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# Formerly used defense sites on Unalaska Island, Alaska: Mapping a legacy of environmental pollution

Renee Jordan-Ward,[1] Frank A. von Hippel,[2] Jennifer Schmidt,[3] and Marc P. Verhougstraete[2]
[1]Department of Biological Sciences, Northern Arizona University, Flagstaff, Arizona, USA
[2]Department of Community, Environment and Policy, Mel and Enid Zuckerman College of Public Health, University of Arizona, Tucson, Arizona, USA
[3]Institute of Social and Economic Research, University of Alaska Anchorage, Anchorage, Alaska, USA

## Abstract

Unalaska Island, Alaska, served as a US military base during World War II. The military installed bases on Unalaska and nearby islands, many of which were built adjacent to Unangan communities. The military used toxic compounds in its operations and left a legacy of pollution that may pose health risks to residents and local wildlife. The goals of this study were to identify hotspots of contamination remaining at Unalaska formerly used defense (FUD) sites, evaluate the risk posed by arsenic, and examine "no US Department of Defense action indicated" (NDAI) status determinations for FUD sites near communities. We compiled soil chemistry data from remediation reports prepared by the US Army Corps of Engineers at 18 FUD sites on and near Unalaska. Nine had past and/or active remediation projects and on-site sampling data. Eight sites did not have sampling data and were characterized as NDAI. One site was listed as closed. For the nine sites with sampling data, we compiled data for 22 contaminants of concern (COC) and compared concentrations to soil cleanup levels for human health (18 AAC 75.341). We mapped contaminant concentrations exceeding these levels to identify hotspots of contamination. We found that concentrations of some of the 22 COC exceeded Alaska cleanup levels despite remediation efforts, including diesel range organics, arsenic, and lead. The highest COC concentrations were at the FUD site adjacent to the City of Unalaska. A quantitative risk assessment for arsenic found that the risk of exposure through drinking water is low. We highlight concerns with NDAI designations and current remedial practices at remote FUD sites located adjacent to communities. Our data suggest the need for further remediation and monitoring efforts on Unalaska for certain contaminants and research to examine potential threats to human and animal health associated with these sites. *Integr Environ Assess Manag* 2024;00:1–12. © 2024 SETAC

**KEYWORDS:** Arctic pollution; Army Corps of Engineers; Health risk evaluations; Military contamination; Risk assessment

## INTRODUCTION

Alaska held strategic importance to the United States during World War II (WWII) and the Cold War (Roucek, 1983). Located at the nexus of east and west, Alaska provided tactical defense positions to the US military. Unalaska and Amaknak Islands, located in the Fox Islands of the Aleutian Archipelago (Figure 1), served as a base of operations by the US military during the Aleutian Islands Campaign of WWII. The Dutch Harbor Naval Operating Base on Unalaska was the westernmost major naval base in Alaska at the onset of WWII and supported facilities, including barracks, underground storage tanks, munitions storage facilities, and a powerplant. In June 1942, Japanese forces launched an aerial attack on Dutch Harbor, and gained occupation of the Aleutian islands of Attu and Kiska, 1080 and 1344 km west of Dutch Harbor (Rourke, 1997; United States National Park Service [USNPS], 2020). In response to these attacks and the occupation of Attu and Kiska Islands, the US military launched the Aleutian Islands Campaign and rapidly expanded its military presence in the archipelago, including the installation and expansion of defense sites on and around Unalaska Island. To protect strategically important locations in the Aleutian Islands, the military constructed defense sites adjacent to communities with existing infrastructure (Scrudato et al., 2012). The Dutch Harbor military base was built adjacent to the town of Unalaska and expanded across western Unalaska and Amaknak Islands to include positions such as those at Fort Learnard, Ugadaga Bay, and Hog Island (Figure 1; Klein et al., 1987; United States Army Corps of Engineers [Army Corps; USACE], 2003, 2017). As a result, Dutch Harbor became one of the largest US bases developed during WWII (Klein et al., 1987).

Military sites on and around Unalaska were mostly abandoned following WWII, leaving behind buildings and

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materials used during operations, including munitions, lumber, paint, electrical wiring, insulation containing asbestos, transformers containing polychlorinated biphenyls (PCBs), and tanks and drums containing hazardous substances such as brake fluid, fuels, and antifreeze (Carpenter et al., 2005; Sepez et al., 2007; USNPS, 2015). As a result, formerly used defense (FUD) sites may continue to pose a risk to human health and the environment.

Military activity in Alaska during WWII and the Cold War resulted in 600 FUD sites across the state (US Department of the Interior [USDOI], 2016; USEPA, 2004), with over 500 sites listed as high-priority sites for remediation (Williams & Cravez, 2018) and over 250 sites identified as containing hazardous, toxic, and/or radioactive waste by the Army Corps (USACE, 2015). However, many of these sites have not been remediated because of the difficulty and costs associated with cleaning up remote sites and the relatively small human populations impacted by contamination (Williams & Cravez, 2018). As of 2021, 80% of the FUD sites in Alaska listed in the Army Corps Defense Environmental Restoration Program did not have cleanup projects (USACE, 2021), including sites identified as containing hazardous waste (USACE, 2015). Furthermore, Alaskan FUD sites that undergo environmental investigation and remediation have, in some cases, been deemed safe for human use based on insufficient sample sizes that prevent comprehensive risk analysis (von Hippel et al., 2018; Jordan-Ward et al., 2022). For example, research at FUD sites on Sivuqaq (St. Lawrence Island), Alaska, showed that toxic military pollution persisted even after extensive remediation efforts, including the most expensive remediation project to date at an Alaskan FUD site (Alaska Department of Environmental Conservation [ADEC], 2019; von Hippel et al., 2018; Miller et al., 2013).

Unalaska Island has the most FUD sites of any island in the Aleutian Archipelago (USACE, 2021), and its economy is based on the local fishing industry. Approximately 4254 residents live year-round on Unalaska Island, with thousands of additional people employed by the fishing industry residing on the island during the summer months (City of Unalaska, 2017; United States Census Bureau, 2023). The International Port of Dutch Harbor is the largest fishing port by volume of seafood in the United States and provides over 318 million kg of fish and shellfish annually (City of Unalaska, 2021; McKenney, 2021). Moreover, the productive marine environment supports a robust ecosystem that includes threatened and endangered species as well as millions of seabirds (Alaska Department of Fish and Game, 2022; Brewer, 2022). Many local animals serve as key subsistence food sources for Unalaska residents (RIDOLFI Inc., 2020; USACE, 1999).

The current study focused on 18 FUD sites located on Unalaska Island and adjacent islands (Figure 1). Remediation projects on Unalaska and the small, connected Amaknak Island began in 1984 and were still underway during the current study (USACE, 2020a). The goals of this study were to identify hotspots (areas of high exceedances) of contamination remaining at FUD sites, evaluate the risk

