDT) (Teuten et al., 2009; Frias et al., 2010). Plastic serves to concentrate and transfer toxic chemicals from the ocean onto the surface of the plastics and when consumed, into the marine food web and to human diets (EPA, 2010; Gouin et al., 2011).

5.1.1 Hyperconcentration

Evidence of the behavior of microplastics and the synergistic interaction with contaminants present in the marine environment has been highlighted by several studies conducted in recent years. Mato et al. (2001) identified PCBs, nonylphenol, and DDE on polypropylene resin pellets collected from Japanese waters at similar or higher concentrations than those found in sediments. When plastics are able to sorb POPs at greater concentrations than the seawater that contains the source of contamination, it is referred to as hyperconcentration. For example, phenanthrene, a PAH, partitions to plastic debris 380 to 13,000 fold over seawater (Karapanagioti, Klontza, 2008).

PBT concentrations on plastic particles will vary with the local concentration of PBTs in the water, the time the plastic debris has spent in the water, the type of plastic, the degree of weathering, and the particle size (Artham and Doble, 2009; Engler, 2012; Rochman et al., 2013a). Rios et al. (2007) detected sorbed contaminants on plastic pellets in Japanese waters: 4,4-DDE was found on all samples up to a concentration of 5,600 ng/g; and PCBs were observed on all but four samples with concentrations of 39 to 1,200 ng/g. Teuten et al. (2007) observed PCBs at concentrations 10^6 higher on polystyrene (commonly called Styrofoam) pellets than in surrounding water. Analysis of plastic fragments (less than 10 millimeters) sampled from pelagic and near shore stations, revealed a range of pollutants, including PCBs, PAHs, DDTs and its metabolites, polybrominated diphenyl ethers (PBDEs), and Bisphenol A adhered to the surface of the plastics at concentrations of 1 to 10,000 ng/g (Hirai et al., 2011; Mato et al., 2001; Rochman et al., 2014).

Recent studies have shown POPs to have greater affinity for a range of plastics, including polyethylene, polypropylene, and polyvinyl chloride (PVC), than for natural sediments. Furthermore, plastic debris sorbs PCBs and DDE about one hundred times better than naturally occurring suspended organic matter (Mato et al., 2001). In a coralline environment such as Tern Island, with associated low organic carbon content, this tendency for PBTs to adsorb to plastics would be exaggerated. Sorption extent and rate are influenced by factors including sorbent properties, sorbate properties, dissolved organic compounds in the aqueous phase, pH, and temperature. At a given environmental temperature, a particular polymer is classified as glassy (such as polyvinyl chloride [PVC] and polyethylene terephthalate [PET]) or rubbery (such as high-density polyethylene, polypropylene and low-density polyethylene). Glassy polymers exhibit greater POP sorption capacities and slower POP release rates than rubbery polymers (Rochman et al., 2013a). Moreover, the size of the plastic pellet or fragment strongly affects the rate at which sorbed POPs can be subsequently desorbed into wildlife upon ingestion. The smaller the particle or fragment, the larger the relative surface area to volume ratio, and the greater relative adsorption and desorption opportunity (Teuten et al., 2009).

A recent study by Holmes et al. showed plastic pellets contained concentrations of trace metals (chromium, nickel, zinc, cadmium, and lead) that in some cases exceeded concentrations reported from the local estuarine sediment. Laboratory experiments showed trace metals adsorb to both virgin and beached pellets, with greater adsorption on aged pellets. This study showed that plastics may represent an important vehicle for metal transport in the marine environment (Holmes et al., 2012).

5.1.2 Bioconcentration and Biomagnification

Bioconcentration is the process of concentrating PBTs from ocean waters or food sources to the tissues of various marine species. Predators may be exposed to PBTs directly through ingestion of seawater, dermal contact, and ingestion of contaminated plastic particles, as well as through prey food that has been contaminated with PBTs. If this dual exposure occurs faster than the toxicant can be eliminated from the organism, the PBT is said to bioaccumulate. Biomagnification refers to the phenomenon in which PBTs are discovered at increasing concentrations in progressively higher trophic levels (Engler, 2012).

Research on the behavior of PBTs in the gut of deposit feeders (e.g., worms) showed that the surfactants present in their digestive process tend to mobilize the PBTs from contaminated sediment and make them available to the worms (Ahrens et al., 2001; Voparil, Mayer, 2000; Mayer et al., 1996). Furthermore, deposit and suspension-feeding species may be selectively ingesting plastic particles over sand grains (Graham, Thompson, 2009).

