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A Baseline Chemical Contaminants Assessment of Sediment from the Nu'uuli Pala Lagoon, American Samoa

NOAA National Centers for Coastal Ocean Science
Stressor Detection and Impacts Division

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December 2019

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NOAA NCCOS Stressor Detection and Impacts Division

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A Baseline Chemical Contaminants Assessment of Sediment from the Nu'uuli Pala Lagoon, American Samoa

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ABSTRACT

Thirteen marine sediment samples were collected as part of an effort to characterize and assess chemical contamination in the Nu'uuli Pala Lagoon on the island of Tutuila, American Samoa. Overall, concentrations of organic contaminants in sediment from the Nu'uuli Pala Lagoon are low as compared to other studies conducted by NOAA's National Status and Trends (NS&T) Program, and are similar to those measured in the nearby Faga'alu watershed and bay. The only organic contaminants measured in the Pala Lagoon that exceeded any known guidelines or thresholds was for total DDT, and then only the Effects Range Low. PBDEs in the Pala Lagoon also appear to be elevated as compared to other relatively lower population coastal US areas. The concentrations of trace and major elements had a number of exceedances of established guidelines, including arsenic, chromium, copper, nickel, and zinc. Nickel was the only metal that exceeded both the ERL and ERM, pointing towards likely adverse impacts to the Pala Lagoon.

INTRODUCTION

This report contains the results of a chemical contaminants assessment of the Nu'uuli Pala Lagoon Special Management Area (SMA) located on the island of Tutuila, American Samoa. This characterization was conducted by the National Oceanic and Atmospheric Administration's (NOAA) National Centers for Coastal Ocean Science (NCCOS), National Status and Trends (NS&T) Program, with funding from NOAA's Coral Reef Conservation Program (CRCP), and in partnership with the American Samoa Environmental Protection Agency (ASEPA), the American Samoa Coral Reef Advisory Group (CRAG), and the American Samoa Community College (ASCC). NOAA's NS&T Program measures a standard suite of 193 chemical contaminants in US coastal waters, including the Great Lakes and coral reef systems, and maintains a database of previous chemical contaminants studies that provides a baseline against which we can compare data from this study. An additional 299 organic chemical contaminants were also measured in addition to the NS&T standard suite.

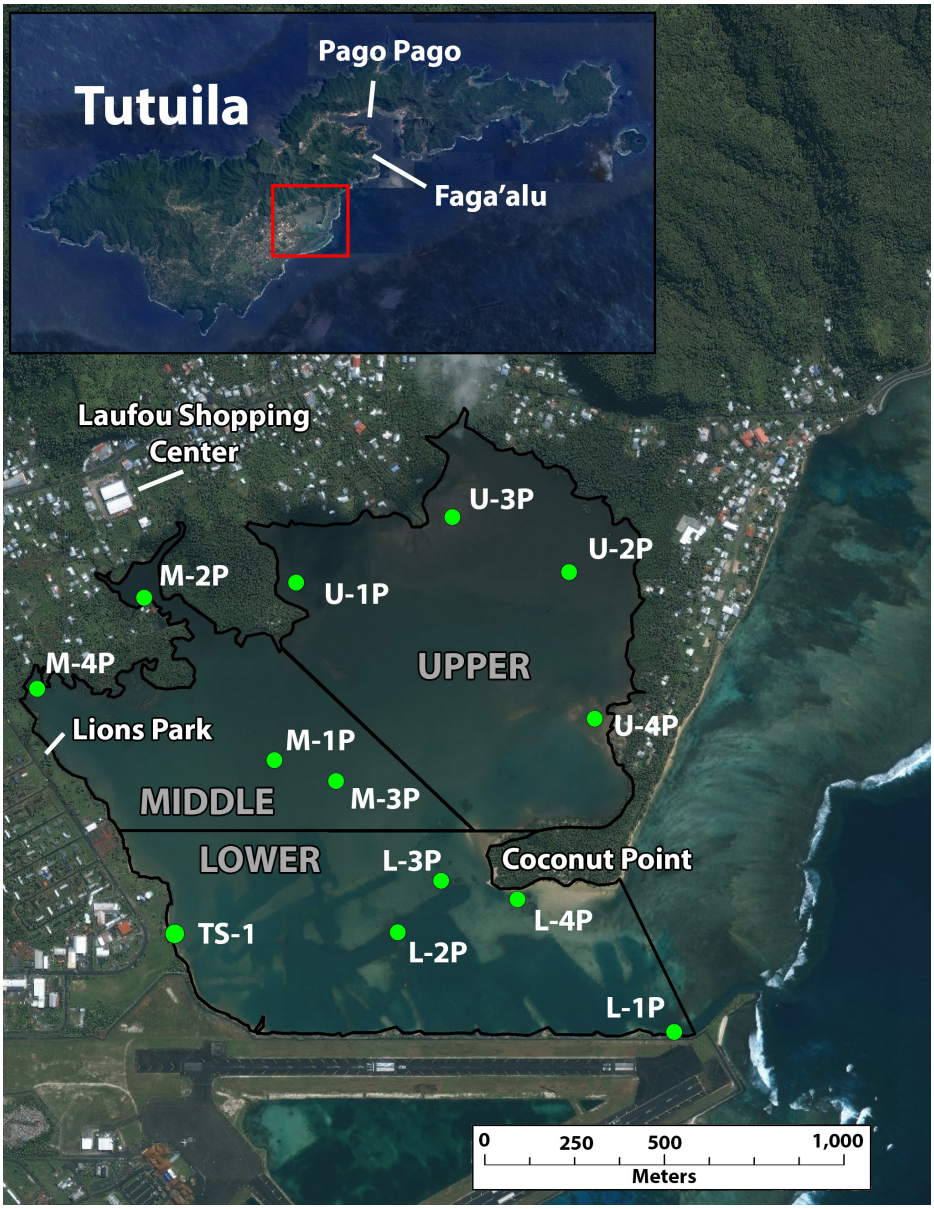

Figure 1. Map of the Nu'uuli Pala Lagoon showing sediment sampling locations and strata.

BACKGROUND

Study Site: Climate, Population, and Geography

Climate conditions in American Samoa are relatively stable throughout the year, consisting of a warm and humid tropical environment. Although there is technically a rainy season (October to April) and a dry season (May to September), rainfall is common throughout the year. Annual rainfall averages range from 320 to 750 cm (NPS, 2015) depending on elevation with mountainous areas receiving more rain.

The Nu'uuli Pala Lagoon watershed drains the most populous area of the island of Tutuila, including the village of Nu'uuli, and parts of Tafuna, Faleniu, Malaeimi, and Mesepa among other areas. The combined population of these villages as of 2011 was estimated at 15,424, or approximately 28% of the total population of American Samoa (ASG, 2011).
The Nu'uuli Pala Lagoon SMA, referred to as just the Pala Lagoon hereafter, is located on the southern coast of the island of Tutuila, just north of the Pago Pago International Airport (Figure 1). It is comprised of 13% emergent vegetation (including mangroves), 2% coral, and 77% uncolonized sediments (NOAA, 2009). During the 1960s, the lagoon's natural circulation patterns were heavily altered through the creation of the airport (Scott, 1993). The construction of the runways directly affected the Pala Lagoon through the removal of dredge material to create new land, and through the artificial restriction of ocean water exchange through the narrow channel between the airport runway and Coconut Point. The lagoon was further impacted in the 1960s by the conversion of approximately 33% of the original mangrove swamp to dry land (NOAA, 2009).

Land based sources of pollution (LBSP) have the potential to negatively impact coral reef ecosystems. The Pala Lagoon has multiple potential sources of LBSP including: runoff from roads, poorly functioning septic systems/cesspools, the airport, a jail, a history of piggeries, and low intensity agriculture (e.g. bananas). This study quantifies the magnitude and distribution of pollution in the lagoon and serves as a baseline against which future impacts can be measured.

Overview of the Chemical Contaminants

Quantifying the concentrations of over 400 chemical contaminants in sediment allows us to describe the nature of the pollution present, make hypotheses about their sources and fate in the environment, and begin to document potential stresses that the observed concentrations can cause in the marine environment, by comparing them to accepted guidelines. Each class of contaminant analyzed for this project is discussed below.

Polycyclic Aromatic Hydrocarbons.
This class of oil-related compounds, also referred to as PAHs, are usually less abundant in crude oil than saturated hydrocarbons and include one or more aromatic benzene rings in their structure (NRC, 1985). PAHs can be associated with the use and combustion of fossil fuels and other organic materials. Additional natural sources of PAHs can include decay of organic material (vegetation) and forest fires. The complete list of PAHs analyzed in this study can be found in Table 1. The PAHs analyzed here are two to six ring aromatic compounds. PAHs can bioaccumulate in both aquatic and terrestrial organisms and many individual compounds are toxic. Some compounds such as benzo[a]pyrene, benzo[a]anthracene, chrysene, benzo[b]fluoranthene, benzo[k] fluoranthene, dibenzo[a,h]anthracene, and indeno[1,2,3-c,d]pyrene, are likely carcinogenic (ATSDR, 1995).

Polychlorinated Biphenyls.
Made up of 209 individual congeners (Table 1), Polychlorinated biphenyls (PCBs) are a chemical contaminant class that was manufactured in the US starting in 1929 through 1977, before they were banned in 1979 as a result of their toxicity. These chemicals were sold in a number of congener mixtures, referred to as Aroclors, and had many industrial uses such as in electrical transformers, pesticides, paints, and heat transfer liquids. PCBs are highly persistent in the environment and have the ability to bioaccumulate in both marine life and humans. Because of their slow degradation and wide use during their manufacture period, PCBs are a commonly measured marine contaminant. Fish exposed to PCBs have been shown to exhibit reduced reproductive viability, including vertebral anomalies, as well as experiencing growth deficits (EPA, 1997).

Organochlorine Pesticides.
This class of chemicals includes 31 individual analyzed components for this study (Table 1), the most well-known being the pesticide dichlorodiphenyltrichloroethane (DDT), which had very wide spread usage beginning in the 1950s. Large scale DDT use was banned (with limited exceptions for indoor applications) in the 1970s because of its environmental persistence. Organochlorine pesticides are generally neurotoxins and are known to be endocrine disruptors (Rogen and Chen, 2005). DDT and its metabolites have been shown to cause thinning of bird egg shells, resulting in substantial decreases in reproductive success in many bird species (Lincer, 1975). Other non-target species affected by DDT and its metabolites include multiple fish species, shrimp, and crayfish.

Table 1. List of legacy chemical contaminants and trace and major elements analyzed as part of this study. PAHs = polycyclic aromatic hydrocarbons; HCH = hexachlorocyclohexane; DDMU = 1-chloro-2,2-(p-chlorophenyl)ethylene; DDD = dichlorodiphenyldichloroethane; DDE = dichlorodiphenyldichloroethylene; DDT = dichlorociphenyltrichloroethane; PCB = polychlorinated biphenyl.

PAHs		Organochlorine Pesticides	PCBs		
cis/trans Decalin	C3-Dibenzothiophenes	Aldrin	PCB1	PCB86	PCB180
C1-Decalins	C4-Dibenzothiophenes	Dieldrin	PCB7/9	PCB87/115	PCB183
C2-Decalins	Fluoranthene	Endrin	PCB8/5	PCB88	PCB185
C3-Decalins	Pyrene	Heptachlor	PCB15	PCB92	PCB187
C4-Decalins	C1-Fluoranthenes/Pyrenes	Heptachlor-Epoxide	PCB16/32	PCB95	PCB189
Naphthalene	C2-Fluoranthenes/Pyrenes	Oxychlordane	PCB18	PCB97	PCB191
C1-Naphthalenes	C3-Fluoranthenes/Pyrenes	Alpha-Chlordane	PCB22/51	PCB99	PCB194
C2-Naphthalenes	C4-Fluoranthenes/Pyrenes	Gamma-Chlordane	PCB24/27	PCB101/90	PCB195/208
C3-Naphthalenes	Naphthobenzothiophene	Trans-Nonachlor	PCB25	PCB105	PCB196/203
C4-Naphthalenes	C1-Naphthobenzothiophenes	Cis-Nonachlor	PCB26	PCB107	PCB199
Benzothiophene	C2-Naphthobenzothiophenes	Alpha-HCH	PCB28	PCB110/77	PCB200
C1-Benzothiophenes	C3-Naphthobenzothiophenes	Beta-HCH	PCB29	PCB114/131/122	PCB201/157/173
C2-Benzothiophenes	C4-Naphthobenzothiophenes	Delta-HCH	PCB31	PCB118	PCB205
C3-Benzothiophenes	Benz(a)anthracene	Gamma-HCH	PCB33/53/20	PCB128	PCB206
C4-Benzothiophenes	Chrysene/Triphenylene	DDMU	PCB40	PCB129/126	PCB209
Biphenyl	C1-Chrysenes	2,4'-DDD	PCB41/64	PCB136	
Acenaphthylene	C2-Chrysenes	4,4'-DDD	PCB42/59/37	PCB138/160	**Elements**
Acenaphthene	C3-Chrysenes	2,4'-DDE	PCB43	PCB141/179	Aluminum (Al)
Dibenzofuran	C4-Chrysenes	4,4'-DDE	PCB44	PCB146	Antimony (Sb)
Fluorene	Benzo(b)fluoranthene	2,4'-DDT	PCB45	PCB149/123	Arsenic (As)
C1-Fluorenes	Benzo(k,j)fluoranthene	4,4'-DDT	PCB46	PCB151	Cadmium (Cd)
C2-Fluorenes	Benzo(a)fluoranthene	1,2,3,4-Tetrachlorobenzene	PCB47/48/75	PCB153/132	Chromium (Cr)
C3-Fluorenes	Benzo(e)pyrene	1,2,4,5-Tetrachlorobenzene	PCB49	PCB156/171/202	Copper (Cu)
Carbazole	Benzo(a)pyrene	Hexachlorobenzene	PCB52	PCB158	Iron (Fe)
Anthracene	Perylene	Pentachloroanisole	PCB56/60	PCB166	Lead (Pb)
Phenanthrene	Indeno(1,2,3-c,d)pyrene	Pentachlorobenzene	PCB66	PCB167	Manganese (Mn)
C1-Phenanthrenes/Anthracenes	Dibenzo(a,h)anthracene	Endosulfan II	PCB70	PCB169	Mercury (Hg)
C2-Phenanthrenes/Anthracenes	C1-Dibenzo(a,h)anthracenes	Endosulfan I	PCB74/61	PCB170/190	Nickel (Ni)
C3-Phenanthrenes/Anthracenes	C2-Dibenzo(a,h)anthracenes	Endosulfan Sulfate	PCB81	PCB172	Selenium (Se)
C4-Phenanthrenes/Anthracenes	C3-Dibenzo(a,h)anthracenes	Mirex	PCB82	PCB174	Silicon (Si)
Dibenzothiophene	Benzo(g,h,i)perylene	Chlorpyrifos	PCB83	PCB176/137	Silver (Ag)
C1-Dibenzothiophenes			PCB84	PCB177	Tin (Sn)
C2-Dibenzothiophenes			PCB85	PCB178	Zinc (Zn)

Trace and Major Elements.

Sixteen trace and major elements were analyzed in sediment for this study (Table 1). Each of these elements are naturally occurring to some extent, though aluminum, iron, and silicon are classified as crustal metals and comprise the major elements for this study. Trace metals occur naturally at much lower levels in marine and terrestrial sediment, though anthropogenic activities, such as mining and manufacturing, can lead to artificially elevated levels. Improper waste disposal of items like batteries can also lead to elevated levels of trace metals in the environment. Though some trace elements are essential micronutrients, they can also be toxic at relatively low levels. Previous research (Whitall et al., 2014) showed that some metals (arsenic, chromium, copper, and nickel) can accumulate in coral tissues.

Arsenic is a naturally occurring metal that can exist in both organic and inorganic forms. Arsenic has a number of applications ranging from use in agriculture, including pesticides and herbicides, to pharmaceuticals (Eisler, 1988). Arsenic is a known carcinogen, mutagen, and teratogen, with adverse effects observed in plants, humans, and aquatic mammals and invertebrates (Eisler, 1988; Novellini et al., 2003).

Chromium has multiple human uses including as a component of stainless steel, in electroplating of metals, and as an industrial catalyst (RCS, 2014). Studies of the effects of chromium in the environment have shown reduced growth in fish, decreased reproductive success in sea urchins, and reduced survival in small crustaceans (Novellini et al., 2003; Eisler, 1986).