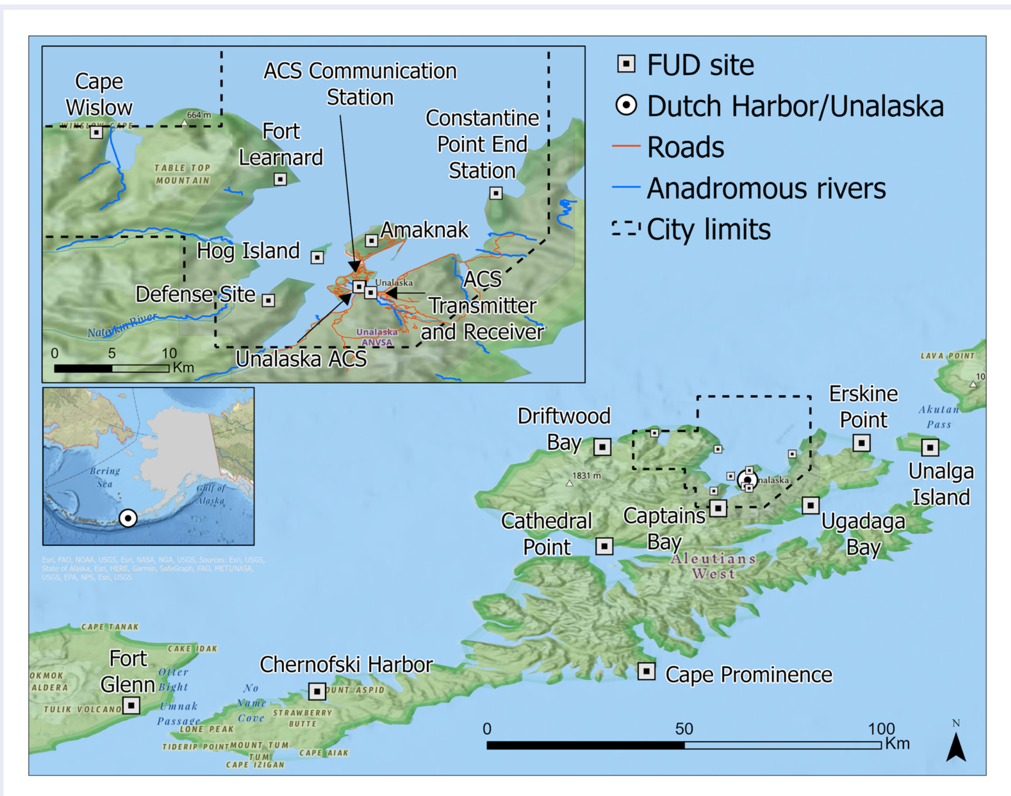


FIGURE 1 Map of formerly used defense (FUD) sites on Unalaska Island, Alaska, and nearby islands. The dashed boundary indicates the City of Unalaska

 

posed by arsenic, and examine Army Corps "no US Department of Defense action indicated" (NDAI) status determinations for FUD sites located near communities. We evaluated existing documentation of contamination at Unalaska FUD sites and mapped contaminants that exceeded Alaska soil cleanup levels for human health (18 AAC 75.341). The State of Alaska has developed soil cleanup levels for approximately 180 substances (ADEC, 2021a); however, only a handful of these substances were tested at Unalaska FUD sites. We compared soil concentrations of 22 contaminants of concern (COC) that were most commonly measured in Unalaska FUD site soil samples. We produced maps showing where soil concentrations of contaminants exceeded the Alaska soil cleanup levels to identify hotspots of contamination and conducted a quantitative risk assessment for arsenic due to concerns about potential contamination of drinking water. This project serves as a case study for mapping contamination across multiple FUD sites and informing the management of FUD sites in the Aleutian and Bering Sea region.

## METHODS

### *Data collection and analysis*

We identified 18 FUD sites on Unalaska and nearby islands using the Army Corps FUD site portal and the ADEC Contaminated Sites Database (Table 1; Figure 1; ADEC, 2021b; RIDOLFI Inc., 2020; USACE, 2021). We collected remediation reports from ADEC records, including site characterizations, site inspections, remedial actions, and site closure reports conducted by the Army Corps. Each FUD site was divided into subsites mirroring those listed in the reports. For example, the Amaknak FUD site was divided into 12 subsites, including Building 551, Captain's Bay, and Pyramid Valley (USACE, 2017). We only analyzed sampling data from the most recent reports for each subsite to best reflect existing concentrations (see Supporting Information data file). Additionally, we only included data on soil concentrations of each contaminant (mg/kg) because soil was the most sampled medium in Army Corps FUD site reports, as opposed to analyses of sediment and surface water samples, which were sparse.

The 22 contaminants most commonly measured in Unalaska FUD site soil samples included diesel and residual-range petroleum hydrocarbons, persistent organic pollutants, and toxic metals and metalloids (Table 2). Data used in this study were extracted from Army Corps FUD site reports and vary across time (1993–present). Some contaminants were tested using different analytical methods at different FUD sites. For example, PCBs were tested as aroclor mixtures at some sites and as total PCBs at other sites. In some cases, analyses were performed on equipment that had limits of quantification higher than the cleanup criteria. We compared the reported concentrations of our

**TABLE 1** List of FUD sites analyzed in this study

| FUD site property name | FUD site ID | Project status | Number of samples |
|---|---|---|---|
| Amaknak | F10AK0841 | Active | 83 |
| Cape Prominence Aircraft Warning System | F10AK0806 | Active | 20 |
| Cape Wislow Aircraft Warning System | F10AK0019 | NDAI | 0 |
| Captain's Bay Steamship Northwestern | F10AK0397 | NDAI | 0 |
| Cathedral Point | F10AK0339 | NDAI | 0 |
| Chernofski Harbor Supply & Storage | F10AK0013 | Active | 32 |
| Constantine Point End Base Station | F10AK0295 | NDAI | 0 |
| Driftwood Bay Radio Relay Station | F10AK0016 | Closed | 71 |
| Erskine Point Fire Control Station | F10AK0296 | NDAI | 0 |
| Fort Glenn | F10AK0298 | Active | 58 |
| Fort Learnard | F10AK0017 | Active | 23 |
| Hog Island Defense Site | F10AK0609 | Closed | 19 |
| Ugadaga Bay Station | F10AK0241 | Active | 10 |
| Unalaska ACS Communication Station | F10AK0610 | NDAI | 0 |
| Unalaska ACS Site | F10AK0611 | NDAI | 0 |
| Unalaska ACS Transmitter and Receiver Site | F10AK0612 | NDAI | 0 |
| Unalaska Defense Site | F10AK0014 | Closed | 0 |
| Unalga Island Naval Radio Station | F10AK0015 | Active | 28 |

Abbreviations: ACS, Alaska Communication System; FUD, formerly used defense; NDAI, no Department of Defense action indicated.

**TABLE 2** List of contaminants and ADEC contaminant screening levels compiled from Army Corps of Engineers FUD site remediation reports on Unalaska Island and nearby islands in the Aleutian Archipelago, Alaska

| Contaminant | Cleanup criteria for soil (mg/kg) | Percent of samples over 10-fold higher than the cleanup criteria |
|---|---|---|
| Diesel range organics | 230 | 56% |
| Residual range organics | 9700 | 19% |
| Arsenic | 0.2 | 74% |
| Barium | 1600 | NE |
| Chromium | 0.089 | 100% |
| Copper | 370 | 50% |
| Lead | 400 | 31% |
| Mercury | 0.36 | 0% |
| Zinc | 2490 | NE |
| Dichlorodiphenyltrichloroethane | 5.1 | 0% |
| PCBs (many tested as aroclors) | 1 | 50% |
| 1,2,4-Trimethylbenzene | 0.16 | 0% |
| 1,3,5-Trimethylbenzene | 0.66 | 0% |
| Benzo[*a*]anthracene | 0.28 | 9% |
| Benzo[*a*]pyrene | 0.17 | 15% |
| Benzo[*b*]fluoranthene | 1.7 | 0% |
| Dibenzo[*a*,*h*]anthracene | 0.17 | 0% |
| Naphthalene | 0.038 | 30% |
| Pyrene | 87 | NE |
| 1,2-Dibromoethane | 0.00024 | NE |
| Trichloroethylene | 0.011 | 0% |
| Chloroform | 0.0071 | 0% |

*Note*: Percentages reflect the number of samples that were 10-fold higher than the ADEC cleanup criteria out of the total number of samples exceeding the cleanup criteria.
Abbreviations: ADEC, Alaska Department of Environmental Conservation; FUD, formerly used defense; NE, no exceedances; PCB, polychlorinated biphenyl.

22 contaminants from FUD sites that had at least one contaminant concentration exceeding ADEC cleanup levels (Table 2; ADEC, 2021a). We did not analyze data from FUD sites that had been partially or fully remediated and had no exceedances at any subsites. Our approach identified hotspots of exceedances for the analyzed list of contaminants (Figures 2–4).