Laboratory studies suggest that mussels and other filter feeding species may ingest microplastics during feeding and eliminate them slowly, so these particles may remain in the shellfish for weeks or months (Browne et al., 2008; Browne et al., 2010). Mussels, as well as mammals, can absorb microplastic particles directly into their circulatory or other organ systems (Volkheimer, 1975; Hussain et al., 2001). A longer residence time of plastic particles within the organism increases the likelihood of PBT desorption and contributes to the bioaccumulation of PBTs (Gouin et al., 2011).

A study of Myctophids examined the relationship between the bioaccumulation of hazardous chemicals associated with plastic debris and density of plastic particles in pelagic habitats in the South Atlantic Ocean. Importantly, this study found that fish analyzed for PBDEs exhibited a significant relationship between plastic densities and the concentration of higher brominated PBDE typical of that found in plastic in their tissue. Both plastic debris and the surrounding seawater were analyzed for the same chemicals as the Myctophids. PBDEs and other POPs were detected on the plastic debris, at concentrations of up to 6 orders of magnitude above those found in the water column. The levels of chemicals in the seawater compared to the levels of the same chemicals found on the plastic particles indicates that the plastics serve to concente the chemicals in the ocean water (Rochman et al., 2014).

Previous research examining PBDEs in short-tailed shearwaters (*Puffinus tenuirostris*) from the North Pacific Gyre found higher PBDE levels in birds than those present in the natural prey. The same compounds were present in plastic found in the stomachs of the birds. Similar to the Myctophid study,these data suggested the transfer of plastic-derived chemicals from ingested plastics to the tissue of marine-based organisms (Tanaka et al., 2013).

The results of a field experiment, in which streaked shearwater chicks were fed with plastic resin pellets to examine the transfer of PCB contaminants from plastic to seabird, indicated the transfer of PCBs, especially lower chlorinated congeners, occurred from ingested plastics to the biological tissue of the organisms that intake the plastics (Teuten, et al., 2009).

Borga et al. found that for arctic cod, over 87% of the exposure to a specific PCB congener was through prey food rather than absorption directly from the water (Borga et al., 2001). Artic cod are in the middle of the trophic food web, so it is not surprising that the majority of the burden of a PBT comes from preyfood rather than direct absorption from the water.

A United Nations case study found that biomagnification of POPs increases the body burden for higher-trophic-level organisms such as apex predators like Hawaiian monk seals or sperm whales (Han and Stone, undated). Tissue concentrations of hydrophobic and poorly metabolized contaminants, such as PCBs, are amplified through the food web. Organisms at higher trophic levels, such as seabirds and marine mammals, are exposed to highly enriched concentrations of hydrophobic contaminants through their prey (Geyer et al., 2000).

Data collected from Tern Island show a clear progression of bioconcentration and biomagnification of PCBs. High trophic species such as fish and eels were found to highly bioaccumulate PCBs at Tern Island (Miao et al., 2000b).

Table 5-1 Concentrations of PCBs in Seawater and Higher Trophic Levels at Tern Island

Seawater	0.00449 µg/L
Coral	21 ng/g
Moray Eel	96,470 ng/g

(URS, 1999; Miao et al., 2000b)

5.2 PLASTIC MOVEMENT

5.2.1 Horizontal and Vertical Migration

Plastics can now be found in most marine habitats; however, the movement of plastics is poorly understood because of the difficulty of studying plastics in remote marine environments. Approximately half of all manufactured plastics have a higher density than seawater (EPA, 1992; Moret-Ferguson et al., 2010). Additionally, even positively buoyant plastics become fouled with growth until the density increases to the extent it will sink, eventually reaching the benthos.

Several studies have identified the primary transport mechanisms by which marine debris accumulates in the convergence zones of the world’s oceans (Kubota, 1994; Martinez et al., 2009; and Ingraham and Ebbesmeyer, 2000). These mechanisms are a combination of Ekman transport and geostrophic currents, and to a lesser degree, Stoke’s drift. Ekman transport is a wind-driven ocean current and has a net transport at right angles to the direction of the prevailing winds in the Northern Hemisphere (Pond and Pickard, 1983). In the North Pacific, the prevailing wind patterns are the Northeast Trade winds blowing generally from east to west in the low latitudes and the westerlies (blowing from west to east in the mid-latitudes) (Figure 4-5).