Copper is a widely used trace metal that, due to its high conductivity properties, is used in many electronic applications. Copper is also a major component of automotive parts including brake pads. Copper also has uses as a component of antifouling paints and other biocides. Copper is an essential nutrient for many plants and animals, but at high exposure levels it has been shown to have adverse effects ranging from deleterious effects on reproduction and development in invertebrates (Eisler, 1998), and sea urchins (Edullantes and Galpate, 2014; Dermeche et al., 2012; and Novellini et al., 2003). For corals, concentrations of copper above 20 µg/L have been shown to impact fertilization success and at concentrations above 75 µg/L reproductive rates dropped to one percent or below (Reichelt-Brushett and Harrison, 2005).

Nickel is a naturally occurring trace element in the earth's crust. Human activities such as mining and use in metal plating, coins, and batteries have served to concentrate nickel levels and result in potential increased levels in the environment. Elevated levels of nickel have been shown to have adverse effects on both marine invertebrates and fish, as well as coral larvae mortality (Novellini et al. 2003; Hunt et al., 2002; Goh, 1991).

Zinc is an essential micronutrient for both plants and animals, but like many other naturally occurring trace elements, it can be toxic at higher levels. Zinc has industrial applications in the creation of the metal alloys bronze and brass, paints, rubber vulcanization, ceramics, fertilizers, batteries, and in corrosion control in drinking water systems (EPA, 2005). Elevated levels of zinc in the environment have been shown to be toxic to aquatic invertebrates and fish, but less so to birds and mammals (Novellini et al., 2003; Edullantes and Galapate, 2014; Besser and Lieb, 2007; USDOI, 1998).

Multi Residue Pesticides and Human Use Pharmaceuticals.

In addition to the standard suite of 193 contaminants (described above and listed in Table 1), another 299 individual chemical contaminants were analyzed. These additional chemicals (listed in Tables 2 and 3) include a number of current use and legacy pesticides and human use pharmaceuticals. Note that there is some overlap between these lists though different analytical methods were used. These chemicals have a wide array of uses and applications along with many potential environmental endpoints and effects. The effects of many of these chemicals to aquatic organisms are not currently well understood. For this study, we focus only on those chemicals that were detected: Amphetamine, triclocarban, DEET (N,N-diethyl-meta-toluamide), clotrimazole, perfluorooctane sulfonate (PFOS), perfluorooctanesulfonic acid (PFOA), chlorpyrifos, beta-endosulfan, alpha hexachlorocyclohexane (HCH), alpha chlordane, trans-nonachlor, and dieldrin. For many of the Multi Residue Pesticides and Human Use Pharmaceuticals measured for this study, no sediment quality guidelines currently exist.

Polybrominated Diphenyl Ethers (PBDEs).

This class of chemicals represents an environmentally persistent set of flame retardant chemicals and is comprised of 10 individual homologues (mono through deca PBDE). Table 3 lists the PBDE congeners that were analyzed as part of this study. PBDEs have been in use since the 1960s with commercial production in the US beginning in the late 1990s (Siddiqi

Table 2. List of human use pharmaceuticals, personal care products, and perfluorinated organic compounds that were analyzed as part of this study. DEET = N,N-diethyl-meta-toluamide.

Human Use Pharmaceuticals and Personal Care Products				
1,7-Dimethylxanthine	Ciprofloxacin	Fluocinonide	Oxazepam	Trenbolone
10-hydroxy-amitriptyline	Citalopram	Fluoxetine	Oxolinic Acid	Trenbolone acetate
2-Hydroxy-ibuprofen	Clarithromycin	Fluticasone propionate	Oxycodone	Triamterene
4-Epianhydrochlortetracycline -[EACTC]	Isochlortetracycline -[ICTC]	Medroxyprogesterone -Acetate	Oxytetracycline [OTC]	Triclocarban
4-Epianhydrotetracycline [EATC]	Clinafloxacin	Furosemide	Penicillin V	Triclosan
4-Epichlortetracycline [ECTC]	Clonidine	Gemfibrozil	Prednisolone	Trimethoprim
4-Epioxytetracycline [EOTC]	Clotrimazole	Glipizide	Prednisone	Tylosin
4-Epitetracycline [ETC]	Cloxacillin	Glyburide	Promethazine	Valsartan
Acetaminophen	Cocaine	Hydrochlorothiazide	Paroxetine	Venlafaxine
Albuterol	Codeine	Hydrocodone	Penicillin G	Verapamil
Alprazolam	Colchicine	Hydrocortisone	Propoxyphene	Virginiamycin M1
Amitriptyline	Cotinine	Ibuprofen	Propranolol	Warfarin
Amlodipine	Cyclophosphamide	Iopamidol	Ranitidine	Zidovudine
Amphetamine	Daunorubicin	Lincomycin	Rosuvastatin	
Amsacrine	DEET	Lomefloxacin	Roxithromycin	**Perfluorinated Compounds**
Anhydrochlortetracycline [ACTC]	Dehydronifedipine	Melphalan	Sarafloxacin	Pentafluorobenzoic acid (PFBA)
Anhydrotetracycline [ATC]	Demeclocycline	Meprobamate	Sertraline	Perfluoro-n-pentanoaic acid (PFPeA)
Atenolol	Desmethyldiltiazem	Metformin	Simvastatin	Perfluorohexanioic acid (PFHxA)
Atorvastatin	Diatrizoic acid	Methylprednisolone	Sulfachloropyridazine	Perfluoroheptanoic acid (PFHpA)
Azathioprine	Diazepam	Metoprolol	Sulfadiazine	Perfluorooctanoic acid (PFOA)
Azithromycin	Digoxigenin	Metronidazole	Sulfadimethoxine	Perfluorononanoic acid (PFNA)
Benzoylecgonine	Digoxin	Miconazole	Sulfamerazine	Perfluorodecanoic acid (PFDA)
Benztropine	Diltiazem	Minocycline	Sulfamethazine	Perfluoroundecanoic acid (PFUnA)
Betamethasone	Diphenhydramine	Moxifloxacin	Sulfamethizole	Perfluorododecanoic acid (PFDoA)
Bisphenol A	Doxorubicin	Naproxen	Sulfamethoxazole	Perfluorobutanesulfonic acid (PFBS)
Busulfan	Doxycycline	Norfloxacin	Sulfanilamide	Perfluorohexanesulfphonic acid (PFHxS)
Caffeine	Drospirenone	Norfluoxetine	Sulfathiazole	Perfluorooctanesulfonic acid (PFOS)
Carbadox	Enalapril	Norgestimate	Tamoxifen	Perfluoroctanesulfonamide (PFOSA)
Carbamazepine	Enrofloxacin	Norverapamil	Teniposide	
Cefotaxime	Erythromycin-H2O	Ofloxacin	Tetracycline [TC]	
Chlortetracycline [CTC]	Etoposide	Ormetoprim	Theophylline	
Cimetidine	Flumequine	Oxacillin	Thiabendazole	

Table 3. List of multi residue pesticides and polybrominated diphenyl ethers (PBDEs) analyzed as part of this study.

Multi Residue Pesticides				**Polybrominated diphenyl ethers (PBDEs)**		
Tecnazene	Nonachlor, cis-	Desethylatrazine	Chlorpyriphos	PBDE-1	PBDE-37	PBDE-166
Hexachlorobenzene	alpha-Endosulphan	Simazine	Fenitrothion	PBDE-2	PBDE-75	PBDE-183
Quintozene	beta-Endosulphan	Atrazine	Malathion	PBDE-3	PBDE-71/49	PBDE-181
Heptachlor	Dieldrin	Ametryn	Parathion-Ethyl	PBDE-10	PBDE-47	PBDE-190
HCH, alpha	2,4'-DDD	Metribuzin	Chlorpyriphos-Oxon	PBDE-7	PBDE-66	PBDE-202
HCH, gamma	4,4'-DDD	Cyanazine	Disulfoton Sulfone	PBDE-11	PBDE-77	PBDE-201
HCH, beta	2,4'-DDE	Hexazinone	Ethion	PBDE-8	PBDE-100	PBDE-204
HCH, delta	4,4'-DDE	Phorate	Phosmet	PBDE-12	PBDE-119	PBDE-197
Chlorothalonil	2,4'-DDT	Terbufos	Azinphos-Methyl	PBDE-13	PBDE-99	PBDE-198/199/203/200
Aldrin	4,4'-DDT	Diazinon-Oxon	Permethrin	PBDE-15	PBDE-116	PBDE-196
Dacthal	Captan	Diazinon	Cypermethrin	PBDE-32	PBDE-118	PBDE-205
Octachlorostyrene	Perthane	Disulfoton		PBDE-30	PBDE-126	PBDE-194
Chlordane, oxy-	Endrin	Fonofos		PBDE-17	PBDE-85	PBDE-195
Heptachlor Epoxide	Endosulphan Sulphate	Dimethoate		PBDE-25	PBDE-155	PBDE-208
Chlordane, gamma	Mirex	Chlorpyriphos-Methyl		PBDE-33	PBDE-154	PBDE-207
Chlordane, alpha	Methoxychlor	Parathion-Methyl		PBDE-28	PBDE-153	PBDE-206
Nonachlor, trans-	Endrin Ketone	Pirimiphos-Methyl		PBDE-35	PBDE-138	PBDE-209

et al., 2003; Hardy, 2002) and still continues today for certain congeners. The European Union (EU) banned the use of PentaBDE and OctaBDE commercial mixtures in 2004 (BSEF, 2007) with US chemical manufacturers also voluntarily halting production. As of 2013, both the EU (banned) and the US (voluntarily phased out) have also halted production of DecaBDE.

PBDEs are commonly used in the manufacture of polyurethane foam for mattresses and other padded furniture and carpets, as well as TV casings. Thus, marine debris and improper disposal of household goods can become sources of PBDEs in the marine environment. Atmospheric deposition of PBDEs is also possible through combustion of PBDE containing products. There currently are no established guidelines or thresholds for levels of PBDEs in sediments or tissues. PBDEs have been found to bioaccumulate in aquatic species, especially marine mammals (Johnson et al., 2005).

Bacterial Indicator.

In this study we analyzed the bacterium *Clostridium perfringens* as an indicator of fecal pollution in the marine environment. *C. perfringens* occurs naturally in the intestines of many mammals including humans, dogs, and bats, and is a common cause food borne illnesses. While *C. perfringens* are not a chemical contaminant, it allows us to further quantify land-based sources of pollution entering the Pala Lagoon. The presence of *C. perfringens* in the marine environment can have multiple sources including leaking sewage infrastructure and domestic and wild animals in the watershed.

METHODS

Field collections

Sediment samples (n=13) in the Pala Lagoon SMA were collected using kayaks to reach each site (Figure 2). Sites were randomly selected using ArcGIS within three predetermined strata classified as Upper, Middle, and Lower (Figure 1). Four samples were collected from each area to allow for statistical comparison among strata. An additional targeted sample was collected (TS-1) as an area of interest, though it is not included in the statistical strata comparison analysis for this study. Individual sediment sample collection was achieved using a telescoping pole and custom designed sample jar holder to allow for fresh certified pre-cleaned 250ml IChem jars to collect sediment from each site. All field personnel wore nitrile gloves to avoid contaminating samples. In an effort to quantify loading of land-based sources of pollution entering the Pala Lagoon, surface salinity was measured using a hand-held refractometer at each sediment collection site. Samples were labelled and placed on ice in a cooler until they could be transferred to a freezer at the conclusion of each sampling day. A subset of each sample was placed into a Whirl-pak™ bag for *C. perfringens* and grain size analysis and refrigerated upon the conclusion of each sample day. Samples were shipped under chain-of-custody and arrived in good condition to TDI Brooks International in College Station, TX for analytical services.

Figure 2. Field collection at site L-3P, facing the Pago Pago Airport runway fence line.

All laboratory analysis were performed using protocols from the NS&T Program by TDI-Brooks, International or their subcontractor, AXYS Analytical. Detailed descriptions of NS&T protocols, including quality assurance/quality control (QA/QC) and analytical methods

used can be found in Kimbrough et al., 2006. Laboratory analysis methods specifically for AXYS related analytical results (current use pesticides and human use pharmaceuticals) are proprietary and confidential. The method names used for this study were MLA-035 REV.07.04 and MLA-070 REV.07.04. Contact information for further references is: AXYS Analytical Services Ltd, 2045 Mills Road W., Sidney, BC, Canada, V8L 5X2. Tel. (250) 655-5800, fax (250) 655-5811.

NOAA numerical sediment quality guidelines (SQG) developed by Long and Morgan (1990) and Long et al. (1995), known as Effects Range Median (ERM), and Effects Range-Low (ERL), each express statistically derived contamination levels above which toxic effects can be expected. These guidelines express statistically derived levels of chemical contamination in surficial sediments below which effects to benthic organisms were rarely (<10%) expected (ERL) and above which toxic effects would be expected to be observed with at least a 50% frequency (ERM). The ratio of the ERM value to the sediment concentration for each chemical, or sum of chemicals such as total PAHs, is called the ERM quotient or ERMq (Long et al., 1998). This quotient expresses how close measured concentrations are to the established ERM level on a zero to one scale. A quotient of one or greater means the concentrations are at or above the ERM. This also normalizes the ERMs for different chemicals to a common scale. By averaging the mean ERMq of contaminants it is possible to express a measure of contamination across the entirety of all analytes. Previous studies by Hyland et al. (1999) suggest that mean ERMq values of 0.1 in southeast U.S. coastal waters represent a threshold above which degradation in benthic communities start appearing. The mean quotient of the ERMs and contaminant concentrations have been calculated on a site-by-site basis.

Statistical analysis for this report was conducted using JMP statistical software version 12.1.0. Data from this study were not normally distributed, therefore nonparametric Wilcoxon Signed Rank (Kruskal-Wallis where more than two groups were compared) statistics were used to determine statistical differences among strata and contaminants. An alpha of 0.05 was used for determining significant results.

Results for this study are compared with those from Whitall and Holst (2015) due to the fact that the many of the same chemicals were analyzed using the same methodology and analytical laboratory. The location of Faga'alu is shown in Figure 1 (inset).

RESULTS

Salinity

Mean salinity for the Pala Lagoon was 27.33 ± 9.25 (standard deviation, same throughout the rest of this report) PSU. Maximum salinity of 36 PSU was recorded at site L-4P while minimum salinity of 10 PSU was measured at both M-2P and M-4P (Figure 3).

Lower salinity numbers point toward the potential for increased land-based runoff, though it is important to note that significant rainfall events occur regularly and

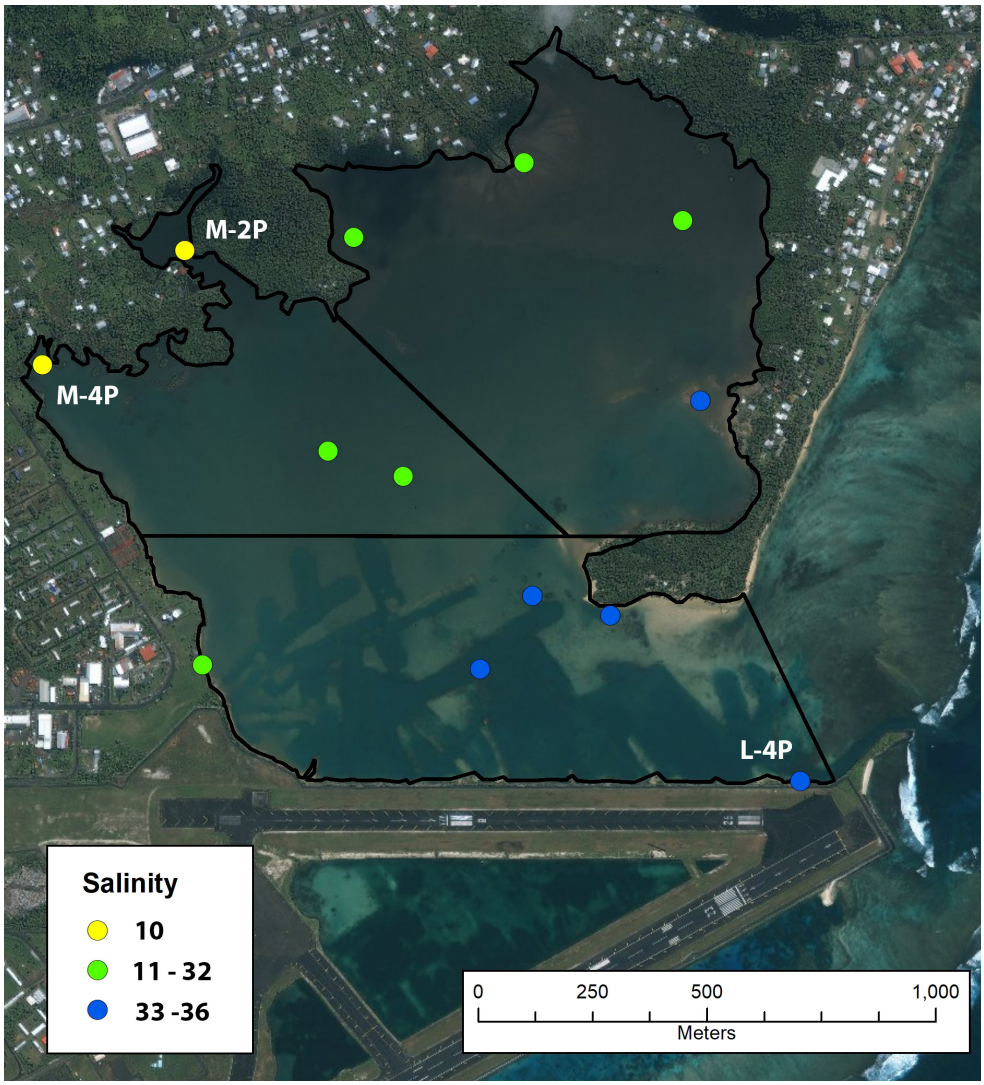

Figure 3. Measured salinity (PSU) during sediment collection.

could potentially affect the salinity results as only surface measurements were collected. That said, the distribution of lower salinity sites are significantly correlated (α=0.05) to distance from freshwater inputs into the Pala Lagoon (nonparametric Wilcoxon Signed Rank = 0.0002) suggesting that salinity values that were measured for this study are primarily driven by freshwater runoff and tidal influence instead of direct deposition of rainfall.