### *Mapping contaminant distributions*

We collected GPS coordinates for each sampling location from FUD site reports when available and estimated them from site maps when GPS documentation was either insufficient or unavailable. Several FUD site reports listed coordinates using the US state plane coordinate system (northing and easting coordinates). We converted these coordinates into decimal degrees (latitude and longitude degrees) using Google Earth online coordinate conversion software with Alaska Zone 10 (code 5010) and US Survey Feet parameters (Earth Point, 2021). We created all maps using ArcGIS Pro (version 2.9.0), which we also used to perform all spatial analyses. To identify site locations, we created a minimum bounding polygon tool using the samples associated with a site. To further examine the footprint of contamination, we created a hexagon grid using the general tessellation tool at two scales. We represented the entire study area (2043–2076 $km^2$) using a 5 km scale and the City of Unalaska (408–415 $km^2$) using a 1 km scale (inset maps in Figures 2–4). This allowed samples to fall within a single hexagon at both scales.

The FUD site reports varied in the stage of remediation, number of analytes tested, and cleanup criteria thresholds, which were not standardized across Unalaska FUD sites. For example, cleanup thresholds for benzo[*a*,*h*]anthrocene ranged from 0.27 to 5.5 mg/kg (USACE, 2003, 2018, 2020d). Therefore, we compared contaminant concentrations to the ADEC Method Two cleanup levels for soil (which are based on human health endpoints due to ingestion, inhalation, or migration to groundwater; Table 2; ADEC, 2021a) to standardize the comparison values. Specifically, we compared contaminant concentrations to the ADEC Method Two for the migration to groundwater exposure pathway because these screening levels were used by the Army Corps at several Unalaska FUD sites. For lead and PCBs, the ADEC does not list migration to groundwater cleanup thresholds, so we used the ADEC human health cleanup value for areas receiving annual precipitation of more than 40 inches (102 cm; Unalaska receives about 152 cm of precipitation annually; City of Unalaska, 2021). For benzo[*a*]anthracene, benzo[*a*]pyrene, benzo[*b*]fluoranthene, dibenzo[*a*,*h*]anthracene, and 1,2,4-trimethylbenzene, we used the screening levels used at Unalaska FUD sites, which were more conservative than the ADEC Method Two cleanup levels (USACE, 2018). All cleanup values used in this study reflect values used in multiple FUD site reports; however, these cleanup levels do not necessarily reflect the risk posed by a contaminant at a specific FUD site due to varied local conditions such as soil and water chemistry, which may influence contaminant bioavailability. Additional approaches to modeling the data could use different screening levels to assess relative contamination profiles across the island (please see the Supporting Information data file, which is provided to facilitate alternative modeling approaches).

We designed a standard scoring system based on ADEC cleanup thresholds to compare contaminant concentrations across FUD sites at the same scale (Table 2). This enabled us to visualize areas with elevated levels of contaminants. We evaluated contaminants based on their concentration

 

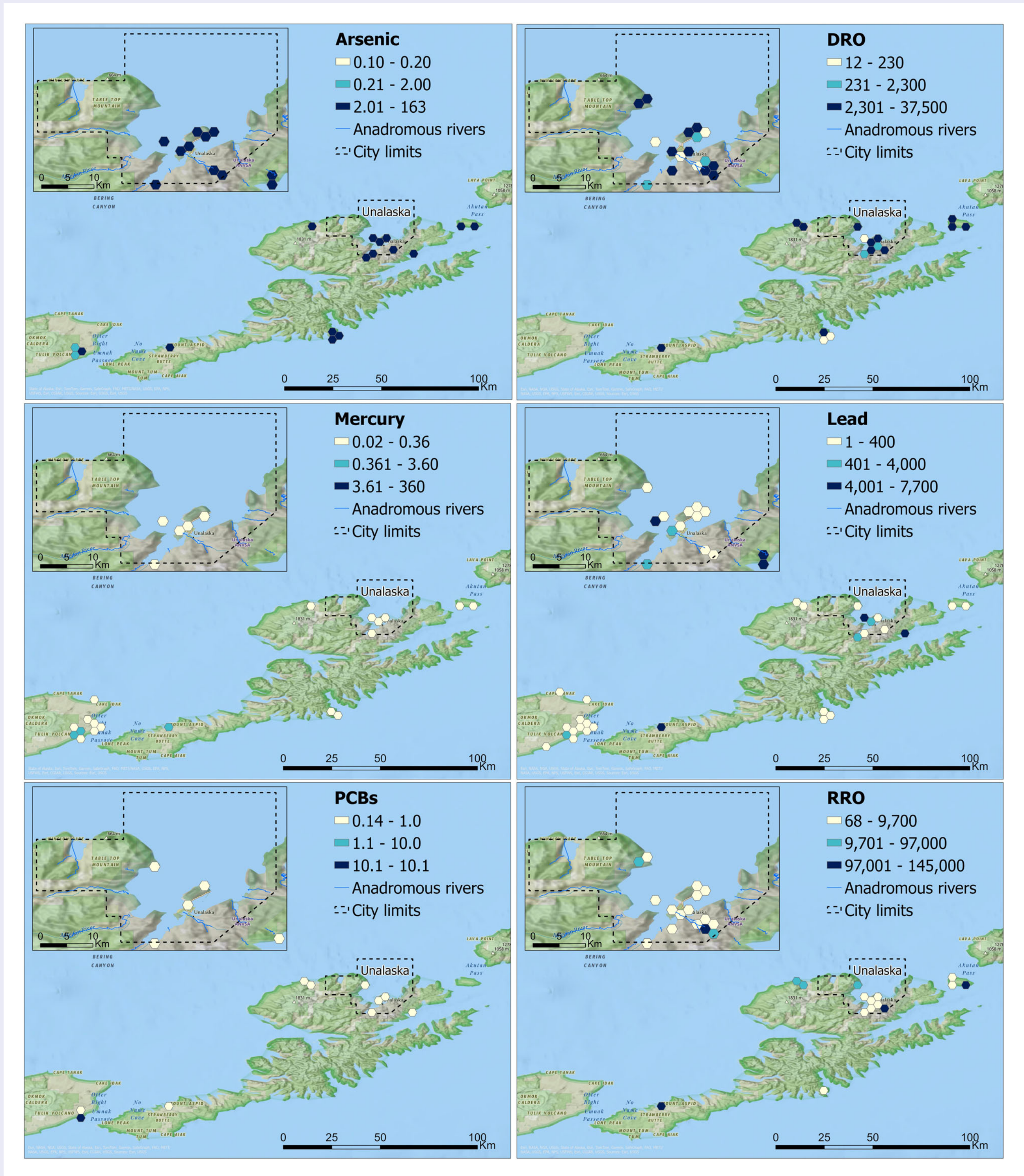


FIGURE 2 Distributions of six contaminants originating from formerly used defense sites on Unalaska Island, Alaska, and nearby islands. Contaminant concentrations were compiled from Army Corps of Engineers remediation reports and compared with the ADEC Method Two cleanup levels for soils (Table 2). Color denotes the contaminant exceedance level based on the maximum concentration within a hexagonal area; beige = not applicable or below ADEC cleanup level, medium blue = 0–10× higher than ADEC cleanup level, and navy = over 10× higher than ADEC cleanup level (the maximum detected value is shown in the range). Hexagons in the main map of Unalaska denote 5 $km^2$ areas and those in the inset map of the City of Unalaska denote 1 $km^2$ areas. ADEC, Alaska Department of Environmental Conservation; DRO, diesel range organics; PCB, polychlorinated biphenyl; RRO, residual range organics