Geostrophic currents are ocean currents that travel at right angles to horizontal pressure gradients (from high to low pressure) (Brown et al., 1989). In the North Pacific, high pressure dominates the mid-latitudes; therefore, the geostrophic flow pattern becomes clockwise around this high pressure, flowing westward in the low latitudes (North Pacific Equatorial Current), northward in the west (Kuroshio Current), eastward in the higher latitudes (North Pacific Current), and southward in the east (California Current). Stoke’s drift is the net transport of water in the direction of wave travel (Pond and Pickard, 1983).

The coupling of these atmospheric and oceanographic processes creates the North Pacific STCZ. The STCZ is located north of the Hawaiian Islands between the mid-latitude westerlies and the easterly trade winds. The STCZ migrates between 23°N and 37°N with changes in atmospheric high pressure (Pichel et al., 2007; EPA, 2011b). Using satellite imagery, a study in 2005 confirmed the STCZ contains high densities of marine debris (Morishige et al., 2007) and that the islands and atolls of Hawai‘i receive marine debris as a result of the STCZ (Pichel et al., 2007).

Studies based on satellite-derived information and ocean circulation models and confirmed by flight observations show that the largest debris concentration in the North Pacific is found just north of the Chlorophyll-a Front within the North Pacific STCZ, as described in Section 4.1.4.3. Debris densities appear to be significantly correlated with sea-surface temperature and chlorophyll-a concentration (Pichel et al., 2007). The study that determined this correlation was limited to observations of larger- size debris plastics (i.e. identified visually from a plane). Due to the correlation between density of plastics and chlorophyll (because the same climactic forces are mobilizing both), the Chlorophyll-a Front can be used as a proxy for plastic movement.

The correlation of the Chlorophyll-a Front with the STCZ is significant to the pelagic animals that feed there. Pelagic animals preferentially forage in the same convergence zones that concentrate marine debris, thus increasing their risk of ingestion and interaction (Pichel et al., 2007).

5.2.2 Uptake into the Food Chain

Plastics entering the food web have been studied for decades. Perhaps the first study was conducted on Laysan albatross from the reef at Pearl and Hermes Atoll in the NWHI in 1966 (Kenyon, Kridler, 1969). Since that time, studies have demonstrated that plastics enter the food web at many trophic levels from planktavores to apex predators (Goldstein, Goodwin, 2013; Choy, Drazen, 2013; Jacobsen et al., 2010).

Results of a 2013 study showed that 33.5% of goosenecked barnacles (a planktavore) collected from the North Pacific Gyre surface ingested microplastics. The sizes and types of ingested particles were representative of microplastics found on the surface water. Plastic ingestion in these barnacles may be explained by non-selective suspension feeding while exposed to high concentrations of microplastics (Goldstein, Goodwin, 2013).

Setala et al. (2014) studied Baltic Sea zooplankton taxa to scan their potential to ingest plastics. Mysid shrimps, copepods, cladocerans, rotifers, polycheate (worm) larvae, and ciliates were exposed to polystyrene microplastics. Ingestion was confirmed in all taxa studied. The individuals with the highest percentage of ingested microplastics were the polycheate larvae. The study also documented the microparticle transfer up one trophic level when zooplankton that had ingested the microplastic sphere were ingested by a mysid shrimp (Setala et al., 2014).

Ingestion of mostly microplastic fibers was found in 83% of the Norway lobster (Murray and Cowie, 2011). Ingested microplastic debris was also identified from 10 fish species from the English Channel (Lusher et al., 2012). A study of the movement of debris from mussels to crabs in the benthic system also indicates that microplastics introduced into the food web by feeding at one trophic level may transfer to other higher trophic level organisms (Farrell and Nelson, 2013).

The inverse could be true as well: as plastics are made physically smaller and excreted from one trophic level, they are made available for lower trophic levels. A recent study of seven species of large predatory pelagic fishes from the central North Pacific found 19% of all individuals examined (595 total) contained some form of marine debris, the majority of which consisted of plastic or fishing-related line. (Choy, Drazen, 2013). Due to the visual analysis utilized in this study nano-sized particles are unlikely to have been identified and therefore the percentage of individuals containing plastics may be underestimated.