Grain Size and Total Organic Carbon (TOC)

Fine grained sediments, such as silt and clay, have higher surface areas and typically higher organic carbon content that increases the adsorption rate of organic chemical contaminants. Conversely, sand and gravel have smaller surface areas and a lower affinity for organic chemical contaminants. As such, organic chemical contaminants tend to accumulate in sediments with high organic carbon content as compared to sediments low in organic carbon. The charge structure on the surface of clay particles also tends to attract and bind metals as well.

Sand and gravel (shell and coralline rubble) were the dominant grain size fraction in the sediment sampled from the Pala Lagoon. In all but two samples, M-2P and U-1P, sand and gravel comprised over 50% of the total content, with a maximum fraction of 97.32% at site L-1P, the site closest to the mouth of the Lagoon. The highest percent fines (%silt + %clay) was measured at site U-1P at 61.47%. A nonparametric Wilcoxon (Rank Sums, α=0.05) analysis indicated that percent gravel (shell and coralline rubble) varied significantly among the Lower stratum versus the Middle and Upper strata (Chi Square = 0.0274). There were no other significant differences between other grain size categories and strata.

The mean percent total organic carbon (TOC) in the sediments collected from the Pala Lagoon was 3.05 ± 2.94%, and ranged from a low of 0.9% at site L-4P to a high of 11.56% at site M-2P. There was no significant difference between percent TOC and strata.

Polycyclic Aromatic Hydrocarbons (PAHs)

Total PAHs include the sum of all 64 individual PAHs, sulfur-containing aromatics, and decalins listed in Table 1. The mean concentration for the total PAHs for this study was 68.44 ± 143.71 ng/dry g. The median concentration of total PAHs was 16.47 ng/dry g. The maximum concentration of total PAHs was 506.25 ng/dry g at site M-4P while the minimum concentration of 2.69 ng/dry g was found at site L-2P (nonparametric Wilcoxon Signed Rank, Chi-square > 0.9001, α=0.05; Figure 4).

Comparison with other data.

There was no statistically significant difference between the total PAHs measured by Whitall and Holst (2015) in the Faga'alu watershed and bay and those measured in the Pala

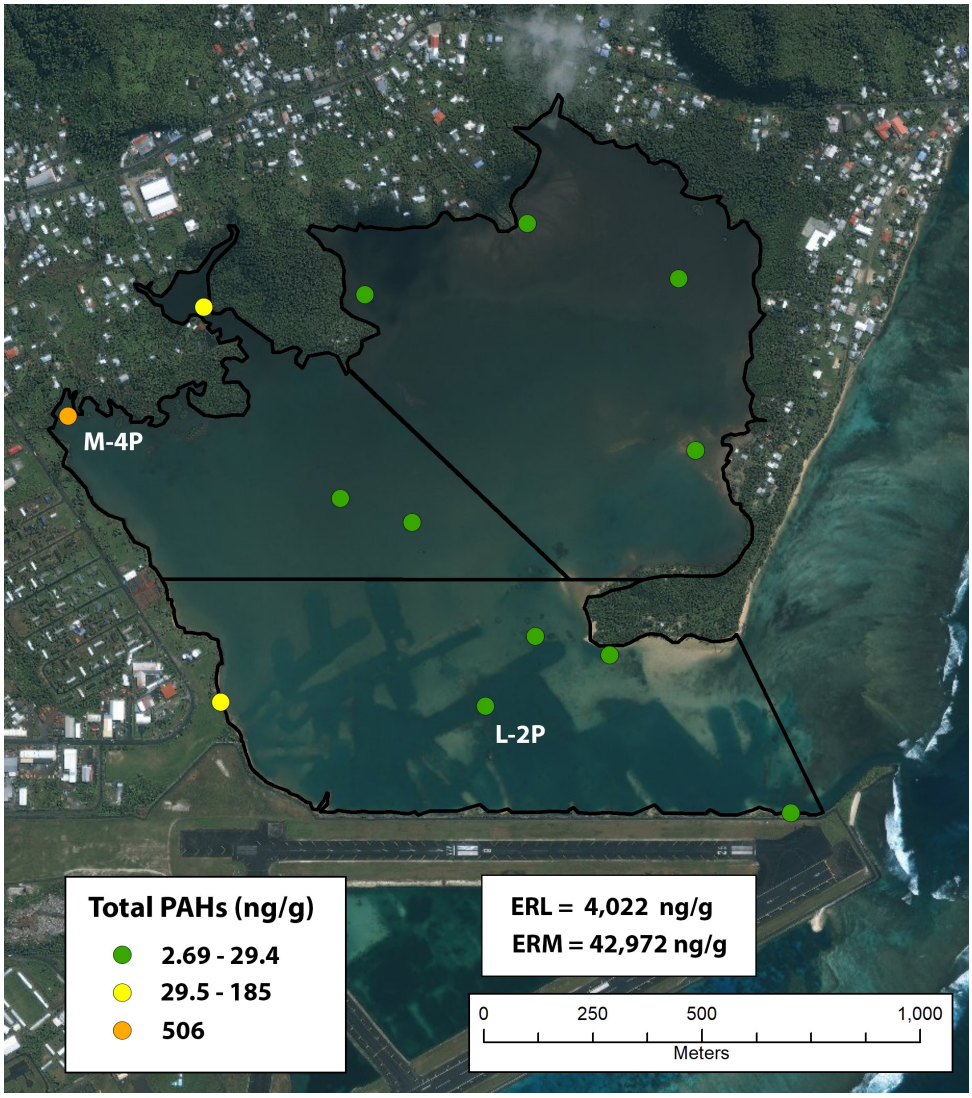

Figure 4. Map of total polycyclic aromatic hydrocarbon (PAH) concentrations (ng/g dry weight) measured in sediment from the Pala Lagoon. ERL = Effects Range Low, ERM = Effects Range Median.

Lagoon in this study (Table 4). The highest measured concentration of total PAHs in sediment from Faga'alu (2,097 ng/dry g) was an order of magnitude higher than the highest concentration measured in the sediment from the Pala Lagoon (506 ng/dry g).

NOAA Sediment Quality Guidelines for Total PAHs.

The NS&T Program has developed effects-based, numeric guidelines that allow for the estimation of likely toxic effects of certain sediment contaminants (Long et al., 1998). Values between the ERL and ERM thresholds represent concentrations at which toxic effects occasionally may be observed (NOAA NS&T, 1998). ERL and ERM values for total PAHs (n=64) are shown in Figure 4. No sediment samples from the Nu'uuli Pala Lagoon exceeded the ERL of 4,022 ng/g.

ERL and ERM guidelines have also been calculated for a number of individual PAHs. These guidelines are shown in Table 5. No sediment samples analyzed for this study exceeded any of the ERL or ERM thresholds for individual PAH compounds.

Polychlorinated Biphenyls (PCBs)

Total PCBs analyzed as part of this study refers to the sum of all 81 congeners listed in Table 1. For this study only total PCBs are reported. The mean concentration of total PCBs for the Pala Lagoon was 0.29 ± 0.49 ng/dry g while the median concentration was 0. The maximum concentration for total PCBs in this study was 1.36 ng/dry g at site M-4P while the multiple sites across the Lagoon had non-detections for total PCBs. There were multiple locations where no PCBs were detected (Figure 5). There were no differences among strata for PCB concentrations.

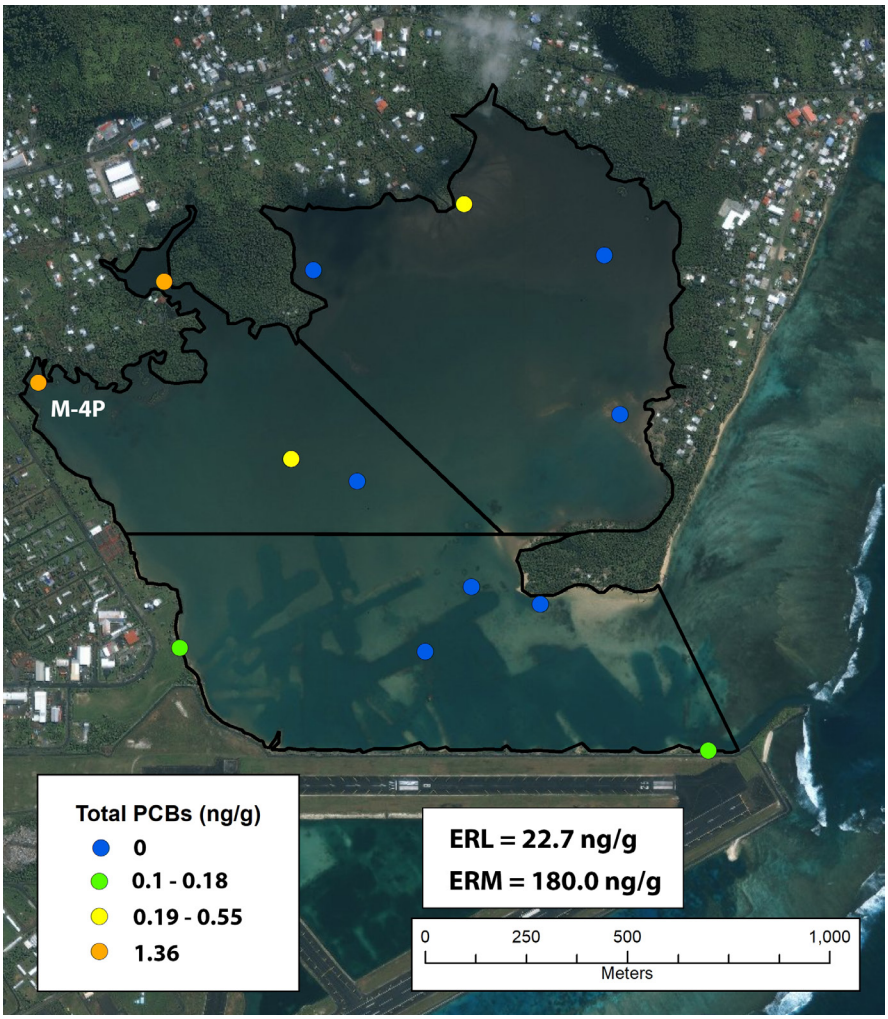

Figure 5. Map of total polychlorinated biphenyl (PCB) concentrations (ng/g dry weight) measured in sediment from the Pala Lagoon. ERL = Effects Range Low, ERM = Effects Range Median.

The NS&T mean concentration for sediments nationwide is 13.7 ng/dry g which is an order of magnitude higher than the highest measured value from the Pala Lagoon. Additionally, NOAA ERL and ERM guidelines for total PCBs (sum = 18 congeners) are 22.7 ng/dry g and 180.0 ng/dry g, respectively, and both are at least an order of magnitude higher than any measured value from the Pala Lagoon.

Comparison with other data.

Total PCBs concentrations measured by Whitall and Holst (2015) in sediment from the Faga'alu watershed and bay were significantly higher than those in the Pala Lagoon (nonparametric Wilcoxon Rank Sums, α=0.05, Chi-square > 0.0001; Table 4). The highest concentration of total PCBs from Faga'alu of 92.89 ng/dry g was an order of magnitude greater than the highest measured concentration of total PCBs in sediment from the Pala Lagoon (4.75 ng/dry g).

Dichlorodiphenytrichloroethane (DDT)

Total DDT for this study represents the

Table 4. Comparison of chemical contaminants in sediment between the Nu'uuli Pala Lagoon and Faga'alu Bay and watershed. ERL = Effects Range Low.

Analyte	Nu'uuli Pala Lagoon	Faga'alu	Chi Square
Aluminum	No difference		-
Iron	No difference		-
Silicon	No difference		-
Arsenic	Higher (8)	Lower (3)	0.0006
Cadmium	Lower (0)	Higher (0)	0.0078
Chromium	Higher (6)	Lower (2)	0.0417
Silver	Lower (0)	Higher (4)	0.0195
Antimony	No difference		-
Copper	No difference		-
Lead	No difference		-
Manganese	No difference		-
Mercury	No difference		-
Nickel	No difference		-
Selenium	No difference		-
Tin	No difference		-
Zinc	No difference		-
Total PCBs	Lower (0)	Higher (3)	0.0001
Total PAHs	No difference		-
Total DDT	No difference		-

Note: Values in parentheses denote number of ERL exceedences

Table 5. Comparison of selected individual PAH concentrations to NOAA National Status and Trends (NS&T) Program historical data and sediment quality guidelines. ERL = Effects Range Low, ERM = Effects Range Median.

	Sites													NS&T Statistics and Guidelines			
Compound	L-1P	L-2P	L-3P	L-4P	M-1P	M-2P	M-3P	M-4P	TS-1	U-1P	U-2P	U-3P	U-4P	Median	85th Percentile	ERL	ERM
Acenaphthylene	ND	ND	1.00	0.27	0.10	0.72	0.06	2.44	0.80	0.19	0.09	0.14	0.14	2.1	15.1	44	640
Anthracene	0.16	0.02	0.13	0.58	0.13	1.37	0.05	5.67	1.32	0.30	0.14	0.19	0.14	3.4	38.7	85.3	1,100
Napthalene	0.36	0.35	0.71	0.83	0.34	3.54	0.40	10.30	0.50	1.10	0.69	0.96	0.44	3.7	27.6	160	2,100
Benzo-a-pyrene	0.24	ND	0.42	1.37	0.52	5.60	0.22	16.40	7.25	0.91	0.38	0.78	0.54	14.7	127	430	1,600
Dibenzo(a,h)anthracene	0.25	ND	ND	0.33	ND	4.28	ND	2.80	1.32	0.70	0.30	ND	0.24	5	23.8	63.4	260

All concentrations are in ng/dry g. ND = Non Detect

sum of 2,4'-DDT, 4,4'-DDT and their metabolites 2,4'-DDE, 4,4'-DDE, 2,4'-DDD, 4,4'-DDD, and 1,1-Bis(p-chlorophenyl)-2-chloroethene (DDMU). The results from this analysis can be seen in Figure 6. The mean concentration of total DDT for the Pala Lagoon was 0.44 ± 1.30 ng/dry g while the median value was 0.02 ng/dry g. The maximum measured concentration of total DDT was 4.75 ng/dry g at site M-4P. There were no statistically significant differences among strata for total DDT concentrations.