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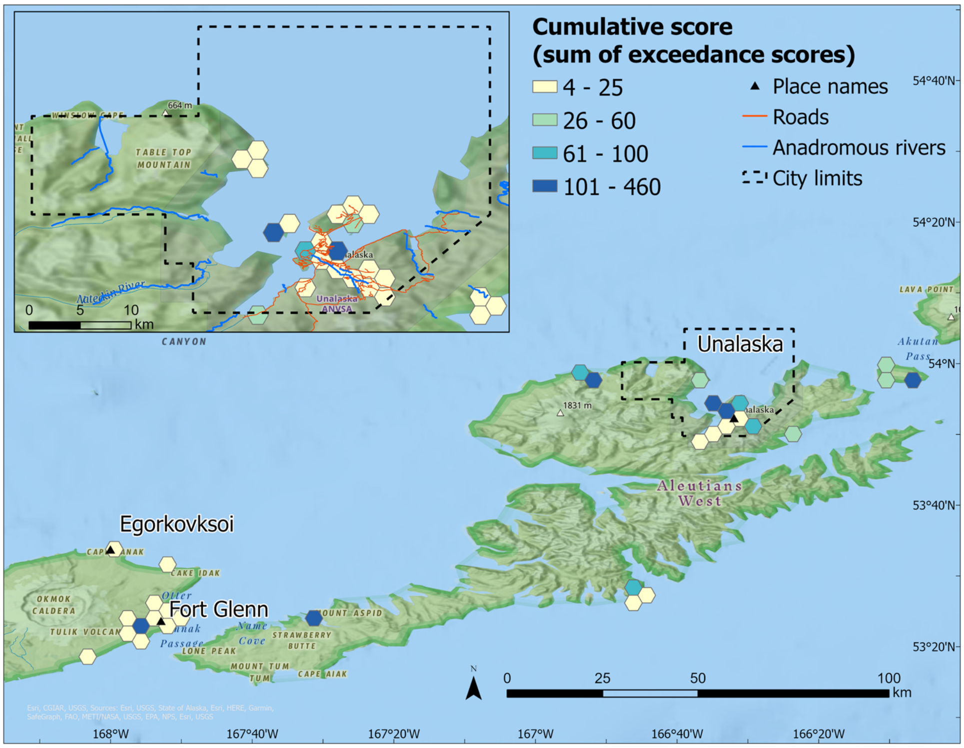


FIGURE 3 Cumulative score of contamination originating from FUD sites on Unalaska Island, Alaska, and nearby islands. Contaminant concentrations were compiled from Army Corps of Engineers FUD site cleanup reports and compared with ADEC Method Two cleanup criteria for soils. Exceedance scores were calculated on a scale from 0 to 3 for each soil sample, and then summed over all samples in each hexagonal area to generate the cumulative score. A sample received an exceedance score of 0 if the contaminant was not detected or analyzed, a score of 1 if the contaminant concentration was below the ADEC cleanup level, a score of 2 if the contaminant concentration was 0–10x higher than the ADEC cleanup level, and a score of 3 if the contaminant concentration was more than 10x higher than the ADEC cleanup level. Cumulative scores reflect the total exceedance score for each hexagonal area. Hexagons in the main map of Unalaska denote 5 $km^2$ areas and those in the inset map of the City of Unalaska denote 1 $km^2$ areas. ADEC, Alaska Department of Conservation; FUD, formerly used defense

relative to the ADEC cleanup levels, which we termed the exceedance score. We applied an exceedance score ranging from 0 to 3 for each contaminant sample: a sample received a score of 0 if the concentration was not applicable (i.e., unavailable, data not compiled due to low values, or not detected), a score of 1 if the concentration was below the ADEC cleanup level, a score of 2 if the contaminant concentration was above the ADEC cleanup level and up to 10x the cleanup level, and a score of 3 if the concentration was more than 10x higher than the ADEC cleanup level (Table 2). We chose to use a cutoff of 10x as a standard of exceedance across the different contaminants.

We calculated cumulative and mean exceedance scores to provide a simplified metric of the number of contaminants at a site (cumulative score) and the degree of threshold exceedance over all contaminants (mean score). Cumulative scores across the study area represent the sum of the exceedance scores for each sample within the boundary of a hexagon (Figure 3). The cumulative score depends on the number of contaminants analyzed within each area. We calculated the mean exceedance scores by dividing each cumulative score by the number of contaminants tested in the area, thus providing a mean exceedance score for each hexagonal area (Figure 4).

### *Risk assessment*

To facilitate a quantitative risk assessment for arsenic, concentrations were converted from soil into water following previously described methods (USEPA, 2005b). Briefly, the concentrations of arsenic in soil were converted into concentrations of arsenic in water by dividing the $\log_{10}$ soil concentration by the median soil–water sorption distribution coefficient ($K_d = 3.4$) for arsenic.

Following Muhammad et al. (2010) and Cooksey et al. (2023), a risk assessment function was developed in R platform (R Core Team, 2018) to calculate an average daily dose (ADD) of arsenic for an individual consuming water containing the mean arsenic concentration in water:

$$\text{ADD} = C \times \text{IR} \times \text{ED} \times \text{EF}/(\text{BW} \times \text{AT}), \quad (1)$$

where $C$ represents the arsenic concentration in water (mg/L), IR is the ingestion rate (1.53 L/day), ED is the exposure duration (70.5 years) based on the average life expectancy at birth for Alaska Native people (Alaska Native Epidemiology Center, 2021), EF is the exposure frequency (365 days/year), BW is the body weight for males and females found for Alaska Natives from one study (68.2 kg; Young et al., 2007), and AT represents the average life span (25 733 days).

 

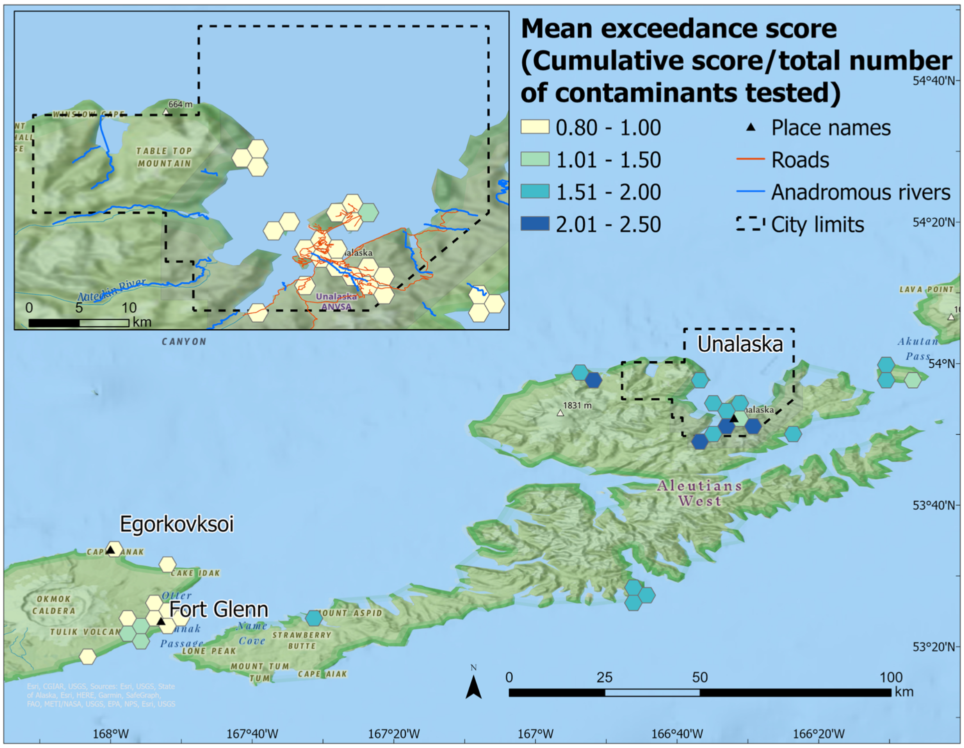


FIGURE 4 Mean exceedance score of contamination originating from FUD sites on Unalaska Island, Alaska, and nearby islands. Contaminant concentrations were compiled from Army Corps of Engineers FUD site cleanup reports and compared with ADEC Method Two cleanup criteria for soils. The mean exceedance score for each hexagonal area is indicated by color: beige = below state cleanup level, light green = low exceedance of the state cleanup levels, teal = medium exceedance of the state cleanup levels, and navy = high exceedance of the state cleanup levels. Hexagons in the main map of Unalaska denote 5 $km^2$ areas and those in the inset map of the City of Unalaska denote 1 $km^2$ areas. ADEC, Alaska Department of Conservation; FUD, formerly used defense