Ingestion of marine debris can be fatal to large whales. In 2008 two sperm whales stranded along the northern California coast with 134 different types of plastic debris in their stomachs. One animal had a ruptured stomach; the other was suspected to have died from gastric impaction (Jacobsen et al., 2010).

Plastic ingestion is not limited to direct ingestion; it has also been documented as a secondary ingestion. Higher trophic fish not only consume plastics directly, mistaking it for food, but also consume prey that have ingested plastic. The origin of plastic particles found in some piscivorous fishes has been linked to consumption of prey containing ingested plastics (Davidson, Asch, 2011).

The potentially toxic effects of microplastics on the ecosystem at Tern Island have not been studied. Due to the restricted geographic ranges of the endemic fish, and the proximate foraging ranges of the Hawaiian monk seals found in FFS, the exposure to microplastics through the food web is identified as an area that requires further study.

5.3 TERN ISLAND DEPOSITION

The unique bathymetry and relative geography of the NWHI form a debris convergence zone and deposition area, with ocean currents and prevailing winds aggregating derelict fishing gear and other forms of marine debris in this area (Kubota, 1994; Ingraham and Ebbesmeyer, 2001). A 16-year study spanning 1990 through 2006 looked at the composition and trends of macro marine debris deposition at FFS. During that time, a total of 52,442 marine debris items were deposited on Tern Island beaches, with the annual deposition ranging from 1,116 in 2001 to 5,195 items in 2004. Plastics, excluding polystyrene, comprised 71% of the marine debris deposited on Tern Island during the study, followed by glass at 17%, and polystyrene, rope, metal, rubber, and wood comprising less than 13% as a group. Marine debris deposition did not change significantly with seasonal variation, although significant variations were observed during El Niño events. Average debris deposition was calculated biweekly and totals during El Niño periods were greater than those for La Niña periods or non-event periods (Friedlander et al., 2005; Morishige et al., 2007).

Surveys conducted by NOAA from August 2000 to April 2011 collected marine debris in the FFS. A total of approximately 77,221 kg of debris was recovered, including 62,797 kg of trawl/seine netting and 9,393 kg of monofilament or multifilament gillnetting (NOAA, 2014g) (Figure 5-1).

Seabirds are also a source of plastic deposition. When seabirds regurgitate a bolus (pellet of indigestible matter), there is a potential that the bolus contains plastics. Passing plastics through the gut also results in plastic deposition. Finally, plastics ingested by seabirds that die would become available (Hawaiʻi Pacific University [HPU], 2013). Plastics in seabirds will be discussed in detail in Section 5.4.

Our understanding of the characteristics and behavior of marine debris is generally confined to studies collecting data on marine debris in areas along the coastlines (e.g., beaches) or in the upper reaches of the water column. The vast majority (90%) of plastic debris found in the pelagic environment is generally less than 5 mm in diameter (Eriksen et al., 2013; Browne et al., 2010; Thompson et al., 2004; Rochman et al., 2014). The microplastics on Tern Island have not been studied and are identified as a data gap in understanding the impacts to sensitive species that live on and around the island.

5.4 PLASTICS IN SEABIRDS

Plastic ingestion by seabirds has been studied for decades. The threats posed by ingesting plastics include gastrointestinal impaction, ulceration, starvation, dehydration, exposure to contaminants, entanglement, and added weight causing more energy expenditure for foraging and flying (HPU, 2013). Albatross garner the most attention when it comes to ingestion of plastics because of the sheer volume consumed (Figure 5-4).

The transfer of contaminants from plastics to seabirds was studied in Streaked Shearwater chicks in 2011 by feeding the chicks plastic resin pellets contaminated with PCBs. Eight 40-day old chicks were used for the experiment. Five were fed the polyethylene pellets containing significant amounts of PCBs mixed with fish, and three were the control and were fed fish without the pellets. The preen gland oil was collected from the chicks every 7 days and tested for PCB concentrations. The PCB concentrations in the preen gland oil increased in the early periods (day 0 to 7) in the plastic-fed group but not in the control. This study suggests that ingestion of contaminated plastics could facilitate the metabolism of PCBs in the chicks (Yamashita et al., 2014). An earlier study corroborated Yamashita's findings but studied great shearwaters (Ryan, 1987). The Ryan study found a significant positive correlation between PCBs and plastic loads in the birds, suggesting a pathway from contaminated plastics facilitating PCB metabolism. The earlier study used 20 female great shearwaters and their eggs (Ryan et al., 1988).