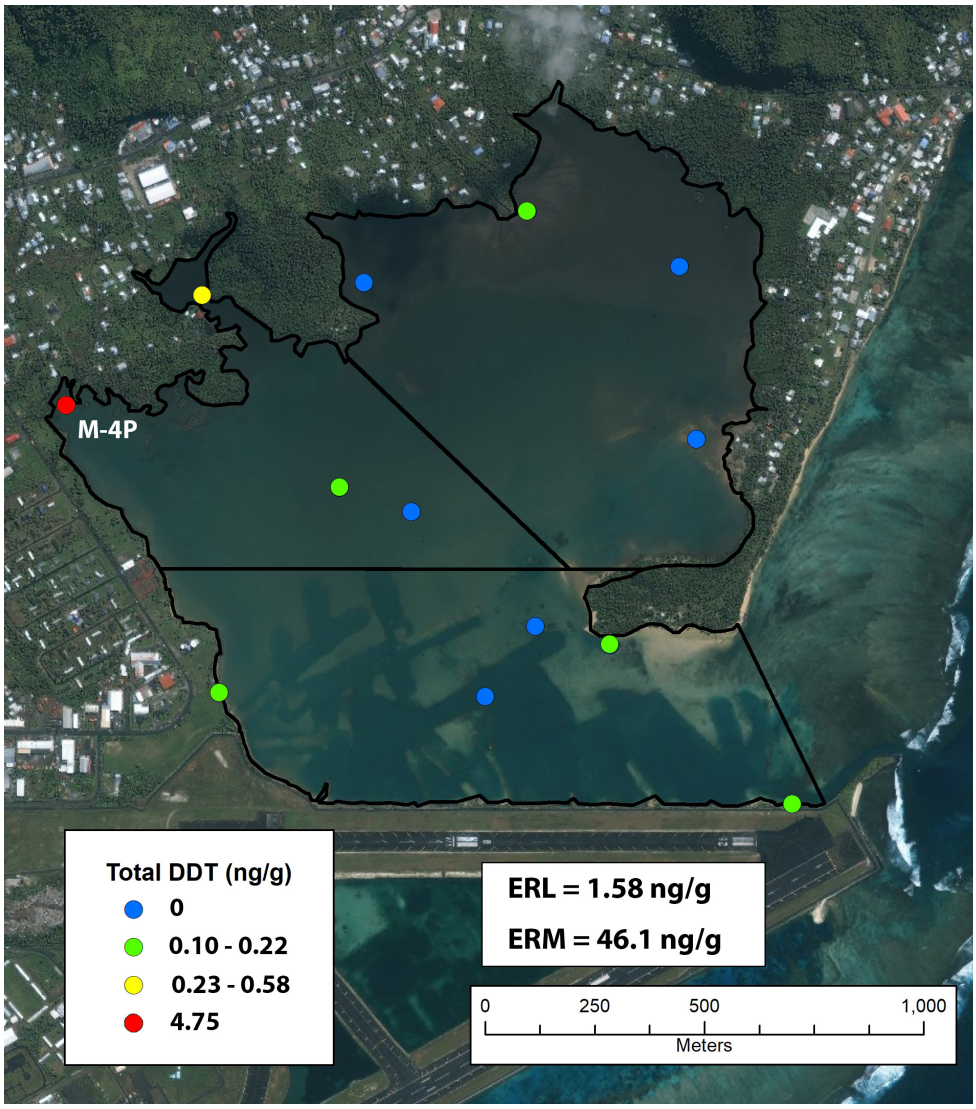

Figure 6. Map of total DDT concentrations (ng/g dry weight) measured in sediment from the Pala Lagoon. ERL = Effects Range Low, ERM = Effects Range Median.

The NS&T mean concentration for total DDT in sediments nationwide is 3.11 ng/dry g, which is below only the highest concentration measured in the Pala Lagoon. Site M-4P also exceeded the ERL of 1.58 ng/dry g total DDT, but did not exceed the ERM of 46.1 ng/dry g. The ratio of DDT to DDE and DDD, one way to estimate how degraded DDT is in the environment, was 72% DDT, 8% DDE, and 20% DDD at site M-4P. Though this suggests a relatively 'fresh' source of DDT entering the Pala Lagoon, in the marine environment DDT and its metabolites degrade very slowly, on the order of decades (Chattopadhyay and Chattopadhyay, 2015). Additionally, the relatively low concentrations measured, along with the low organic carbon content of sediments in the Pala Lagoon limit the ability to make more precise conclusions as to the relative age of the total DDT present.

Comparison to other data.

There were no statistically significant differences between total DDT concentrations in sediment from the Pala Lagoon and those measured by Whitall and Holst (2015) in the watershed and bay of Faga'alu (nonparametric Wilcoxon Signed Rank, Chi-square > 0.8102, α=0.05; Figure 4). The highest concentration of total DDT in Faga'alu (2.29 ng/dry g) was comparable to the highest concentration of total DDT measured in the Pala Lagoon (1.36).
An additional 24 individual organochlorine pesticides were analyzed as part of this study (Table 1). However, there were no detections of any of these chemicals and no additional summary of their potential impacts is included in this report.

Polybrominated Diphenyl Ethers (PBDEs)

As discussed previously, PBDEs are a class of flame retardant chemicals that are common contaminants in the environment. PBDEs preferentially bind to organic containing sediment, and therefore the low amount of TOC measured in sediment from the Pala Lagoon (high of 11.56% at site M-2P; see previous section on TOC) points toward a similarly low ability for sediments in the Lagoon to trap and accumulate PBDEs. Even so, relatively high levels of PBDEs, as compared

to historical NS&T data for the coastal US (Kimbrough et al., 2009) were measured in the Pala Lagoon.

The mean concentration of total PBDEs (sum of 51 congeners) for this study was 10.87 ± 25.50 ng/dry g while the median concentration was 3.22 ng/dry g. The maximum concentration measured was 94.99 ng/dry g at site M-4P while it was not detected in sediment at site L-1P. The maximum value at site M-4P was the 4th highest concentration ever measured by the NS&T Program (Kimbrough et al., 2009) for locations including coastal Alaska, Hawai'i, the continental Pacific coast, the continental Atlantic coast, the Gulf of Mexico, and in the Great Lakes. Figure 7 shows the comparison of total PBDE concentrations from this study and the NS&T historical database. Other than total PBDEs measured at site M-4P, concentrations of PBDEs in sediment in the rest of the Pala Lagoon appear to be low. When compared to mean PBDE data from around the world (sum of subset of 8 congeners) compiled by Zhang et al. (2016), the median concentration for the Pala Lagoon (2.42 ng/dry g for the same subset of 8) falls well below the higher means for China and Korea, but are comparable to those recorded for the Philippines and the south and central San Francisco Bay in 2007 (Table 6), an urban area with approximately 7.15 million people (US Census Bureau, 2013). As of 2010, the population estimate for all of American Samoa, including all outlying islands, was 67,380 (ASG, 2011), or roughly 0.94% the population of the San Francisco Bay area.

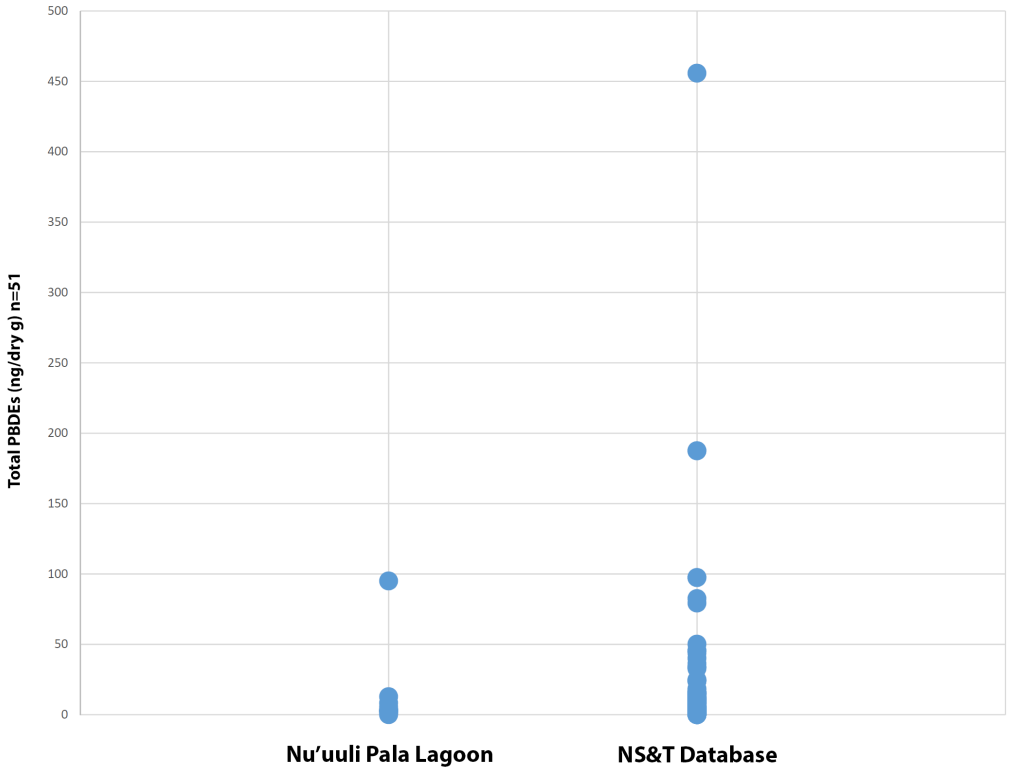

Figure 7. Comparison of all PBDE data (n=51) from both the Nu'uuli Pala Lagoon and the NS&T database. NS&T database includes Mussel Watch historical sites.

Table 6. Comparison of worldwide median PBDE (n=8) concentrations in sediments with the median concentration of PBDEs (n=8) in sediment from Nu'uuli. MWP = NOAA Mussel Watch Program.

Region	Median (ng/g)	Source
Macao, China	26.85	Zhang et al. 2016
Hong Kong, China	7.56	Zhang et al. 2016
Ulsan Bay, South Korea	31.17	Zhang et al. 2016
Busan Bay, South Korea	77.5	Zhang et al. 2016
Tokyo, Japan	46	Zhang et al. 2016
Philippines	2.36	Zhang et al. 2016
San Francisco Bay area	3.84	Zhang et al. 2016
Coastal US (MWP)	0.2	Kimbrough et al. 2009
Nu'uuli (2017)	2.42	--

Multi Residue Pesticides, Human Use Pharmaceuticals, and Perfluorinated Compounds

Multi residue pesticides, human use pharmaceuticals, and perfluorinated compounds represent a diverse range of organic contaminants that only recently have begun to be measured in the marine environment. This group of chemicals for this study included 141 individual human use pharmaceuticals and personal care products, 62 individual current use and legacy pesticides, 13 perfluorinated compounds, and 51 multi residue pesticides (Tables 2 and 3). Currently there are no sediment guidelines or thresholds determining environmentally relevant concentrations or concentrations at which potentially adverse effects may occur to marine organisms. Given the lack of guidelines, for this study we simply report the concentrations measured. Due to the high cost of analysis, only a subset of the thirteen total collected samples were analyzed for these organic contaminants, six for perfluorinated compounds and three of those six for human use pharmaceuticals and multi residue pesticides.

Table 7. Results from multi residue pesticide, human use pharmaceutical, and perfluorinated compound analysis for sediment from the Nu'uuli Pala Lagoon. All concentrations in ng/dry g. DEET = N,N-Diethyl-meta-toluamide, PFOS = Perfluorooctanesulfonic acid, PFOA = Perfluorooctanoic acid, HCH = hexachlorocyclohexane, N/A = Not analyzed

Site	Amphetamine	Triclocarban	DEET	Clotimazole	PFOS	PFOA
L-3P	N/A	N/A	N/A	N/A	--	--
M-2P	2.84	--	15.7	2.5	--	--
M-4P	1.87	14.8	8.12	10.7	0.337	--
U-1P	1.72	--	4.07	0.674	--	--
U-2P	N/A	N/A	N/A	N/A	0.223	--
U-4P	N/A	N/A	N/A	N/A	0.318	0.107

Site	Chlorpyriphos	Beta-Endosulfan	HCH, alpha	Chlordane, alpha	Nonachlor, trans-	Dieldrin
L-3P	0.035	--	--	--	--	--
M-2P	--	1.22	--	--	--	--
M-4P	0.058	--	0.01	0.251	0.332	0.026
U-1P	--	--	--	--	--	--
U-2P	--	--	--	--	--	--
U-4P	--	--	--	--	--	--

A summary of all these results are included in Table 7. Of the total 299 additional chemicals analyzed for this study, only twelve were detected in sediment from the Pala Lagoon. These were amphetamine, triclocarban, DEET, clotrimazole, PFOS, PFOA, chlorpyrifos, beta-endosulfan, alpha-hexachlorocyclohexane (HCH), alpha chlordane, trans-nonachlor, and dieldrin. Amphetamine, triclocarban, and clotrimazole are all human use pharmaceuticals while DEET is a well-known insect repellant. Amphetamine is central nervous system stimulant pharmaceutical while triclocarban is an antibacterial chemical and a common component of antibacterial soaps. Clotrimazole is an antifungal drug commonly included in many over-the-counter antifungal products. The presence of these chemicals in the sediments of the Pala Lagoon are most likely indicators of the presence of both grey water (non-sewage) and human waste reaching the marine environment of the Pala Lagoon. The presence of the insect repellant DEET is also not surprising in a tropical environment where wide spread usage of mosquito repellant is common. The presence of both PFOS and PFOA, an environmentally persistent class of chemicals found in products such as Teflon™ and Scotchgard™, is also not surprising due to their high solubility in water which can lead to significant transport via surface and ground waters.

Chlorpyrifos is a current use pesticide commonly used in commercial agriculture and may still be in use on the island of Tutuila. Beta-endosulfan, alpha-HCH, alpha-chlordane, trans-nonachlor, and dieldrin are all banned pesticides that are classified as persistent organic pollutants that do not easily breakdown in the environment. The presence of these chemicals in the sediment of the Pala Lagoon is likely from past usage prior to the individual bans that currently exist, and not due to ongoing application.

The three sites selected for the full suite of chemical analysis were chosen as they were deemed to be the sites most likely to contain measureable levels of organic contaminants (based on preliminary grain size and TOC analysis along with their proximity to freshwater inputs to the lagoon). The fact that so few chemicals were detected in sediments may be a factor of the low organic content of the sediments instead of a complete lack of these chemicals in the Pala Lagoon. A follow up study of fish or other marine animals (invertebrates), or an analysis of the dissolved phase of the water in the Pala Lagoon could further shed light on the presence or absence of a larger suite of CECs in the environment.

Trace and Major Elements

Detailed results for aluminum, iron, and select elements that had elevated concentrations are included below. Summary results for all sixteen trace and major elements are included in Table 8.

<u>Aluminum, Iron, and Silicon</u>

The island of Tutuila is comprised of five Pliocene-to-Pleistocene volcanoes, with the central part of the island dominated by a basaltic-to-andesitic shield volcano (Addison et al., 2006; Macdonald, 1968). Weathering of basaltic volcanic rock produces oxisolic soils, which are low in mineral content but high in iron and aluminum oxides. In locations with large amounts of rainfall, such as American Samoa, silicate clays are known to leach from basaltic volcanic rock and produce poor soil fertility. Andisetic deposits, derived from ash and cinder accretion, also have high aluminum and iron content (HDOH, 2012).

Table 8. Summary data for trace and major elements sampled for this study. All units in µg/g. ND = Non-detection.

Element	Mean	Standard Dev	Median	Max
Aluminum (Al)	25,428	23,619	14,800	68,400
Antimony (Sb)	0.286	0.239	0.24	0.874
Arsenic (As)	12.0	6.7	13.0	24.1
Cadmium (Cd)	0.036	0.090	0	0.286
Chromium (Cr)	94.1	90.2	47.2	276
Copper (Cu)	12.73	13.31	7.67	50.50
Iron (Fe)	39,910	39,053	19,400	115,000
Lead (Pb)	6.47	6.61	3.16	24.70
Manganese (Mn)	385	333	269	1,040
Mercury (Hg)	0.01240	0.01480	0.00827	0.05600
Nickel (Ni)	44.2	42.7	25.8	123.0
Selenium (Se)	ND	ND	ND	ND
Silicon (Si)	55,765	51,839	29,000	162,000
Silver (Ag)	ND	ND	ND	ND
Tin (Sn)	2.19	2.55	1.03	9.55
Zinc (Zn)	101.6	105.3	48.1	332

Based on the geology of the island of Tutuila, we expect to see high amounts of aluminum, iron, and silicon in marine sediment due to erosion. A comparison of the correlation between these and other trace metals can be used to determine approximately how much of a given metal's presence in marine sediments can be attributed to crustal erosion. Because of these relationships, poor correlations between aluminum, iron, and silicon and other trace metals can point to potential anthropogenic sources behind elevated concentrations. For this study, although silicon had the highest number of significant correlations with all the other trace metals (R-square > 0.70), based on previous established methods, aluminum was selected for estimating the amount of erosional influence on trace metal concentrations (Table 9). Iron showed almost identical patterns to aluminum, but with slightly less significant results. The correlation between aluminum and iron had an adjusted R-Square value of greater than 0.8949 for sediment in the Pala Lagoon, indicating a very close relationship between the two crustal metals. More detailed information for aluminum, iron, and silicon are included below.