To encapsulate exposure variability and uncertainty, we conducted a Monte Carlo simulation involving 10 000 iterations. Each iteration entailed the generation of values of novel arsenic concentrations in water based on a randomly selected arsenic value from a normal distribution from the converted water arsenic concentrations. Cancer risk (CR) was calculated following Equation (2), where the cancer slope factor (CSF) for arsenic is 1.5 mg/kg/day (USEPA, 2005a).

$$CR = ADD \times CSF. \tag{2}$$

Significance was ascribed to a risk value exceeding the defined threshold of 1/10 000, indicating the potential for one cancer outcome in 10 000 exposures (R code for ADD and CR archive: https://github.com/mverhougstraete/mverhougstraete_trial/tree/mverhougstraete-unalaska.

## RESULTS AND DISCUSSION

### *Contaminant exceedances at Unalaska FUD sites*

Eight of the 18 FUD sites on Unalaska and nearby islands lacked characterization data and yet were categorized as NDAI by the Army Corps, with no planned remediation projects to date. An additional location (Unalaska Defense site) also lacked data and was listed as closed (Table 1). Only nine of the 18 FUD sites had past and/or active remediation projects and on-site sampling data collected by the Army Corps (Table 1). Each of these nine FUD sites contained at least one contaminant that exceeded the Alaska cleanup criteria (Table 2), with varying cumulative scores (Figure 3). We found that contaminant concentrations across all sampled FUD sites were typically between 0- and 10-fold higher than the ADEC cleanup criteria (Figure 4). Of the samples that exceeded the cleanup criteria, 24% had concentrations over 10-fold higher than the cleanup criteria, although this varied by the contaminant tested (Table 2). Contamination originating from FUD sites was most elevated within the boundary of the City of Unalaska (Figure 3) despite extensive remediation efforts at Dutch Harbor, including the removal of over 200 underground storage tanks and treatment of 42 000 tons of petroleum-contaminated soil (USACE, 2020a).

We found that diesel range organics (DRO) was the most common contaminant class analyzed at Unalaska FUD sites, and DRO concentrations were consistently over 10-fold higher than ADEC cleanup thresholds (Figure 2). Some contaminants, including dichlorodiphenyltrichloroethane (DDT) and pyrene, were only tested at one FUD site (Chernofski Harbor and Ugadaga Bay, respectively) and so their actual distributions are unknown.

For Unalaska FUD sites with sampling data, contaminant concentrations remain above Alaska soil cleanup levels despite remediation efforts. Results from previous work (Adams et al., 2019; von Hippel et al., 2018; Jordan-Ward et al., 2022, 2024) demonstrate that current cleanup levels may not be protective for communities that rely heavily on subsistence foods. Because many FUD sites in Alaska are co-located with rural communities, contaminated sites may potentiate the risk to human health (von Hippel et al., 2016; Williams & Cravez, 2018). In our review of technical site documents, we found that the Army Corps did not evaluate contaminant concentrations in subsistence foods at Unalaska FUD sites, which would inform important exposure pathways to residents. Future remediation projects would benefit from more comprehensive sampling at FUD sites adjacent to communities. For example, the US Environmental Protection Agency has stricter regulatory thresholds for subsistence fishers consuming contaminated fish due to increased exposure rates (USEPA, 2000).

Contamination originating at Unalaska FUD sites may continue to pose health risks to local wildlife despite remediation efforts. Although we found that PCB concentrations fell below state cleanup levels at most Unalaska FUD sites (Figure 2), previous studies indicate that these sites may still act as point sources of PCB contamination (Adams et al., 2019; Anthony et al., 2007; Miles et al., 2009). Anthony et al. (2007) found that bald eagle (*Haliaeetus leucocephalus*) eggs collected at Dutch Harbor had elevated total PCB concentrations compared to eggs collected at reference sites. Adams et al. (2019) found elevated PCB concentrations in blue mussels (*Mytilus edulis*), threespine stickleback (*Gasterosteus aculeatus*), and fish species in the family Salmonidae collected near Unalaska FUD sites compared to those collected at nonmilitary sites. These findings are consistent with previous work in the western Aleutian Islands that found that FUD sites contributed to higher total PCB and dichlorodiphenyldichloroethylene (DDE) concentrations in fish (Miles et al., 2009) and seabirds (Ricca et al., 2008). Collectively, these results indicate that Unalaska FUD sites, and others across the Arctic, may continue to pollute local environments despite remediation efforts and remain a potential health threat to residents and local wildlife.

Contaminant distributions across Unalaska FUD sites show that the City of Unalaska remains a hotspot of contamination (Figures 3 and 4). Many Unalaska residents rely on subsistence foods harvested from traditional lands, including those co-located with FUD sites (Adams et al., 2019; Lipka & Fox, 2017; USACE, 1999). From 1997 to 1998, approximately 888 metric tons of subsistence foods were harvested within 24 km downstream of the Ugadaga Bay FUD site (USACE, 1999). This site contains several contaminants that exceed cleanup criteria, including arsenic, chromium, lead, PCBs, benzo[a]anthracene, benzo[*a*]pyrene, benzo[*a*]fluoranthene, dibenzo[*a*,*h*]anthracene, and naphthalene (USACE, 1999). Similarly, several stream systems flow through the Amaknak FUD site to Dutch Harbor, Captains Bay, and Unalaska Bay and could provide a pathway for migration and incorporation of contaminants into food webs downstream of the FUD site (Lemke & Vanderpool, 1995). As a result, residents who consume subsistence foods collected downstream of the Amaknak FUD site may be exposed to contaminants originating from military activities, such as PCBs, through their diet (Adams et al., 2019).

*Deficiencies in current assessments*

Evaluation of contaminants at Unalaska FUD sites occurred through a process with changing guidelines and inconsistencies between state and federal procedures. For example, the Army Corps concluded that no further action was necessary at several sites despite reporting contaminants that exceeded the cleanup criteria used at that site (USACE, 2007, 2020d). Several drum subsites at the Fort Learnard FUD site were not recommended for further action because the extent of contamination, albeit in exceedance of the site-specific cleanup criteria, was of small volume (USACE, 2007). Similarly, the Army Corps did not recommend further remediation of an above-ground storage tank at the Hog Island FUD site even though lead and arsenic levels exceeded cleanup criteria (USACE, 2020d). We also found that cleanup decisions at some sites were based on results that were biased low and/or where quality control measures had failed (USACE, 2017, 2018, 2020b, 2020c). Furthermore, site recommendations at the Unalga Island and Chernofski Harbor FUD sites were based on analytical data collected on equipment that had limits of quantification higher than the cleanup criteria. Additionally, PCB concentrations at most Unalaska FUD sites were tested as aroclor mixtures, which likely underestimate the true concentration present in the environment and preclude the analysis of congener-specific effects that may be important to remediation efforts (von Hippel et al., 2018; Letcher et al., 2010). These issues point to the need for consistent application of cleanup criteria that meet the most stringent applicable state or federal guidelines for the protection of human health and the environment.