The Yamashita study was significant because it showed that PBTs sorbed to plastics will desorb and concentrate in seabirds. Recent research by Lavers et al. demonstrated that flesh-footed shearwaters (*Puffinus carneipes*) showed high concentrations of both chromium and silver as fledglings, and that the concentration level for each metal was positively correlated with the mass of plastic ingested by the birds. This is the first study to show a correlation between the amount of consumed plastic and the concentration of trace metals in bird tissues.

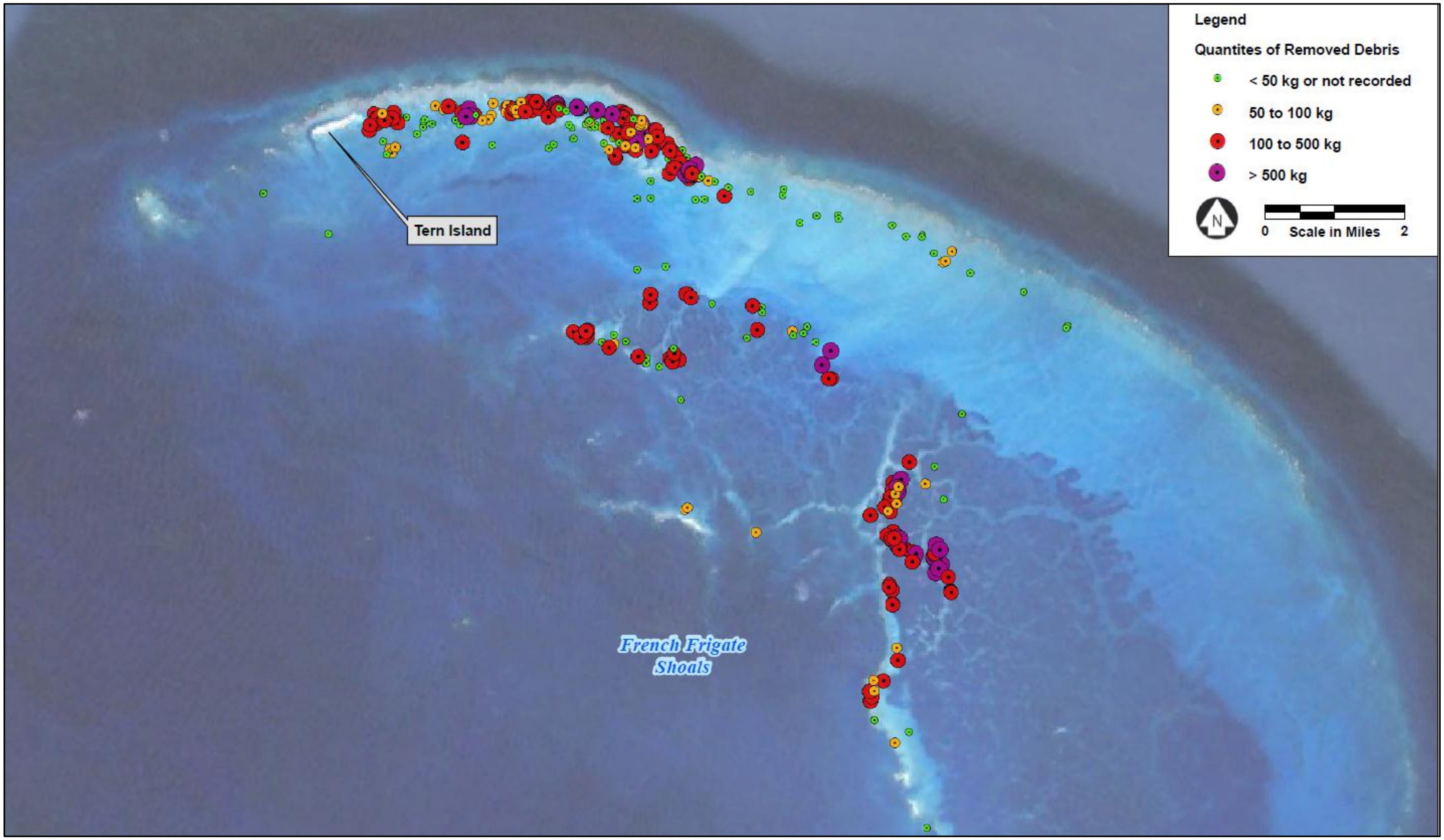

Figure 5-1 Locations of Marine Debris Removal by NOAA

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Three of the nine fledglings sampled contained chromium concentrations above those that can lead to adverse neurotoxic effects (Lavers et al., 2014).