The mean concentration of aluminum in sediment in the Pala Lagoon was 25,428.46 ± 23,619.38 µg/g while the median concentration was 14,800 µg/g. The maximum concentration of aluminum was 68,400 µg/g at site M-4P and the minimum concentration was 1,160 µg/g at site L-2P (Figure 8).

Table 9. Correlations between trace and major elements for this study. Green = high correlation (R-square > 0.70), Orange = low correlation (R-square < 0.70).

	Al	Fe	Si
Al	--	0.89	0.97
As	0.37	0.47	0.26
Cd	0.35	0.09	0.41
Cr	0.80	0.89	0.83
Cu	0.62	0.32	0.71
Fe	0.89	--	0.84
Hg	0.35	0.25	0.31
Mn	0.79	0.90	0.75
Ni	0.35	0.37	0.46
Pb	0.34	0.12	0.49
Sb	0.49	0.24	0.54
Si	0.97	0.84	--
Sn	0.71	0.40	0.77
Zn	0.96	0.77	0.97

The mean concentration of iron in sediment in the Pala Lagoon was 39,910.77 ± 39,053.37 µg/g with a median concentration of 19,400 µg/g. The maximum concentration of iron of 115,000 µg/g was measured in sediment at site U-1P while the minimum concentration of 3,890 µg/g was measured at site L-2P.

For silicon, the mean concentration for the Pala Lagoon was 55,765.38 ± 51,838.91 µg/g with a median concentration of 29,000 µg/g. The maximum concentration of 162,000 µg/g was measured at site M-4P while the minimum concentration of 3,580 µg/g was measured at site L-2P.

Comparison with other data.

There were no statistically significant differences between aluminum, iron, or silicon concentrations measured in the sediment from the Pala Lagoon and those measured by Whitall and Holst (2015) for the Faga'alu watershed and bay (Table 4). This points to comparable levels of erosion between the two bays. The means, standard deviations, and

Table 10. Summary statistics for select sediment contaminants in the Nu'uuli Pala Lagoon and Faga'alu watershed and bay. Faga'alu data from Whitall and Holst (2015).

Analyte	**Faga'alu** n=17	**Nu'uuli Pala Lagoon** n=13
TOC %	1.35 ± 0.81 (2.85)	3.05 ± 2.94 (11.56)
Total PAHs ng/dry g	14.35 ± 501.25 (2,097)	77.34 ± 141.26 (506)
Total PCBs ng/dry g	14.35 ± 29.06 (92.89)	0.44 ± 1.30 (4.75)
Total DDT ng/dry g	0.23 ± 0.54 (2.29)	0.29 ± 0.49 (1.36)
Aluminum µg/g	25,683 ± 28,816 (72,400)	25,428 ± 23,619 (68,400)
Arsenic µg/g	4.44 ± 2.90 (11.5)	12.04 ± 6.67 (24.1)
Cadmium µg/g	0.10 ± 0.09 (0.31)	0.04 ± 0.09 (0.29)
Chromium µg/g	39.47 ± 46.42 (191)	101.91 ± 89.49 (276)
Copper µg/g	8.53 ± 9.67 (37.7)	13.74 ± 13.38 (50.5)
Iron µg/g	28,484 ± 29,827 (103,000)	39,911 ± 39,053 (115,000)
Nickel µg/g	35.13 ± 50.66 (211)	44.21 ± 42.66 (123)
Silver µg/g	0.49 ± 0.81 (2.74)	Non-detect
Zinc µg/g	109.69 ± 119.72 (416)	101.58 ± 105.35 (332)
C. perfringens (CFUs)	301.88 ± 432.26 (1,722)	258.96 ± 359.98 (1,183.8)

*Values in paranethesis represent maximum measured concentrations

maximum concentrations for both aluminum and iron in both waterbodies are presented in Table 10.

Arsenic

Arsenic is a naturally occurring metal in the earth's crust, though anthropogenic influences such as mining have served to concentrate and increase the amount present in the environment. The mean concentration of arsenic for this study was 12.04 ± 6.68 µg/g and a median concentration of 13.00 µg/g. The maximum concentration of arsenic in sediment from the Pala Lagoon was 24.1 µg/g at site U-1P while the minimum concentration was 2.82 µg/g at site L-1P. Eight of the thirteen sites sampled for arsenic exceeded the ERL of 8.2 µg/g (Figure 9) indicating potential adverse effects at those sites. None of the sites sampled exceeded the ERM of 70 µg/g.

A bivariate analysis of arsenic and aluminum showed a significant relationship ($F > 0.0160$), however the adjusted R-square value, or in this case an estimate of how much of the variation in concentrations of arsenic could be attributed to crustal erosion (aluminum) was low at only 0.3711.

Additionally, a non-parametric Wilcoxon test (Rank Sums) showed that arsenic concentrations in the Upper and Middle Pala Lagoon are significantly higher than those of the Lower Pala Lagoon (Chi-Square > 0.0335).

Comparison with other data.

Arsenic concentrations measured in the Pala Lagoon were significantly higher than those measured by Whitall and Holst (2015) in the watershed and bay of Faga'alu (nonparametric Wilcoxon Rank Sums, $\alpha=0.05$, Chi-square > 0.0006; Table 4). Despite the significant difference between the two waterbodies, the highest concentration of arsenic in sediments from the Pala Lagoon (24.1 µg/g) is comparable with the highest concentration of arsenic measured in sediment from the Faga'alu watershed and bay (11.5 µg/g; Table 10). Arsenic concentrations in the Pala Lagoon were also slightly higher than those measured in Pago Pago Harbor (CH2MHill, 2007), which had concentrations ranging from 4.54 to 14.58 µg/g and a mean of 10.46 µg/g.

Chromium

Concentrations of chromium in sediment from the Pala Lagoon ranged from a maximum of 276 µg/g at site U-1P to a minimum of 0.4 µg/g at site L-2P. The mean concentration of chromium was 94.11 ± 90.19 µg/g with a median concentration of 47.2 µg/g. Six of the thirteen samples exceeded the ERL sediment guideline threshold of 81 µg/g (Figure 10).

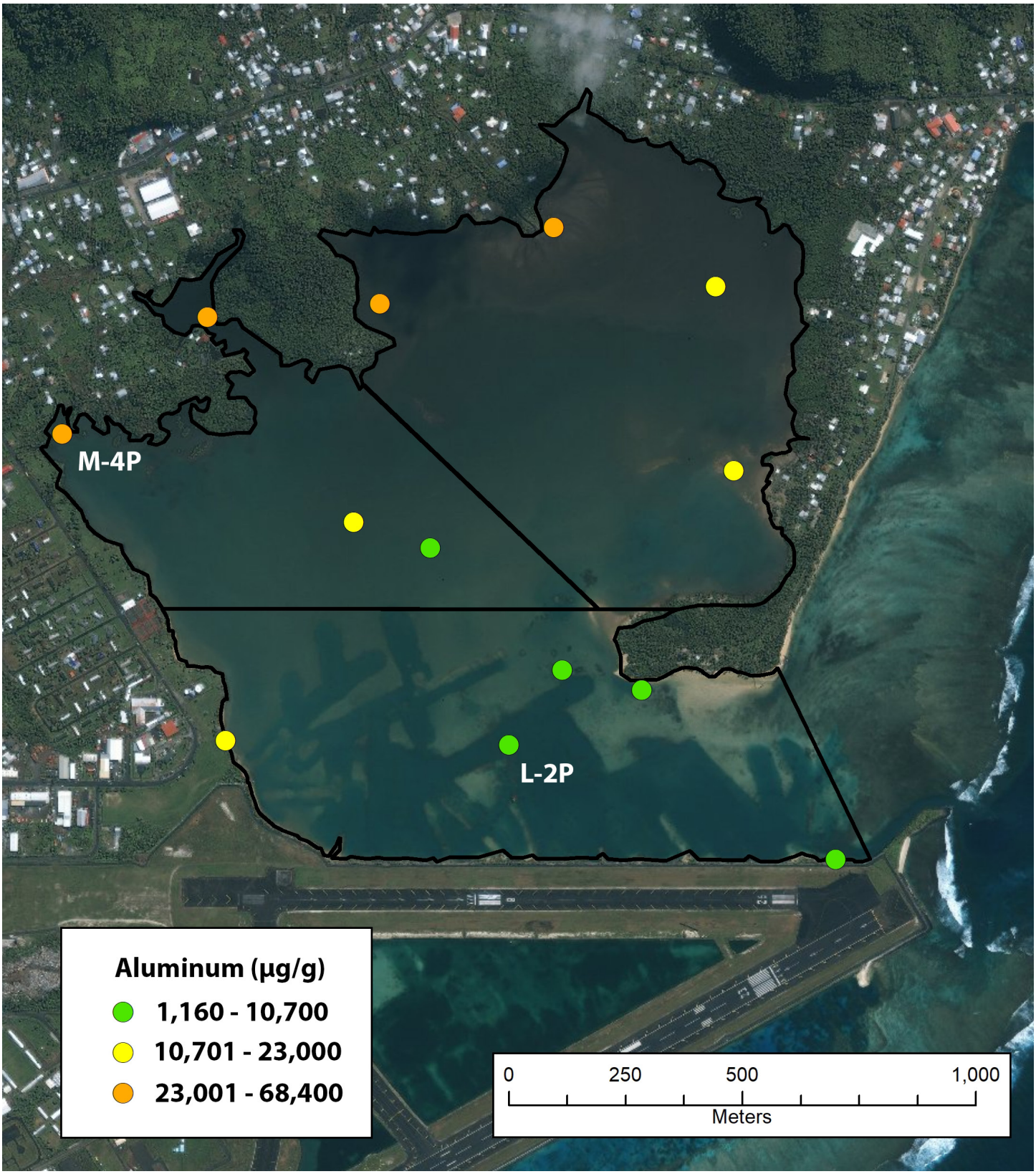

Figure 8. Aluminum concentrations (µg/g dry weight) in sediment from the Nu'uuli Pala Lagoon.

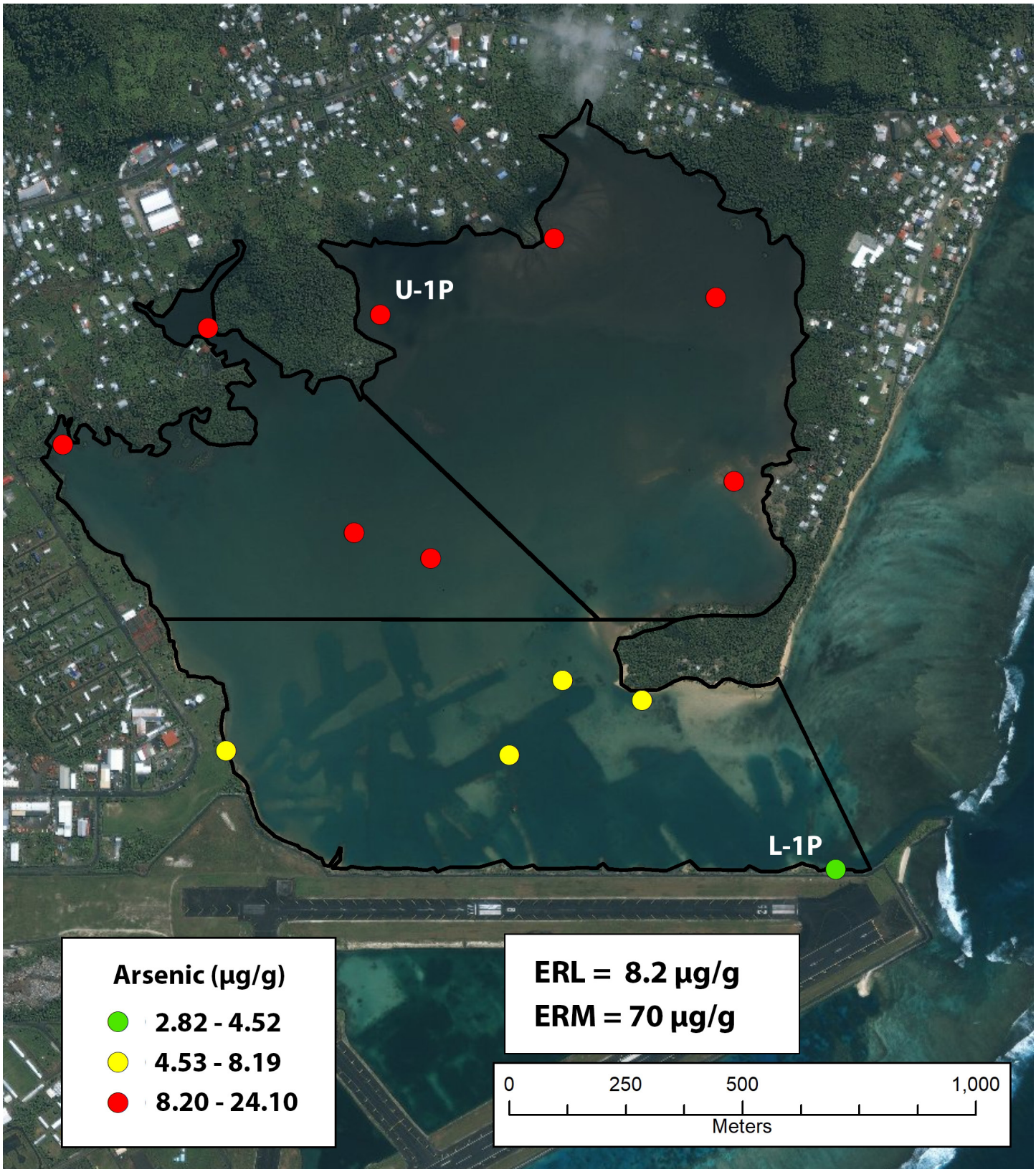

Figure 9. Arsenic concentrations (µg/g dry weight) in sediment from the Nu'uuli Pala Lagoon. Sites in red exceed the Effects Range Low (ERL). ERM = Effects Range Median.

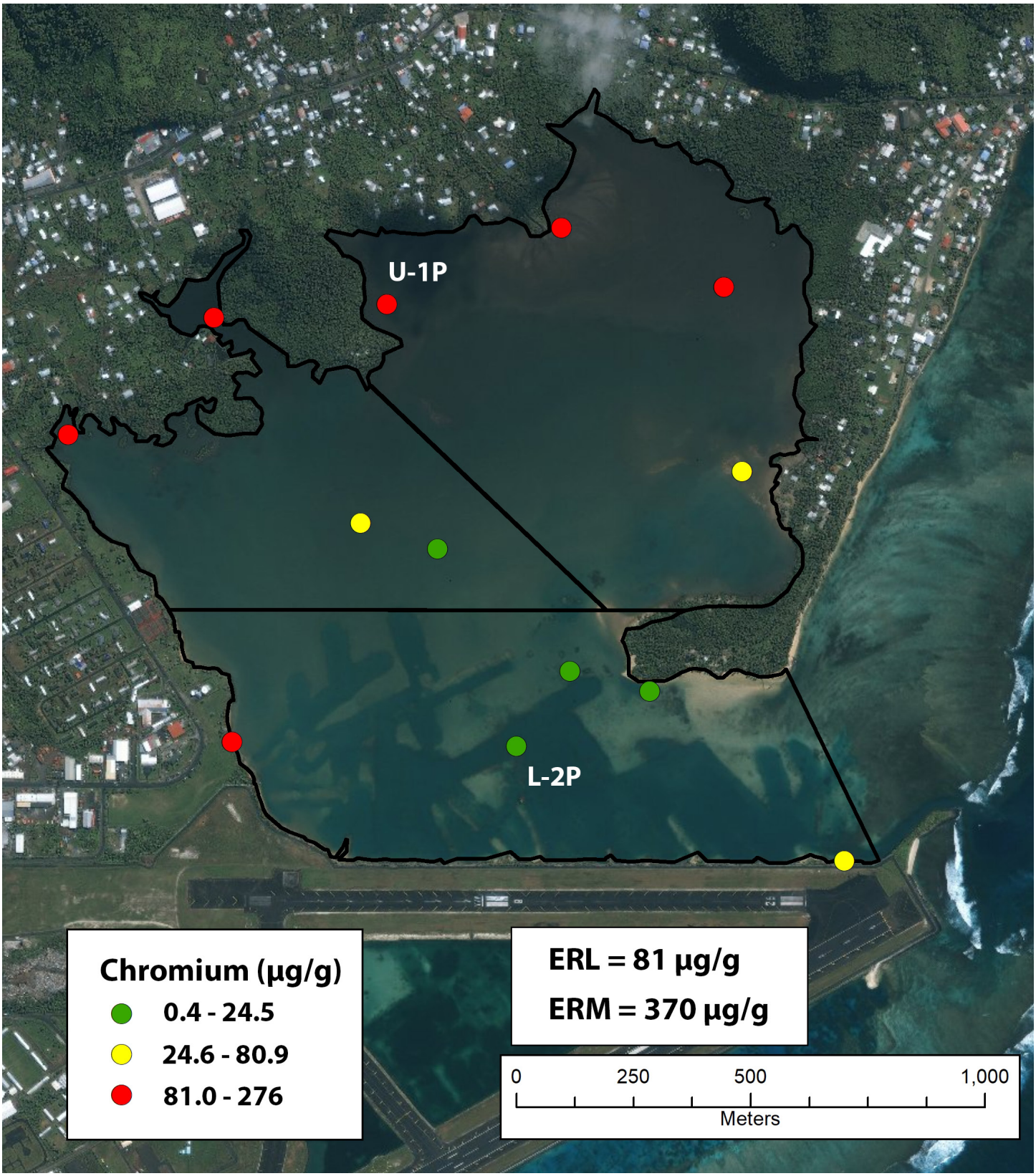

Figure 10. Chromium concentrations (µg/g dry weight) in sediment from the Nu'uuli Pala Lagoon. Sites in red exceed the Effects Range Low (ERL). ERM = Effects Range Median.