Many Army Corps reports attributed elevated toxic metal (loid) concentrations to naturally occurring sources and not to FUD site contamination. We found that arsenic concentrations were consistently over 10-fold higher than the ADEC cleanup threshold of 0.2 mg/kg (Figure 2). Although the Aleutian Islands have elevated metal and metalloid concentrations from natural sources (Gough et al., 1988; Perryman et al., 2020), we found that the Army Corps did not consistently assess background levels and that this precluded analysis of the contribution of FUD sites to local metal(loid) contamination. At the Chernofski Harbor FUD site, the Army Corps concluded that high arsenic concentrations were consistent with background levels despite a 16.5-fold increase in the maximum arsenic concentration at the FUD site (163 and 9.86 mg/kg, respectively; USACE, 2018). However, these levels may still be protective of human health, as suggested by the low CR for arsenic exposure through drinking water (mean risk $= 5.83 \times 10^{-6}$, discussed below).

Eight of the 18 FUD sites (44%) had no active or planned cleanup projects (RIDOLFI Inc., 2020). This is consistent with

Williams and Cravez (2018), who reported that 33% of all Alaskan FUD sites did not have cleanup projects. The Army Corps designates sites as NDAI only if no evidence of hazardous materials or contamination from former military activity is observed or reported (United States General Accounting Office [USGAO], 2002). Once an NDAI determination is made, the site is no longer monitored for potential hazards related to former military use (USGAO, 2002). However, the USGAO (2002) found that the process used by the Army Corps to determine if a site meets NDAI criteria was insufficient. In particular, the Army Corps failed to identify all potential hazards and did not establish sufficient evidence of safety for 38% of FUD sites listed as not needing remediation across the United States. Furthermore, the USGAO found that the Army Corps failed to conduct required site visits for 18% of NDAI sites and failed to notify current site owners of NDAI determination for 72% of sites. For FUD sites that were remediated, the USGAO found that the Army Corps did not adequately conduct the required five-year reviews or re-evaluate FUD sites for emerging contaminants once their cleanup process was complete (USGAO, 2009). Therefore, FUD sites remediated by the Army Corps, as well as sites designated as NDAI, may still pose a risk to human health and the environment.

The Cape Wislow FUD site provides an example of deficiencies in NDAI designation. The USGAO (2002) determined that the Cape Wislow FUD site (listed as Cape Winslow in the report) was not sufficiently characterized and data were lacking on potential hazards to provide a sound basis for NDAI determination. Located on the northeast coast of Unalaska, Cape Wislow served as an aircraft warning system during WWII (USDOI, 1991) and included a 518 m tramway, housing and utility structures, and a 7.6 m steel radar tower with a 15.2 m antenna (Klein et al., 1987). The site was abandoned in 1947, and significant military debris was left behind (Klein et al., 1987). Potential COC at Cape Wislow include toxic metals from electronics and PCBs from degraded storage tanks (RIDOLFI Inc., 2020). The local community is concerned about the impacts of pollution on sockeye salmon (*Oncorhynchus nerka*) in Wislow (Reese) Bay and McLees Lake, which are less than a kilometer from the Cape Wislow FUD site (RIDOLFI Inc., 2020). Sockeye salmon harvested from McLees Lake comprised 48%–89% of Unalaska subsistence harvests between 2012 and 2016 (Lipka & Fox, 2017). Despite the importance of McLees Lake as a subsistence fishery, the Army Corps did not plan to evaluate the potential risks posed by contamination at the Cape Wislow FUD site (USGAO, 2002). To date, the Cape Wislow FUD site retains its NDAI status, which reduces the likelihood of an Army Corps investigation.

### *Risk assessment of arsenic*

Concentrations of arsenic in water following the conversion of soil–water partitioning had a mean of 0.2195 μg/L, with a standard deviation of 0.1290. The risk assessment model indicated that all expected CRs are below the 1/10 000 risk threshold. The mean risk was $7.39 \times 10^{-6}$, which equates to an expected 7.39 cases per 1 million exposures (Table 3). The highest risk case was 2.51 cases in 100 000 exposures assuming that the highest arsenic concentrations were consumed every day of a person's 70.5-year life span. This analysis suggests that groundwater containing arsenic derived from Unalaska FUD sites would not pose an appreciable CR for residents. The analysis also demonstrates that even in cases where a contaminant exists at concentrations above cleanup criteria at multiple sites, this does not necessarily translate into increased risk for human health. If the groundwater in the aquifer beneath the Unalaska FUD sites was used as source water for the community, treatment at the municipality would further reduce arsenic concentrations at the tap and thus arsenic-associated CRs would be lower than modeled.

### *Limitations*

Our analysis was limited to available data from existing military reports, and the same contaminants were not always tested across sites. Our analysis was also constrained by data quality standards used at each site. We were not able to evaluate contaminant levels for sites with NDAI status, even though they may also pose a health risk to residents and wildlife (Adams et al., 2019; RIDOLFI Inc., 2020). Nonetheless, we demonstrated that several FUD sites, including those adjacent to and within the City of Unalaska, remain hotspots of environmental contamination despite remediation efforts (Figures 2–4). While cleanup efforts are active at many of these sites, criteria for cessation of cleanup have changed over time and vary among sites. These problems could be addressed through a revision of federal guidelines such that the Army Corps is empowered to apply suitably protective measures at FUD sites throughout the United States.

### *Broader implications*

Collectively, the results from the present study and from previous work suggest that FUD sites in the Bering Sea region continue to pollute local environments and that the completed remediation of these sites may not sufficiently protect communities and wildlife adjacent to them. The military activities on Unalaska Island resulted in a legacy of pollution that will continue to impact residents and the local environment. Contaminant concentrations remain above

**TABLE 3** Risk assessment descriptive statistics for arsenic

| Minimum | 25th Percentile | Median | Mean | 75th Percentile | Maximum |
|---|---|---|---|---|---|
| $1.15 \times 10^{-6}$ | $4.46 \times 10^{-6}$ | $7.39 \times 10^{-6}$ | $7.39 \times 10^{-6}$ | $1.03 \times 10^{-5}$ | $2.51 \times 10^{-5}$ |

state cleanup thresholds at many sites despite remediation efforts, although remediation is ongoing at some sites. Contaminant distributions suggest that the City of Unalaska remains a hotspot of pollution. Additionally, cleanup thresholds do not account for the high consumption levels of local foods by subsistence communities.

The present study and previous research exemplify the need for more robust evaluation and remediation of contaminants at FUD sites. At present, FUD sites are managed independently without consideration of the cumulative effects of multiple FUD sites on the environment. Similarly, cleanup levels are set for each contaminant and do not account for the potential synergistic effects of mixtures.

Our analysis of Unalaska FUD sites highlights the importance of continued efforts to involve community members in the evaluation and remediation of FUD sites. This is especially important in Tribal communities that have experienced persecution, such as the Unangan (Aleut) people of Unalaska and other Aleutian islands. In July 1942, the US relocated 881 Unangan residents from their traditional lands, including Unalaska, to camps in southeast Alaska, where approximately 10% died due to poor living conditions; nonnative civilians were not forced to evacuate (Klein et al., 1987; Madden, 1992; Mason, 2010; Sepez et al., 2007; US National Library of Medicine Online, 1942). Despite the defeat of Japanese forces at Attu and Kiska Islands in 1943, Unangan people were kept at US internment camps until 1945 and 1946 (Gable, 1980). Furthermore, the Unangan people of Unalaska were not included in decisions on military site selection or activities that took place adjacent to their community during WWII and the Cold War. Such lack of local control over land use and the subsequent pollution of those lands is a common issue in communities throughout the Arctic. Disproportionate exposure to carcinogenic and endocrine-disrupting compounds remains an environmental justice issue in the Arctic and may contribute to health disparities (Arctic Monitoring and Assessment Programme, 2015).