Studies have shown a correlation between the amount, type, and size of plastic ingested by seabirds and the seabirds' feeding mode (e.g., aerial plunging, piracy, surface seizing, etc.) Species which fed by aerial plunging or piracy and primarily on fish have the lowest incidence of plastic consumption (Hyrenbach et al., 2014). These species are more likely to take subsurface particles and are more closely cued to prey movement (Ashmole, 1971), resulting in less attraction to floating, manmade debris. In addition, plunging and pirating seabirds are perhaps less likely to concentrate their foraging activities along oceanic fronts (Haney and McGillivary, 1985) where plastic particles accumulate. Birds that feed on crustaceans and squid by pattering, surface seizing, and pursuit plunging or pursuit diving showed the highest incidence of plastic consumption. Similar results were reported by Day et al.(1985) and Ryan (1987). The preferential selection of sizes and types of plastic was studied by Colton et al. (1974) in the North Atlantic and Day et al. (1985) in the North Pacific. These studies found that plastic fragments made up the vast majority of plastic pieces consumed. Because different types of plastics sorb POPs and metals at different rates (Rochman et al., 2013a), the preferential selection of some plastics over others could increase the risk for certain species that prefer certain types of plastic.

Figure 5-2 Plastic from One Laysan Albatross from Midway (Photo credit FWS volunteer)

HPU has a well-developed ornithological program, a portion of which is devoted to studying birds on Tern Island. A study, as yet unpublished, on Tern Island was conducted to determine what percentage of a specimen's total weight consisted of ingested plastic. Hyrenbach et al., found that 13% of the body weight of a Laysan albatross and 6% of the body weight of a Tristram's storm petrel was ingested plastic. Although the cause of mortality cannot be directly attributed to plastic ingestion in these two birds, it is assumed that a high percentage plastic-to-specimen weight ratio could have deleterious effects on the birds. The study was biased in that it only sampled dead birds. The study found that far fewer Suliformes (diving species such as great frigatebird and boobies) contained plastics when compared to the Procellariiformes (tube nosed species such as albatross and petrels) (Figure 5-3). Alarmingly, 100% of Tristram's storm petrels (IUCN species of high concern) contained ingested plastics (Figure 5-3). This species has a low reproductive rate when compared with other storm petrels; however, it is unknown whether the population is declining (McClelland et al., 2008). The high mortality rate for Tristram's storm petrels was also of note because there are only 200 breeding pairs known to nest on Tern Island (Hartzell et al., 2012)