None of the samples exceeded the ERM.

A bivariate analysis of chromium and aluminum showed a strong significant correlation ($F > 0.0001$) with an adjusted R-square value of 0.8029, indicating that the majority of chromium measured in the sediment in the Pala Lagoon could be the result of erosion.

A non-parametric Wilcoxon Rank Sums analysis showed that when the Upper and Middle stratum are combined they are significantly higher ($\alpha=0.05$, Chi-Square > 0.0272) than the Lower Pala Lagoon. There are no statistically significant differences between all three strata when analyzed individually.

Comparison with other data.

Chromium concentrations measured in the Pala Lagoon were significantly higher than those measured by Whitall and Holst (2015) in the watershed and bay of Faga'alu (nonparametric Wilcoxon Rank Sums, $\alpha=0.05$, Chi-square > 0.0417; Table 4). Despite the significant difference between the two waterbodies, the highest concentration of chromium in sediments from the Pala Lagoon (276 µg/g) is comparable with the highest concentration of arsenic measured in sediment from the Faga'alu watershed and bay (191 µg/g; Table 10). Chromium concentrations in the Pala Lagoon were also higher than those measured in the sediment of the Pago Pago Harbor (CH2MHill, 2007), which had a mean concentration of 56.03 µg/g and a range of 17.9 to 85.7 µg/g.

Cadmium

The mean concentration of cadmium in sediment from the Pala Lagoon was 0.04 ± 0.09 µg/g with a median concentration of 0 µg/g. The maximum concentration of 0.29 µg/g was measured at site M-4P. Cadmium was only detected at two sites within the Pala Lagoon, M-4P and M-2P (Figure 11). No sediment samples exceeded the ERL or ERM for cadmium. Despite having only two detections, a bivariate analysis of cadmium concentrations versus aluminum showed a significant correlation ($F > 0.0188$), though the adjusted R-square value was low at 0.3542 indicating that the cadmium measured in the sediment of the Pala Lagoon likely is not from crustal erosion. There are no statistically significant differences among strata for cadmium concentrations in sediment.

Comparison with other data.

Cadmium concentrations measured by Whitall and Holst (2015) in sediment from the Faga'alu watershed and bay were significantly higher than those measured in the Pala Lagoon (nonparametric Wilcoxon Rank Sums, $\alpha=0.05$, Chi-square > 0.0078; Table 4). Despite the significant difference between the two waterbodies, the highest concentration of cadmium in sediments from the Pala Lagoon (0.29 µg/g) is comparable with the highest concentration of cadmium measured in sediment from the Faga'alu watershed and bay (0.31 µg/g; Table 10).

Copper

The mean concentration of copper in the Pala Lagoon sediments was 12.73 ± 13.31 µg/g with a median concentration of 7.67 µg/g. The maximum concentration of copper of 50.5 µg/g was measured at site M-4P while the minimum concentration of 0.65 µg/g was measured at site L-2P. Only one of the thirteen sediment samples exceeded the ERL (Figure 12) and none exceeded the ERM. A bivariate analysis of copper and aluminum showed a statistically significant correlation ($F > 0.0008$) with an adjusted R-square value of 0.6248. There are no statistically significant differences among strata for copper.

Comparison with other data.

There were no statistically significant differences between copper concentrations measured in the sediment from the Pala Lagoon and those measured by Whitall and Holst (2015) for the Faga'alu watershed and bay (Table 4). The highest concentration of copper in sediment from the Faga'alu watershed and bay (37.7 µg/g) is also comparable to the highest concentration measured in sediment from the Pala Lagoon (50.5 µg/g; Table 10). Sediment copper concentrations in the Pago Pago Harbor (CH2MHill, 2007) were an order of magnitude higher than those measured in sediment from this study. Pago

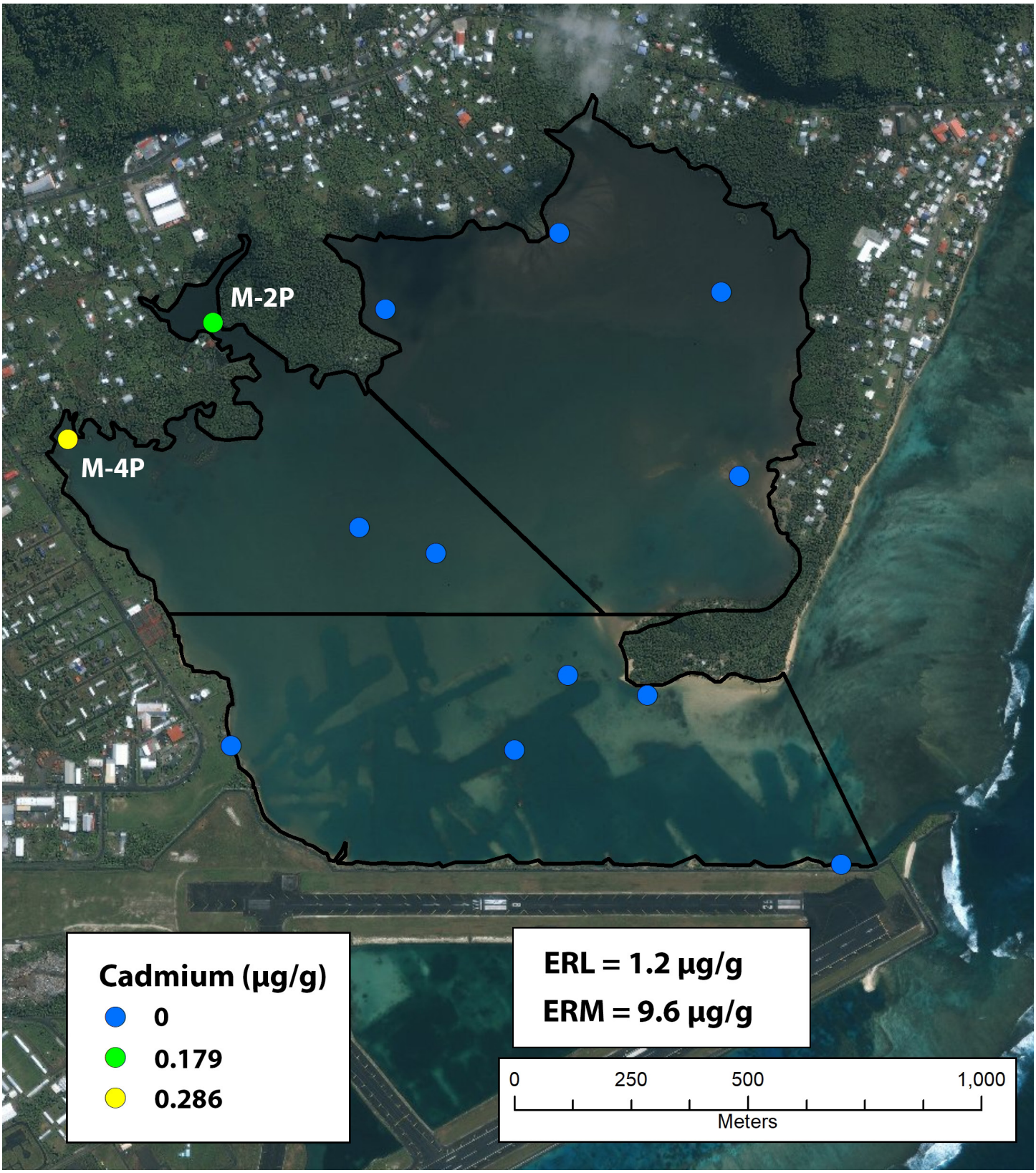

Figure 11. Cadmium concentrations (µg/g dry weight) in sediment from the Nu'uuli Pala Lagoon. ERL = Effects Range Low, ERM = Effects Range Median.

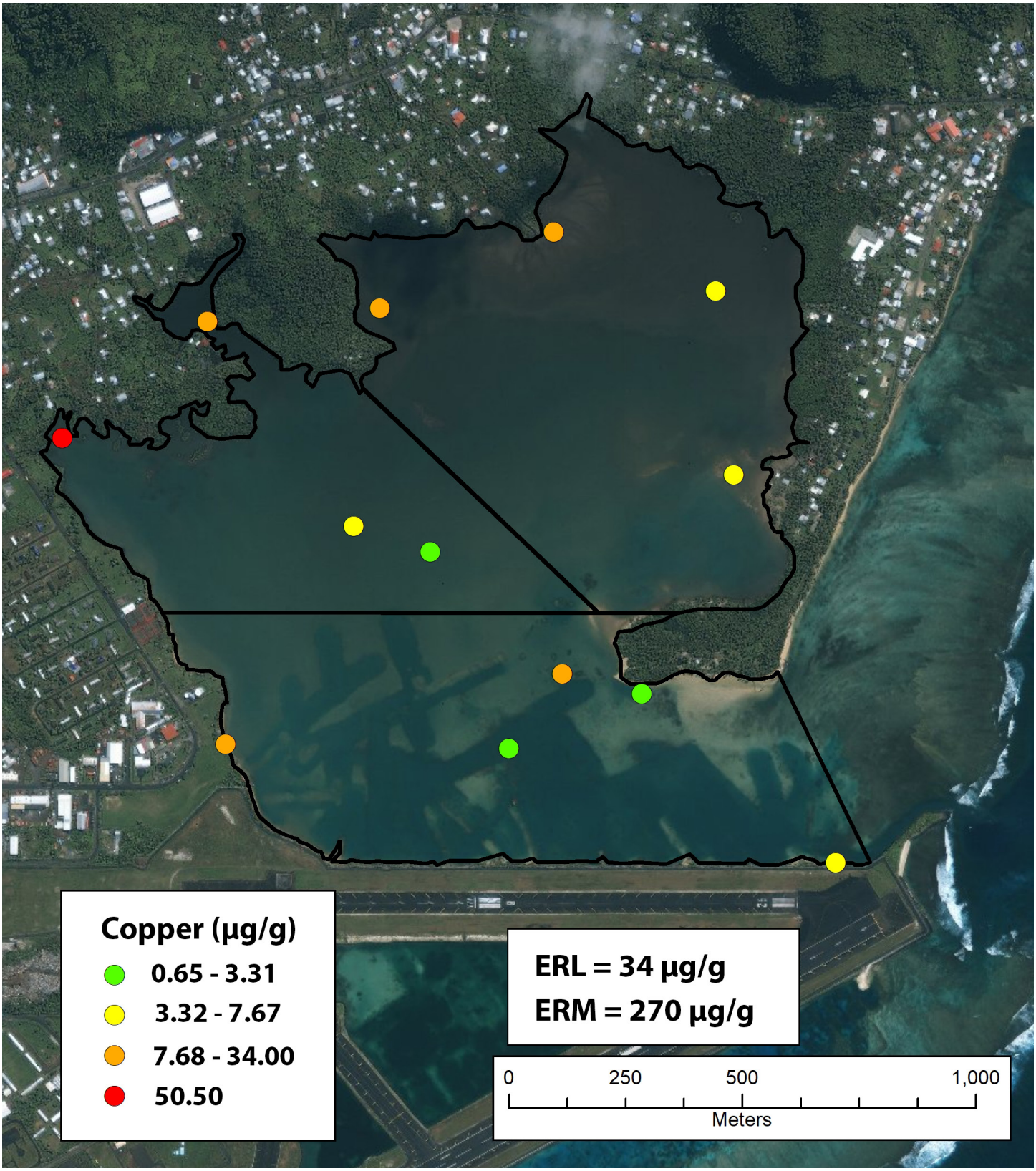

Figure 12. Copper concentrations (µg/g dry weight) in sediment from the Nu'uuli Pala Lagoon. Sites in red exceed the Effects Range Low (ERL). ERM = Effects Range Median.

Pago Harbor copper concentrations ranged from 4.82 to 564 µg/g with a mean concentration of 211.3 µg/g. The higher copper concentrations in sediment from the Pago Pago Harbor are not surprising due to the amount of boat traffic in that area as compared to the Pala Lagoon, with copper being a common component of anti-fouling boat paints.

Nickel

Concentrations of nickel in the sediment from the Pala Lagoon ranged from a maximum of 123 µg/g at site TS-1 and a minimum of 2.53 µg/g at site L-2P. The mean concentration of copper was 44.21 ± 42.66 µg/g with a median concentration of 25.8 µg/g. Five sites exceeded the ERL for nickel while an additional four sites exceeded both the ERL and the ERM (Figure 13). A bivariate analysis of nickel and aluminum showed a statistically significant correlation ($F > 0.0191$), however the adjusted R-square (0.3525) indicates that the majority of nickel in the Pala Lagoon is not likely related to crustal erosion. There are no significant differences between any strata for nickel concentrations.

Comparison with other data.

There were no statistically significant differences between nickel concentrations measured in the sediment from the Pala Lagoon and those measured by Whitall and Holst (2015) for the Faga'alu watershed and bay (nonparametric Wilcoxon Rank Sums, $\alpha=0.05$, Chi-square > 0.3909; Table 4). The highest concentration of nickel in sediment from the Faga'alu watershed and bay (211 µg/g) is also comparable to the highest concentration measured in sediment from the Pala Lagoon (123 µg/g; Table 10). Nickel concentrations in the Pala Lagoon were slightly higher than those measured in sediment from the Pago Pago Harbor (CH2MHill, 2007) which had a mean of 40.2 µg/g and a range of 10.4 to 62.5 µg/g.

Zinc

The mean concentration of zinc in sediment from the Pala Lagoon was 101.58 ± 105.35 µg/g with a median concentration of 48.1 µg/g. The maximum concentration of 332 µg/g was measured at site M-4P while the minimum concentration of 6.52 µg/g was measured at site L-2P. Four of the thirteen sediment samples analyzed for zinc exceeded the ERL of 150 µg/g (Figure 14). No samples exceeded the ERM.

A bivariate analysis of zinc concentrations versus aluminum showed a very high significant correlation ($F > 0.0001$) with an adjusted R-square value of 0.9626 indicating that the majority of zinc in the sediment of the Pala Lagoon potentially driven by erosion.

A non-parametric Wilcoxon Rank Sums analysis of logNormal zinc concentrations showed a statistically significant difference between the combined Upper/Middle strata and the Lower strata ($\alpha=0.05$, Chi Square > 0.0107), where the combined Upper/Middle strata was significantly higher than the Lower strata.

Comparison with other data.

There were no statistically significant differences between sediment from the Pala Lagoon and those measured by Whitall and Holst (2015) for the Faga'alu watershed and bay for zinc concentrations (Table 4). The highest concentration of zinc in sediment from the Faga'alu watershed and bay (416 µg/g) is also comparable to the highest concentration measured in sediment from the Pala Lagoon (332 µg/g; Table 10). Concentrations of zinc measured in the sediment from Pago Pago Harbor (CH2MHill, 2007) were higher than those measured in the Pala Lagoon. The Pago Pago Harbor sediment had zinc concentrations that ranged from 33.4 to 1,810 µg/g and a mean concentration of 778.9 µg/g.