Collectively, our results suggest that future remediation projects should (1) conduct comprehensive testing for legacy contaminants at FUD sites to better evaluate risk, (2) assess cleanup thresholds to ensure that they are protective for rural communities, which may require changes to federal guidelines, and (3) continue to involve Tribal governments and local residents in decision-making and site prioritization. Unalaska Island is but one of many islands in the Aleutian and Bering Sea region with FUD sites. Future research could expand upon the approach used here to identify additional hotspots of contamination for the region. Similarly, contaminated FUD sites exist throughout the Arctic, so the implications of this work reflect a broader problem of arctic pollution.

## AUTHOR CONTRIBUTION

**Renee Jordan-Ward**: Conceptualization; data curation; formal analysis; funding acquisition; investigation; methodology; project administration; resources; writing—original draft; writing—review and editing. **Frank A. von Hippel**: Conceptualization; funding acquisition; investigation; methodology; project administration; supervision; writing—original draft; writing—review and editing. **Jennifer Schmidt**: Conceptualization; formal analysis; funding acquisition; methodology; software; visualization; writing—original draft. **Marc P. Verhougstraete**: Formal analysis; methodology; writing—original draft.

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## CONFLICT OF INTEREST

The authors declare no conflicts of interest.

## DATA AVAILABILITY STATEMENT

Summary data are provided in the tables in the article and Supporting Information materials. Raw data are provided as a Supporting Information data file.

## ORCID

Renee Jordan-Ward http://orcid.org/0000-0002-5503-4190

## SUPPORTING INFORMATION

List of additional formerly used defense (FUD) sites in the Aleutian (#1-41) and Bering Sea (#42-70) region.

The raw data used in this study.

Map of study locations (jpg).

## REFERENCES

Adams, E. M., von Hippel, F. A., Hungate, B. A., & Buck, C. L. (2019). Polychlorinated biphenyl (PCB) contamination of subsistence species on Unalaska Island in the Aleutian Archipelago. *Heliyon*, *5*, e02989.

Alaska Department of Environmental Conservation (ADEC). (2019). *Northeast Cape and Gambell formerly used defense sites*. Retrieved January 2, 2022, from: https://dec.alaska.gov/spar/csp/sites/st-lawrence/

Alaska Department of Environmental Conservation (ADEC). (2021a). *18 AAC 75 oil and other hazardous substances pollution control*.

Alaska Department of Environmental Conservation (ADEC). (2021b). *Contaminatd sites search*. Alaska Department of Environmental Conservation, Division of Spill Prevention and Response. Retrieved November 15, 2021, from: https://dec.alaska.gov/Applications/SPAR/PublicMVC/CSP/Search

Alaska Department of Fish and Game. (2022). *Federal special status species*. Retrieved January 30, 2022, from: http://www.adfg.alaska.gov/index.cfm?adfg=specialstatus.fedendangered

Alaska Native Epidemiology Center. (2021). *Alaska native mortality: 1980–2018*.

Anthony, R. G., Miles, A. K., Ricca, M. A., & Estes, J. A. (2007). Environmental contaminants in bald eagle eggs from the Aleutian Archipelago. *Environmental Toxicology and Chemistry*, *26*, 1843–1855.

Arctic Monitoring and Assessment Programme. (2015). *Summary for policymakers: Arctic pollution issues 2015* (pp. 12).

 

Brewer, R. (2022). *The City of Unalaska: Wildlife*. City of Unalaska. Retrieved January 30, 2022, from: https://www.ci.unalaska.ak.us/community/page/wildlife

Carpenter, D. O., DeCaprio, A. P., O'Hehir, D., Akhtar, F., Johnson, G., Scrudato, R. J., Apatiki, L., Kava, J., Gologergen, J., Miller, P. K., & Eckstein, L. (2005). Polychlorinated biphenyls in serum of the Siberian Yupik people from St. Lawrence Island, Alaska. *International Journal of Circumpolar Health*, *64*, 322–335.

City of Unalaska. (2017). *Unalaska community profile*. Retrieved January 30, 2022, from: https://www.ci.unalaska.ak.us/sites/default/files/fileattachments/City%20Manager%26%23039%3Bs%20Office/page/963/community_profile_2017_03_27.pdf

City of Unalaska. (2021). *The City of Unalaska*. Retrieved January 7, 2022, from: https://www.ci.unalaska.ak.us

Cooksey, E., Verhougstraete, M., Sneed, S. J., Joseph, C. N., Blohm, J., Paukgana, M., Joshweseoma, L., Sehongva, G., Hadeed, S., Harris, R., & O'Rourke, M. K. (2023). Drinking water and health assessment in a Northern Arizona community. *Human and Ecological Risk Assessment*, *29*, 157–173.

Earth Point. (2021). *State plane coordinate system—Convert, View on Google Earth*. Tools for Google Earth. Retrieved November 18, 2021, from: https://www.earthpoint.us/stateplane.aspx

Gable, D. (1980). The Aleuts: Forgotten casualties of Japanese invasion, American internment. *Fishand Wildlife News, 6-7*.

Gough, L. P., Severson, R. C., & Shacklette, H. T. (1988). *Element concentrations in soils and other surficial materials of Alaska.* US Department of the Interior, US Geological Survey.

Jordan-Ward, R., von Hippel, F. A., Wilson, C. A., Rodriguez Maldonado, Z., Dillon, D., Contreras, E., Gardell, A., Minicozzi, M. R., Titus, T., Ungwiluk, B., Miller, P., Carpenter, D., Postlethwait, J. H., Byrne, S., & Buck, C. L. (2024). Differential gene expression and developmental pathologies associated with persistent organic pollutants in sentinel fish in Troutman Lake, Sivuqaq, Alaska. *Environmental Pollution*, *340*, 122765.

Jordan-Ward, R., von Hippel, F. A., Zheng, G., Salamova, A., Dillon, D., Gologergen, J., Immingan, T., Dominguez, E., Miller, P., Carpenter, D., Postlethwait, J. H., Byrne, S., & Buck, C. L. (2022). Elevated mercury and PCB concentrations in Dolly Varden (*Salvelinus malma*) collected near a formerly used defense site on Sivuqaq, Alaska. *Science of the Total Environment*, *826*, 154067.

Klein, J. L., Nolan, J. L., Warren-Findlay, J., Brenner, W. A., Gillespie, R. E., & Vetter, J. (1987). *World War II in Alaska: A historic and resources management plan. United States.* Army Corps of Engineers.

Lemke, K. J., & Vanderpool, A. M. (1995). *Overview of environmental and hydrogeologic conditions at Dutch Harbor, Alaska* (Open-File Report 95-411). US Geological Survey.

Letcher, R. J., Bustnes, J. O., Dietz, R., Jenssen, B. M., Jørgensen, E. H., Sonne, C., Verreault, J., Vijayan, M. M., & Gabrielsen, G. W. (2010). Exposure and effects assessment of persistent organohalogen contaminants in arctic wildlife and fish. *Science of the Total Environment*, *408*, 2995–3043.

Lipka, C. G., & Fox, E. K. C. (2017). *McLees Lake Salmon Escapement Monitoring Report, 2012–2017*. Alaska Department of Fish and Game, Fishery Management Report No. 17-49, Anchorage.

Madden, R. (1992). The forgotten people: The relocation and internment of Aleuts during World War II. *American Indian Culture and Research Journal*, *16*, 55–76.

Mason, R. (2010). You can't go home again: Processes of displacement and emplacement in the "lost villages" of the Aleutian Islands. *Alaska Journal of Anthropology*, *8*, 17–29.

McKenney, H. (2021, May 27). *Dutch Harbor is nation's top fishing port for 23rd straight year*. Alaska Public Media.

Miles, A. K., Ricca, M. A., Anthony, R. G., & Estes, J. A. (2009). Organochlorine contaminants in fishes from coastal waters west of Amukta Pass, Aleutian Islands, Alaska, USA. *Environmental Toxicology and Chemistry*, *28*, 1643–1654.