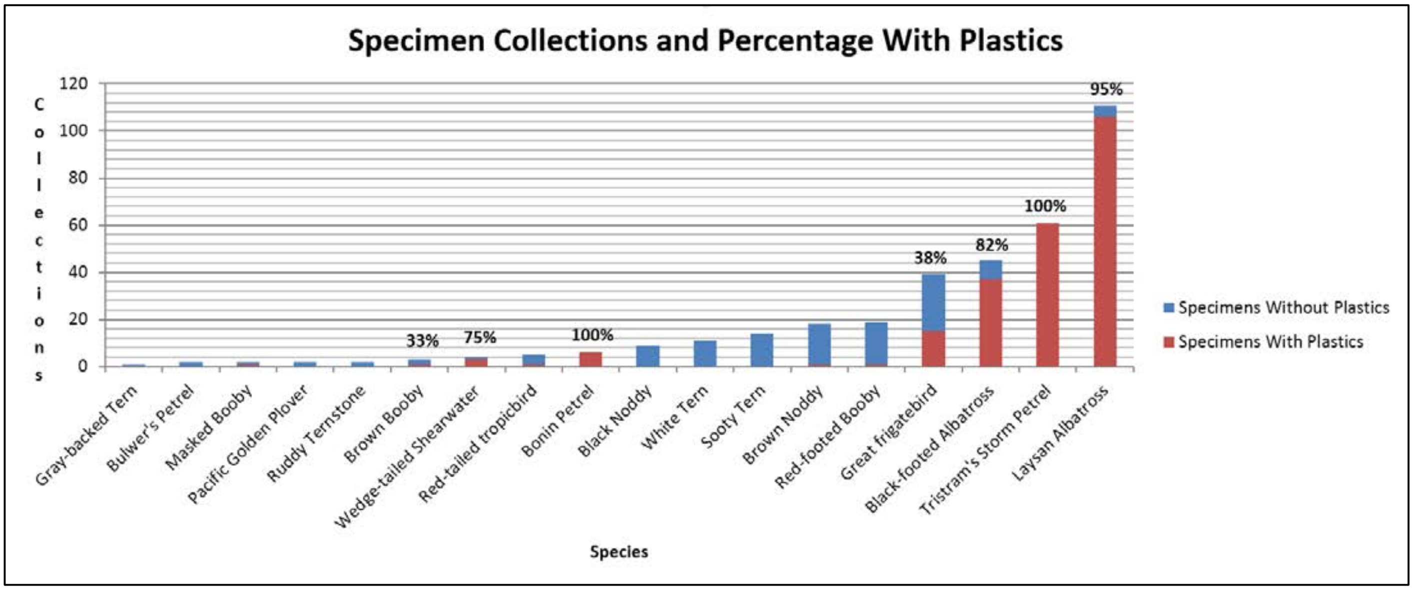

Figure 5-3 Percentage of Birds with Ingested Plastics 2010-2014

Source Hyrenbach et al., 2014

Seabirds that feed their chicks by regurgitation (such as albatross) transfer plastic from adult populations to chick populations. It is suggested that the size of the plastic ingested often correlates with the preferential size of food items common to each species of seabird (Sileo et al., 1990). Plastic ingestion may cause seabird starvation if the presence of plastic in the gut signals satiety and reduces bird appetites (Day et al., 1985).

The bolus is a compacted mass that albatross chicks regurgitate prior to their first flight (fledging). The content of the boluses from the Laysan and black-footed albatross collected from Tern Island reflect the differing feeding strategies of the two species. The Laysan albatross boluses contained pieces and chunks of hard and floating plastics in odd shapes, including an intact cigarette lighter and numerous squid beaks (natural prey). The bolus of the Black-footed albatross contained filamentous plastics and large pieces of polystyrene and were more firmly compacted. The large pieces of polystyrene were nearly identical to a mass of flying fish eggs, which is natural prey (HPU, 2013).

A study of 144 boluses from Laysan and Black-footed albatrosses collected on Kure Atoll in 2000 found 100% to contain plastics (Kinan, Cousins, 2000). Of the Laysan (88) boluses, 19% had lighters and 1% contained light sticks; however, in the Black-footed (56) boluses, none had lighters or light sticks. The Black-footed boluses contained on average more than twice as much plastics as the Laysan boluses. This could be contributed to how they forage – Laysan albatross forage more in subarctic waters and Black-footed albatross focus foraging efforts in subtropical waters (Hyrenbach et al., 2002). Chick survival is dependent on the foraging success of the parent birds. A high percentage of plastics in the stomachs of the chicks could be detrimental to the development of the chicks by displacing natural food sources that could be providing nutrients and fats (HPU, 2013).

Studies indicate that plastic ingestion is widespread among seabirds, that plastic ingestion by procellariiformes has increased, and that some species may actively select plastic particles, perhaps ingesting them along with natural prey organisms such as flying fish eggs (Moser, Lee, 1992). Given Tern's vital seabird nesting habitat, especially for albatross and petrels, understanding the long-term toxicological effects of plastic ingestion is crucial. The interaction of plastic ingestion and digestive juices and how they relate to the leaching of POPs, such as PCBs, DDT, and DDE (Yamashita et al., 2014), and metals such as chromium (Lavers et al., 2014) is an area needing further study.

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6 SUPPORTING AGENCIES AND ORGANIZATIONS

The following agencies and organizations contributed in the data collection and direct feedback for this TSD:

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- United States Fish and Wildlife Service
- Hawaiʻi Pacific University
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- State of Hawaiʻi Department of Health
- Hawaiʻi Department of Land and Natural Resources
- University of Hawaiʻi at Mānoa
- United States Coast Guard

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