Bacterial Indicator

The bacterial indicator *Clostridium perfringens*, a surrogate for measuring human and animal waste inputs to the environment, was detected in every sediment sample collected in from the Pala Lagoon. The mean concentration of C. *perfringens* was 258.96 ± 359.98 colony forming units per gram (CFU/g) with a median concentration of 119.6 CFU/g. The maximum concentration of *C. perfringens* of 1,183.8 CFU/g was measured at site M-2P, located just south of the Laufou shopping center, while the minimum concentration of 9.1 CFU/g was measured at site L-1P, located at the north side of the end of the Pago Pago airport runway (Figure 15).

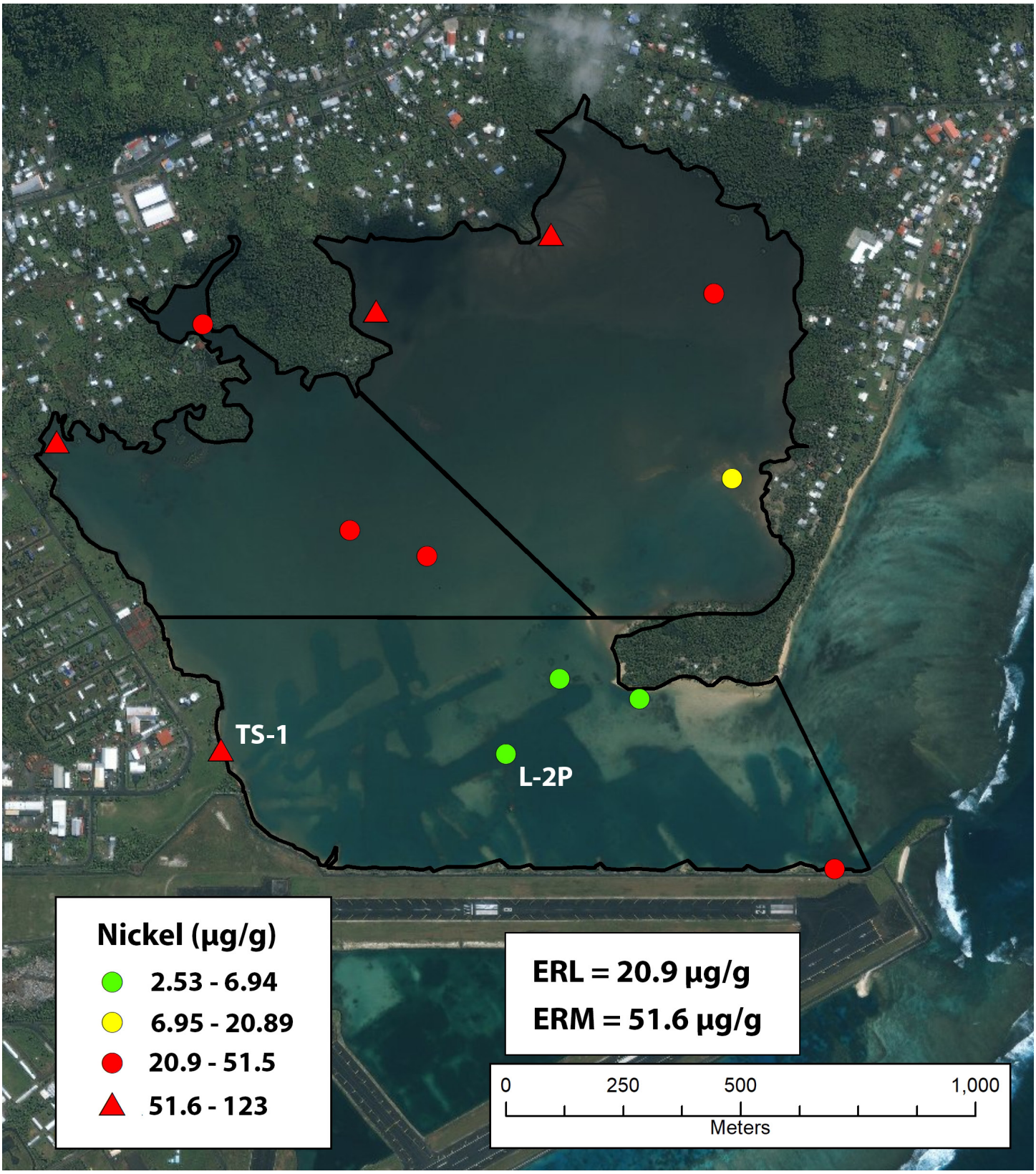

Figure 13. Nickel concentrations (µg/g dry weight) in sediment from the Nu'uuli Pala Lagoon. Sites in red exceed the Effects Range Low (ERL). Sites denoted by triangles exceed the Effects Range Median (ERM).

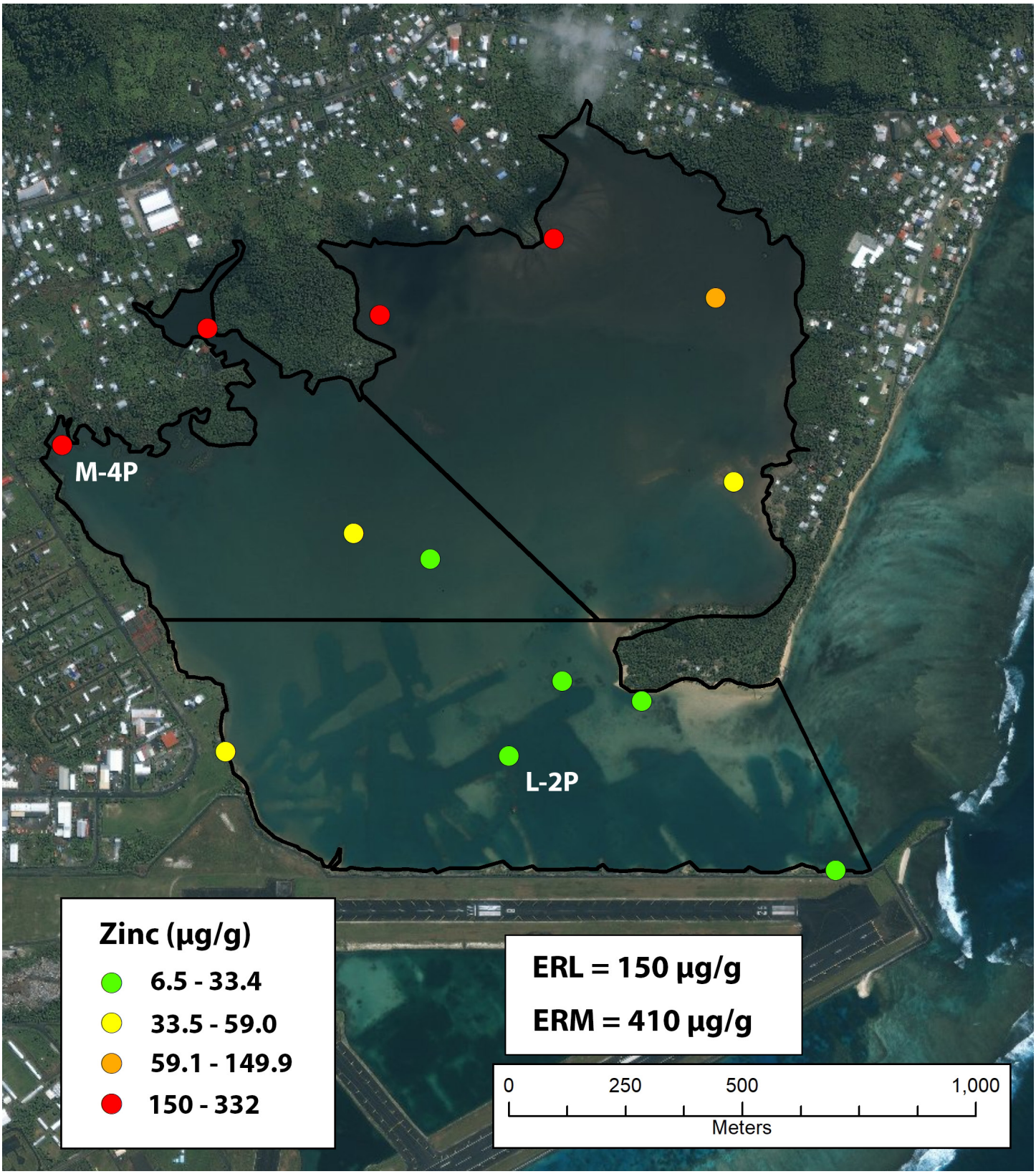

Figure 14. Zinc concentrations (µg/g dry weight) in sediment from the Nu'uuli Pala Lagoon. Sites in red exceed the Effects Range Low (ERL). ERM = Effects Range Median.

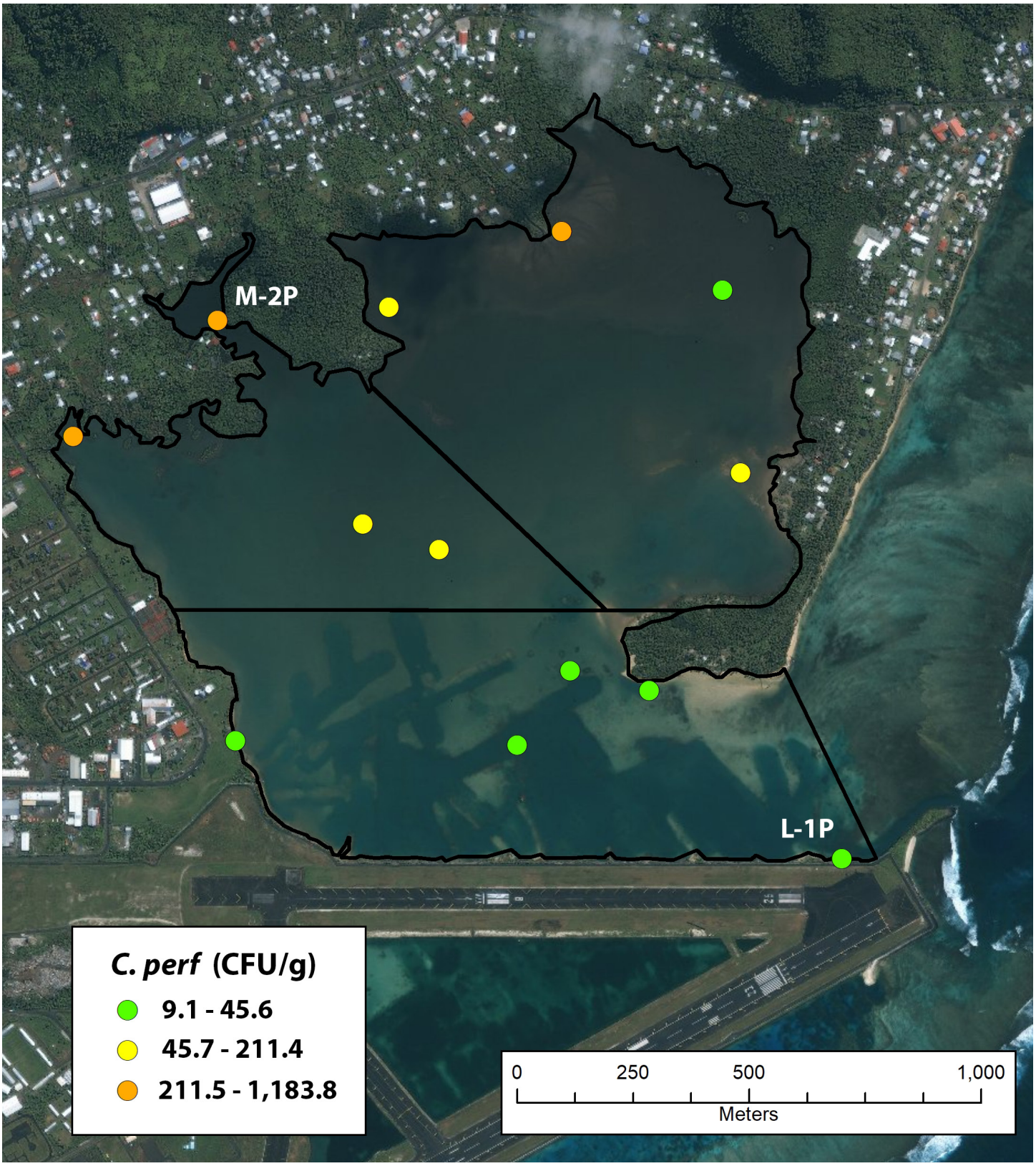

Figure 15. Measured colony forming units (CFU) per gram of *Claustridium perfringens* (*C. perf*) in sediment from the Nu'uuli Pala Lagoon.

A bivariate analysis of *C. perfringens* versus distance from freshwater inputs shows a significant correlation ($F > 0.0152$, $\alpha=0.05$), but the adjusted R-square value is low at 0.3765. This points toward non-point source (i.e. stream runoff, ground water) based sources of potential human and animal waste entering the Pala Lagoon.

Comparison with other data.

There was no statistically significant difference in *C. perfringens* concentrations between this study and that conducted by Whitall and Holst (2015) in the Faga'alu watershed and bay. The maximum measured amount of *C. perfringens* from Faga'alu was higher than that measured in the Pala Lagoon (1,722 CFU/g) though that concentration was measured from the watershed of Faga'alu and not from the bay. The maximum concentration in the Faga'alu bay was 639 CFU/g (Whitall and Holst, 2015) located at their site NB14, or North Bay 14. This is comparable to the amount of *C. perfringens* measured in sediment in the Pala Lagoon at site M-4P (located at the north end of Lions Park) and at site U-3P (the farthest northeast site sampled), but well below the 1,183.8 CFU/g measured at site M-2P (just south of the Laufou shopping center).

The amount of *C. perfringens* present in the Pala Lagoon seems to be elevated as compared to national level sediment data collected by NOAA's NS&T program with the highest concentration of *C. perfringens* found in the Pala Lagoon is in the top 10% of all measured *C. perfringens* samples. That said, these overall values for the Pala Lagoon appear to be typical for what has been measured in other coral coastal environments (Whitall et al., 2014; Whitall and Holst, 2015).

CONCLUSIONS

Overall, concentrations of organic contaminants in sediment from the Nu'uuli Pala Lagoon are low as compared to other studies conducted by NOAA's National Status and Trends (NS&T) Program, and are similar to those measured in the Faga'alu watershed and bay. The only organic contaminants measured in the Pala Lagoon that exceeded any known guidelines or thresholds was for total DDT, and then only the Effects Range Low (ERL). That said, there are currently no established guidelines for the flame retardant class of chemicals that comprise PBDEs. PBDEs in the Pala Lagoon appear to be elevated as compared to other relatively lower population coastal US areas (see above results section for PBDEs). While PBDE levels in the Pala Lagoon are not high compared to some of the most highly contaminated areas, such as Busan Bay, South Korea, concentrations of PBDEs in sediments in the Pala Lagoon are comparable to levels measured in other heavily populated areas in the continental US, such as the San Francisco Bay area. The fact that the relatively low population of the Nu'uuli Pala Lagoon watershed are generating similar levels of PDBEs as those of much more highly populated areas could be an area of potential concern. As PBDEs are often associated with flame retardants in furniture and other household goods, the reduction of bulk trash and other marine debris to the Pala Lagoon could potentially help mitigate future loading of PBDEs to the marine environment. Because of the persistent and ubiquitous nature of PBDEs, any management actions may take decades to have measureable effects on sediment concentrations of PBDEs in the Pala Lagoon.

The levels of multi residue pesticides, human use pharmaceuticals, and perfluorinated compounds appear to be low. Because many of the 299 chemicals measured as part of this analysis are polar, adhesion to the relatively low organic carbon containing sediments in the Pala Lagoon may not be occurring at appreciable levels. The fact that any of these organic contaminants are measureable in the sediment of the Pala Lagoon points toward the potential presence of additional organic contaminants at lower levels that may not be detectable in sediment. A potential follow up study of either the dissolved phase of marine waters or of aquatic organisms, such as fish or invertebrates, could provide further context and information on the presence or absence, and relative abundance of these chemicals that do not tend to accumulate in sediment. Levels of legacy organic contaminants, including PAHs, PCBs, and DDT, appear to be low and not currently a concern for the Pala Lagoon. A qualitative pattern that appeared across almost all contaminants for this study, including both organic and inorganic compounds, was higher levels of contaminants at or near the sources of freshwater to the Pala Lagoon. Site M-4P, located near the north end of Lions Park, represented 60% of all maximum values measured in the Pala Lagoon (Figure 16). No maximum values for any measured chemical contaminant occurred in the Lower stratum, with all but five of the maximum measured concentrations occurring in the Middle stratum (sites M-4P and M-2P).