Miller, P. K., Waghiyi, V., Welfinger-Smith, G., Byrne, S. C., Kava, J., Gologergen, J., Eckstein, L., Scrudato, R., Chiarenzelli, J., Carpenter, D. O., & Seguinot-Medina, S. (2013). Community-based participatory research projects and policy engagement to protect environmental health on St. Lawrence Island, Alaska. *Int J Circumpolar Health*, *72*, 21656.

Muhammad, S., Tahir Shah, M., & Khan, S. (2010). Arsenic health risk assessment in drinking water and source apportionment using multivariate statistical techniques in Kohistan region, northern Pakistan. *Food and Chemical Toxicology*, *48*, 2855–2864.

Perryman, C. R., Wirsing, J., Bennett, K. A., Brennick, O., Perry, A. L., Williamson, N., & Ernakovich, J. G. (2020). Heavy metals in the Arctic: Distribution and enrichment of five metals in Alaskan soils. *PLoS One*, *15*, e0233297.

R Core Team. (2018). *R: A language and environment for statistical computing*. R Foundation for Statistical Computing.

Ricca, M. A., Keith Miles, A., & Anthony, R. G. (2008). Sources of organochlorine contaminants and mercury in seabirds from the Aleutian Archipelago of Alaska: Inferences from spatial and trophic variation. *Science of the Total Environment*, *406*, 308–323.

RIDOLFI Inc. (2020). *Strategic project implementation plan, Unalaska, Alaska Native American Lands Environmental Mitigation Program*. Prepared by RIDOLFI Inc. for the Qawalangin Tribe of Unalaska.

Roucek, J. S. (1983). The geopolitics of the Arctic. *American Journal of Economics and Sociology*, *42*, 463–471.

Rourke, N. E. (1997). *War comes to Alaska: The Dutch Harbor Attack*. Burd Street Press.

Scrudato, R., Chiarenzelli, J., Miller, P. K., Alexander, J. C., Arnason, J., Zamzow, K., Zweifel, K., Gologergen, J., Kava, J., Waghiyi, V., & Carpenter, D. (2012). Contaminants at arctic formerly used defense sites. *Journal of Local and Global Health Science*, *2*, 1–12.

Sepez, J., Package, C., Malcolm, P. E., & Poole, A. (2007). Unalaska, Alaska: Memory and denial in the globalization of the Aleutian landscape. *Polar Geography*, *30*, 193–209.

US Department of the Interior (USDOI). (1991). *World War II in the Aleutians.* US Department of the Interior, National Park Service.

US Department of the Interior (USDOI). (2016). *Report to Congress: Hazardous substance contamination of Alaska Native Claim Settlement Act Lands in Alaska*. United States Department of the Interior Bureau of Land Management.

USEPA. (2000). *Guidance for assessing chemical contaminant data for use in fish advisories*. United States Environmental Protection Agency Office of Water.

USEPA. (2004). *Making environmental progress, improving local communities: Accomplishments of the EPA region 10 Superfund Program*. United States Environmental Protection Agency Superfund Program.

USEPA. (2005a). *Guidelines for carcinogen risk assessment*. Risk Assessment Forum EPA/630/P-03/001F.

USEPA. (2005b). *Partition coefficients for metals in surface water, soil, and waste*. Science Inventory.

US National Library of Medicine Online. (1942). *Unangan evacuated, interned during WWII*. National Institutes of Health.

United States Army Corps of Engineers (USACE). (1999). *Ugadaga Bay Fire Control Station Draft Preliminary Asesssment Report*. Superfund Technical Assistance and Response Team, TDD: 97-02-0010. Contract No. 68-W6-008.

United States Army Corps of Engineers (USACE). (2003). *2001–2002 Island-wide SI/RI/IRA Report: Amaknak and Unalaska Islands, Alaska*. Prepared by Jacobs Engineering Group Inc, Contract No. DACA85-95-D-0018, Task Order No. 02.

United States Army Corps of Engineers (USACE). (2007). *Final characterization report, Fort Learnard, Unalaska Island, Alaska*. Prepared by Jacobs Engineering Group Inc., Contract No. DACA 85-95-D-0018 Task Order No. 23.

United States Army Corps of Engineers (USACE). (2015). *Formerly used defense sites per state—Alaska.*

United States Army Corps of Engineers (USACE). (2017). *Final Dutch Harbor limited removal action report: Amaknak and Unalaska Islands, Alaska*. Prepared by Ahtna Engineering Services, LLC, Contract No. W911KB-14-D-0005 Task Order No. 0004.

United States Army Corps of Engineers (USACE). (2018). *Final site investigation at the Chernofski Harbor—Mutton Cove formerly used defense site*. Prepared By Environmental Management, Inc. Contract No.: W911KB-17-C-0015.

United States Army Corps of Engineers (USACE). (2020a). *Amaknak formerly used defense site, environmental update*.

United States Army Corps of Engineers (USACE). (2020b). *Draft removal action report, Cape Prominence Formerly Used Defense Site Unalaska Island, Alaska*. Prepared by Bristol Environmental Remediation Services, LLC, Contract No. W911KB-14-D-0006, Task Order No. W911KB19F0014.

United States Army Corps of Engineers (USACE). (2020c). *Final CON/HTRW removal action, formerly used defense site F10AK001502, Unalga Island, Alaska*. Prepared by Ahtna Engineering Services, LLC, Contract No. W911KB-14-D-0005, Project W911KB18F0118.

United States Army Corps of Engineers (USACE). (2020d). *Final demolition and remedial investigation report former radio range facility: Hog Island, Alaska*. Prepared by Brice Environmental Services Corporation, Contract Number 697DCK-19-C-00153.

United States Army Corps of Engineers (USACE). (2021). FUDS portal. Retrieved November 15, 2021, from: https://www.usace.army.mil/Missions/Environmental/Formerly-Used-Defense-Sites/FUDS-Inventory/

United States Census Bureau. (2023). 2020 Census. Retrieved February 12, 2022, from: https://www.census.gov

United States General Accounting Office (USGAO). (2002). *Environmental contamination: Corps needs to reassess its determinations that many former defense sites do not need cleanup*. Report to Congressional Requesters, GAO-02-658.

United States General Accounting Office (USGAO). (2009). *The US Army Corps of Engineers needs to improve its process for reviewing completed cleanup remedies to ensure continued protection*. Report to the Committee on Armed Services, House of Representatives, GAO-10-46.

United States National Park Service (USNPS). (2015). *Aleutian Islands World War II*. Retrieved February 13, 2022, from: https://www.nps.gov/aleu/planyourvisit/safety.htm

United States National Park Service (USNPS). (2020). *World War II in Alaska*. Retrieved February 18, 2022, from: https://www.nps.gov/articles/world-war-ii-in-alaska.htm

von Hippel, F. A., Miller, P. K., Carpenter, D. O., Dillon, D., Smayda, L., Katsiadaki, I., Titus, T. A., Batzel, P., Postlethwait, J. H., & Buck, C. L. (2018). Endocrine disruption and differential gene expression in sentinel fish on St. Lawrence Island, Alaska: Health implications for indigenous residents. *Environmental Pollution*, *234*, 279–287.

von Hippel, F. A., Trammell, E. J., Merilä, J., Sanders, M. B., Schwarz, T., Postlethwait, J. H., Titus, T. A., Buck, C. L., & Katsiadaki, I. (2016). The ninespine stickleback as a model organism in arctic ecotoxicology. *Evolutionary Ecology Research*, *17*, 487–504.

Williams, P., & Cravez, P. (2018). Environmental justice: Challenges of contaminated site cleanup in rural Alaska. *Alaska Justice Forum*, *35*, 1–5.

Young, T. K., Bjerregaard, P., Dewailly, E., Risica, P. M., Jørgensen, M. E., & Ebbesson, S. E. (2007). Prevalence of obesity and its metabolic correlates among the circumpolar Inuit in 3 countries. *American Journal of Public Health*, *97*, 691–695.

 