The concentrations of trace and major elements had a number of exceedances of established guidelines (NOAA's Effects Range Low (ERL) and Effects Range Median (ERM)), including arsenic, chromium, copper, nickel, and zinc. Nickel was

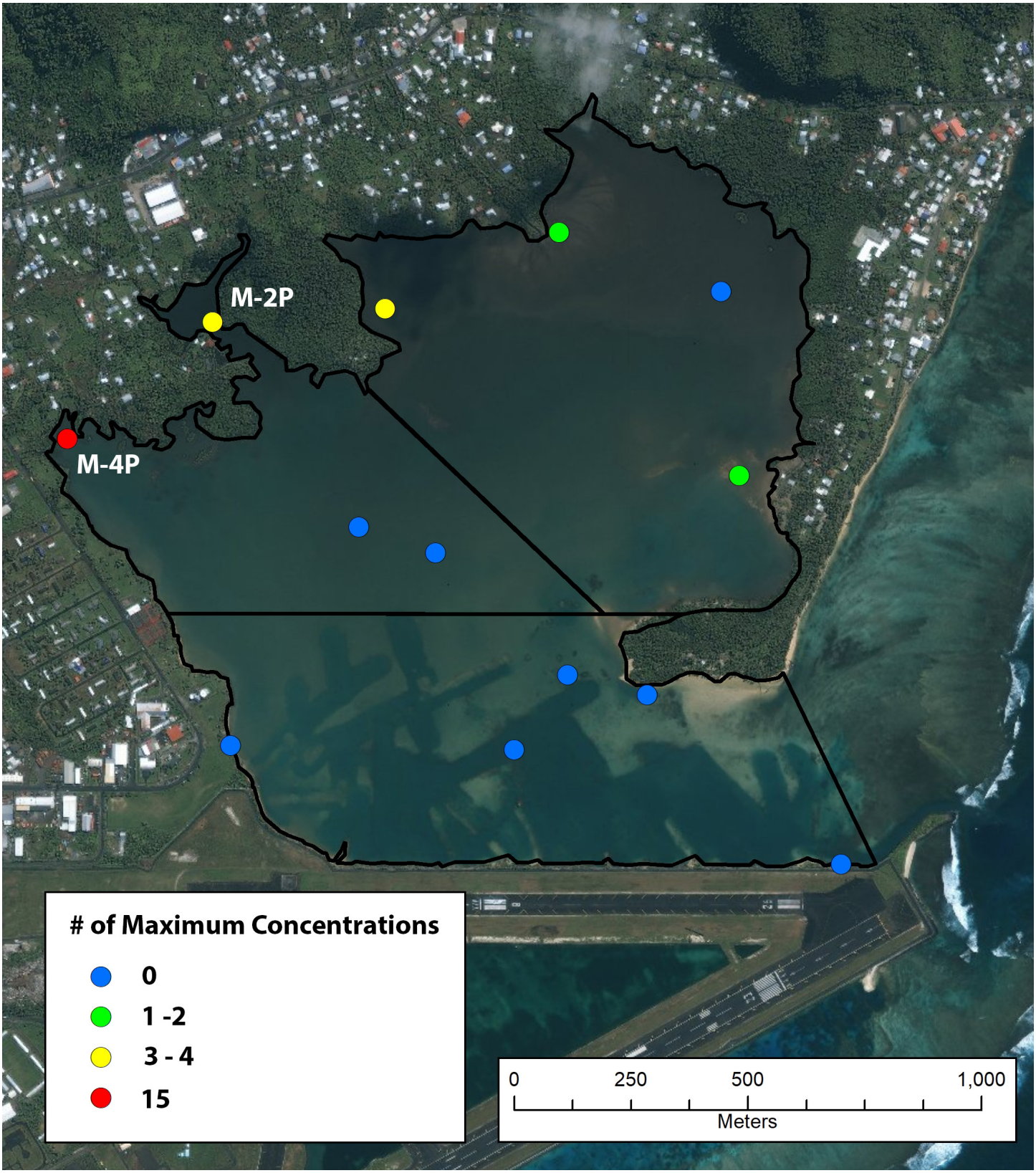

Figure 16. Map depicting the number of maximum concentrations measured in sediments for all chemical contaminant classes in the Nu'uuli Pala Lagoon.

the only metal that exceeded both the ERL and ERM, pointing towards potential adverse impacts to the Pala Lagoon. Of the above mentioned metals, both nickel and arsenic concentrations were not primarily driven by erosion (as compared to any crustal element concentration; Table 9). Trace and major element concentrations in the Lower stratum for the Pala Lagoon were all low with the exception of site L-1P, located at the northeast side of the end of the Pago Pago airport runway, adjacent to the mouth of the Pala Lagoon. The location of L-1P makes it one of the most likely sites to be well-flushed by tidal action and therefore contaminant loads would be expected to be at or near the lowest measured in the Pala Lagoon. While this held true for organic contaminants and most metals, for chromium, nickel, and lead, measured concentrations at site L-1P were the highest for the Lower stratum and even exceeded many of the concentrations from throughout the Pala Lagoon (chromium = 7th highest concentration, nickel = 5th highest concentration, and lead = 4th highest concentration). The concentration of nickel in sediment from site L-1P also exceeded the ERL, indicating potential adverse impacts to benthic organisms at the site. While there could be a number of possible drivers of the elevated levels of these select metals at L-1P, one potential contributor could be the improper disposal of lead-acid batteries along the southern shoreline of the Pala Lagoon. Chromium, nickel, and lead are all common components of lead-acid batteries. During field collections for this study, the authors observed a large number of batteries, in various states of decomposition, along the airport runway fence line and near the sample location for L-1P. Discussions with locals brought to light that the strip of shoreline north of the airport is a popular spot for night fishing activities, and that the source of the batteries may be fishermen improperly discarding flashlight batteries into or adjacent to the marine environment.

Both this study and that of Whitall and Holst (2015) found relatively elevated levels of trace and major metals. Based on comparisons with crustal metals, such as aluminum and iron, it appears that although many of these metals are elevated, much of these measured concentrations may be attributed to naturally high rates of erosion. For example, zinc concentrations in the Pala Lagoon exceeded the ERL at four locations while concentrations in Faga'alu exceeded the ERL at five locations and the ERM at one, but for both waterbodies, zinc concentrations were very highly correlated to aluminum with adjusted R-square values of 0.96 for each. This high level of correlation points toward these elevated concentrations occurring naturally.

Data from this study provide a baseline characterization of the Pala Lagoon that can be used by local managers to both inform their decision making process and to detect changes, both positive and negative, that may occur over time. Additional research may be warrented to better understand the sources and effects of some of the potentially problematic pollutants measured, including arsenic, chromium, nickel, zinc, and PBDEs. Further studies to quantify contaminants in the biota of the Pala Lagoon could also be of interest. All data generated by this study are available at doi:10.25921/d4gh-p564.

LITERATURE CITED

Addison D J, Tago T, Toloa J, Pearthree E, 2006. Ceramic deposit below Fifth to Sixth Century AD volcanic ash fall at Pava'ia'i, Tutuila Island, American Samoa: Preliminary results from site AS-31-171. New Zealand Journal of Archaeology v. 27, p. 5-18.

Agency for Toxic Substances and Disease Registry (ATSDR). 1995. Toxicological Profile for Polycyclic Aromatic Hydrocarbons (PAHs). U.S. Department of Health and Human Services, ATSDR. Atlanta, GA. 487 pp. Online: https://www.atsdr.cdc.gov/toxprofiles/tp.asp?id=122&tid=25 (Accessed 23 Oct 2019)

American Samoa Government (ASG). 2011. American Samoa Statistical Yearbook 2011. Department of Commerce, Statistics Division. Pago Pago, American Samoa.

Besser, J.M. and K.J. Leib. 2007. Toxicity of Metals in Water and Sediment to Aquatic Biota. In: Integrated Investi¬gations of Environmental Effects of Historical Mining in the Animas River Watershed, San Juan County, Colorado. USGS Professional Paper 1651.

BSEF (Bromine Science and Environmental Forum). 2007. Fact Sheet: Brominated Flame Retardant Deca-BDE Decabromodiphenyl Ether. Edition 2007. Accessed 23 Oct 2019. http://icl-ip.com/wp-content/uploads/2012/03/230_45_FR1210_BSEF_factsheet_Deca-BDE_oct07.pdf

CH2MHill. 2007. Report on Fate and Transport Analysis (Study Element 4) for the Pago Pago Harbor Sediment Toxicity Study. Prepared for American Samoa Environmental Protection Agency and U.S. Environmental Protec¬tion Agency.

Chattopadhyay, S. and D Chattopadhyay. 2015. Remediation of DDT and Its Metabolites in Contaminated Sediment. Current Pollution Reports. Volume 1, Issue 4, pp 248-264.

Dermeche, S., F. Chahrour and Z. Boutiba. 2012. Evaluation of the toxicity of metal pollutants on embryonic development of the sea urchin Paracentrotus lividus (Lamarck, 1816) (Echinodermata Echinoidea). Biodiversity Journal 3: 165-172.

Edullantes, B. and R.P. Galapate. 2014. Embryotoxicity of Copper and Zinc in Tropical Sea Urchin Tripneustes gratill. Science Diliman 26: 25-40

Eisler, R. 1986. Chromium hazards to fish, wildlife, and invertebrates: a synoptic review. U.S. Fish and Wildlife Service Biological Report 85(1.6). 60 pp.

Eisler, R. 1988. Arsenic hazards to fish, wildlife, and invertebrates: A synoptic review. Contaminant Hazard Reviews Report 12; Biological Report 85 (1.12)

Eisler, R. 1998. Copper hazards to fish, wildlife, and invertebrates: a synoptic review (Contaminant Hazard Re¬views Report No. 33). US Department of the Interior and US Geological Survey. 1998.

EPA (U.S. Environmental Protection Agency). 1997. Management of Polychlorinated Biphenyls in the United States. Office o fPollution Prevention and Toxics. 6 pp. Online: http://www.chem.unep.ch/pops.

EPA (U.S. Environmental Protection Agency). 2005. Toxicological Review of Zinc and Compounds. EP-A/635/R-05/002

Goh, B. 1991. Mortality and settlement success of Pocillopora damicornis planula larvae during recovery from low levels of nickel. Pacific Science 45: 276-286.

Hardy, M.L. 2002. A comparison of the properties of the major commercial PBDPO/PBDE products to those of major PBB and PCB products. Chemosphere 46:717-728.

Hawai'i Department of Health (HDOH). 2012. Hawaiian Islands Soil Metal Background Evaluation Report. Hawai'I Department of Health, Hazard Evaluation and Emergency Response. Honolulu, HI.

Hunt, J.W., B.S. Anderson, B.M Phillips, R.S. Tieerdema, H.M. Puckett, M. Stephenson, D.W. Tucker and D. Wat¬son. 2002. Acute and chronic toxicity of nickel to marine organisms: implications for water quality criteria. Environ Toxicol Chem. 21: 2423-30.

Hyland, J.L., R.F. Van Dolah, and T.R. Snoots. 1999. Predicting stress in benthic communities of southeastern U.S. estuaries in relation to chemical contamination of sediments. Environmental Toxicology and Chemistry 18(11): 2557-2564. Doi: https://doi.org/10.1002/etc.5620181124

Johnson, B., R. Addink, and D. Adams. 2005. Polybrominated Diphenyl Ethers and Polychlorinated Biphenyls in a Marine Foodweb of Coastal Florida. Environmental science and technology. 39. 8243-50. 10.1021/es051551y.

Kimbrough, K.L. and G.G. Lauenstein (eds). 2006. Major and trace element analytical methods of the National Status and Trends Program: 2000-2006. Silver Spring, MD. NOAA Technical Memorandum NOS NCCOS 29. 19 pp.

Kimbrough, K.L., W.E. Johnson, G.G. Lauenstein, J.D. Christensen, and D.A. Apeti. 2009. An Assessment of Polybrominated Diphenyl Ethers (PBDEs) in Sediments and Bivalves of the U.S. Coastal Zone. Silver Spring, MD. NOAA Technical Memorandum NOS NCCOs 94. 87 pp.

Lincer, J.L. 1975. DDE-induced eggshell thinning in the American kestrel: a comparison of the field situation and laboratory results. Journal of Applied Ecology. 12: 781-793.

Long, E.R. and L.G. Morgan. 1990. The Potential for Biological Effects of Sediment-Sorbed Contaminants Tested in the National Status and Trends Program. NOAA Tech. Memo NOS OMA 52. NOAA, Seattle, WA. 175 pp.

Long, E.R., D.D. MacDonald, S.L. Smith, and F.D. Calder. 1995. Incidence of adverse biologival effects within ranges of chemical concentrations in marine and estuarine sediments. Environmental Management 19: 81-97.

Long, E.R., L.J. Field and D.D. MacDonald. 1998. Predicting toxicity in marine sediments with numerical sedi¬ment quality guidelines. Environmental Toxicology and Chemistry 17(4): 714-727.

Macdonald, G.A, 1968. A contribution to the petrology of Tutuila, American Samoa. Geol Rundschau, 57: 821-837.
National Oceanic and Atmospheric Administration (NOAA) National Status and Trends (NS&T). 1998. National Status and Trends Program for Marine Environmental Quality. National Oceanic and Atmospheric Administration, National Ocean Service, National Status and Trends Program. 32 pp.

National Oceanic and Atmospheric Administration (NOAA). 2009. Coral Reef Habitat Assessment for U.S. Marine Protected Areas. U.S. Territory of American Samoa. National Ocean Service, Management and Budget Office, Special Projects.

National Park Service (NPS). 2015. Weather of American Samoa National Park. http://www.nps.gov/npsa/planyourvisit/weather.htm

National Research Council (NRC). 1985. Oil in the sea: Inputs, fates, and effects. National Academy Press, Washington D.C. 601 pp. doi: https://doi.org/10.17226/314

Novelli, A.A., C. Losso, P.F. Ghetti, and A.V. Ghirardini. 2003. Toxicity of heavy metals using sperm cell and embryo toxicity bioassays with Paracentrotus lividus (Echinodermata: Echinoidea): Comparisons with exposure concentrations in the lagoon of Venice, Italy. Environmental Toxicology and Chemistry 22: 1295-1301.

Reichelt-Brushett, A.J. and P.L. Harrison. 2005. The effect of selected trace elements on the fertilization success of several scleractinian coral species. Coral Reefs 24: 524-534.

Royal Chemistry Society (RCS). 2014. Periodic Table – Chromium. http://www.rsc.org/periodic-table/element/24/chromium

Rogen, W.J., and A. Chen. 2005. Health risks and benefits of bis(4-chlorophenyl)-1,1,1-trichloroethane (DDT). The Lancet. 366: 763-773.

Scott, D.A. (ed.) 1993. A Directory of Wetlands in Oceania. IWRB, Slimbridge, U.K. and AWB, Kuala Lumpur, Malaysia.

Siddiqi, M.A., R.H. Laessig, and K.D. Reed. 2003. Polybrominated diphenyl ethers (PBDEs): New pollutants – Old diseases. Clinical Medicine and Research. Volume 1, Number 4: 281-290

U.S. Census Bureau. 2013. 2010 Census of Population and Housing. Summary Population and Housing Characteristics. CPH-1-1, United States. U.S. Government Printing Office, Washington, DC.

U.S. DOI (Department of the Interior). 1998. Guidelines for Interpretation of the Biological Effects of Selected Constituents in Biota, Water and Sediment: Zinc. http://www.usbr.gov/niwqp/guidelines/pdf/Zinc.pdf

Whitall, D., A. Mason, A. Pait, L. Brune, M. Fulton, E. Wirth, and L. Vandiver. 2014. Organic and metal contamination in marine surface sediments of Guanica Bay, Puerto Rico. Marine Pollution Bulletin 80: 293-301.

Whitall, D. and S. Holst. 2015. Pollution in surface sediments in Faga'alu Bay, Tutuila, American Samoa. NOAA Technical Memorandum NOS/NCCOS 201. Silver Spring, MD. 54 pp. doi: https://doi.org/10.7289/V5/TM-NOS-NCCOS-201

Zhang, Y., W. Wang, J. Song, Z. Ren, H. Yuan, H. Yan, J. Zhang, Z. Pei, and Z. He. 2016. Environmental Characteristics of Polybrominated Diphenyl Ethers in Marine System, with Emphasis on Marine Organisms and Sediments. Hindawi Publishing Corporation. BioMed Research International. Volume 2016, Article ID 1317232, 16 pp. doi: http://dx.doi.org/10.1155/2016/1317232

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