**US Army Corps
of Engineers®**
Engineer Research and
Development Center

Metal Accumulation Capacity in Indigenous Alaska Vegetation Growing on Military Training Lands

Ryan R. Busby, Thomas A. Douglas, Joshua J. LeMonte,
David B. Ringelberg, and Karl J. Indest

August 2021

The U.S. Army Engineer Research and Development Center (ERDC) solves the nation's toughest engineering and environmental challenges. ERDC develops innovative solutions in civil and military engineering, geospatial sciences, water resources, and environmental sciences for the Army, the Department of Defense, civilian agencies, and our nation's public good. Find out more at www.erdclibrary.on.worldcat.org/discovery.

To search for other technical reports published by ERDC, visit the ERDC online library at <http://www.erdclibrary.on.worldcat.org/discovery>.

Metal Accumulation Capacity in Indigenous Alaska Vegetation Growing on Military Training Lands

Ryan R. Busby

*Construction Engineering Research Laboratory
U.S. Army Engineer Research and Development Center
2902 Newmark Drive
Champaign, IL 61822*

Thomas A. Douglas, Joshua J. LeMonte, and Karl J. Indest

*Cold Regions Research and Engineering Laboratory
U.S. Army Engineer Research and Development Center
Fort Wainwright, AK and 72 Lyme Road, Hanover, NH 03755*

David B. Ringelberg

*Environmental Laboratory
U.S. Army Engineer Research and Development Center
3909 Halls Ferry Road
Vicksburg, MS 39180*

Final report

Approved for public release; distribution is unlimited.

Prepared for U.S. Army Corps of Engineers
Washington, DC 20314

Under Environmental Quality 6.2 Applied Research Program

Preface

This study was conducted for the U.S. Army Corps of Engineers (USACE) under the U.S. Army Environmental Quality 6.2 Applied Research Program.

The work was performed by the Engineer Research and Development Center, Construction Engineering Research Laboratory (ERDC-CERL), ERDC Cold Regions Research and Engineering Laboratory (ERDC-CRREL), and the ERDC Environmental Laboratory (ERDC-EL). At the time of publication of this paper, the Acting Deputy Director of ERDC-CERL was Ms. Michelle Hanson and the Director was Dr. Andrew Nelson, the Deputy Director for ERDC-CRREL was Mr. David Ringelberg and the Director was Dr. Joseph Corriveau, and the Deputy Director of ERDC-EL was Dr. Brandon Lafferty and the Director was Dr. Edmund J. Russo Jr.

This article was originally published online in the *International Journal of Phytoremediation* on 23 February 2020.

The authors would like to thank Mr. Anthony Bednar, Mr. Andrew Bray, Ms. Jenifer Milam, and Mr. Jared Smith of the Environmental Laboratory's Analytical Chemistry Laboratory for analyzing metal samples, and Ms. Sarah Kania at the University of Illinois for sample preparation.

The Commander of ERDC was COL Teresa A. Schlosser and the Director was Dr. David W. Pittman.

DISCLAIMER: The contents of this report are not to be used for advertising, publication, or promotional purposes. Citation of trade names does not constitute an official endorsement or approval of the use of such commercial products. All product names and trademarks cited are the property of their respective owners. The findings of this report are not to be construed as an official Department of the Army position unless so designated by other authorized documents.

DESTROY THIS REPORT WHEN NO LONGER NEEDED. DO NOT RETURN IT TO THE ORIGINATOR.

Metal accumulation capacity in indigenous Alaska vegetation growing on military training lands

ABSTRACT

Permafrost thawing could increase soil contaminant mobilization in the environment. Our objective was to quantify metal accumulation capacities for plant species and functional groups common to Alaskan military training ranges where elevated soil metal concentrations were likely to occur. Plant species across multiple military training range sites were collected. Metal content in shoots and roots was compared to soil metal concentrations to calculate bioconcentration and translocation factors. On average, grasses accumulated greater concentrations of Cr, Cu, Ni, Pb, Sb, and Zn relative to forbs or shrubs, and bioconcentrated greater concentrations of Ni and Pb. Shrubs bioconcentrated greater concentrations of Sb. Translocation to shoots was greatest among the forbs. Three native plants were identified as candidate species for use in metal phytostabilization applications. *Elymus macrourus*, a grass, bioconcentrated substantial concentrations of Cu, Pb, and Zn in roots with low translocation to shoots. *Elaeagnus commutata*, a shrub, bioconcentrated the greatest amounts of Sb, Ni, and Cr, with a low translocation factor. *Solidago decumbens* bioconcentrated the greatest amount of Sb among the forbs and translocated the least amount of metals. A combination of forb, shrub, and grass will likely enhance phytostabilization of heavy metals in interior Alaska soils through increased functional group diversity.

Introduction

Permafrost thawing in northern latitudes has accelerated in recent years (O'Donnell *et al.* 2012) and has led to changes in soil hydrology and biogeochemistry (Frey and McClelland 2009; Douglas *et al.* 2014; Brown *et al.* 2015). These alterations increase the likelihood that soil constituents will become more mobile in the environment, including heavy metals. While it is widely known that heavy metals can accumulate in shooting range soils (Sanderson *et al.* 2012; Bandara and Vithanage 2016; Rodríguez-Seijo *et al.* 2016a), metal concentrations occurring in impact areas and at detonation sites due to live fire training have not been fully characterized.

Metals observed to occur in blast residues from ordnance commonly detonated in impact areas include Cu, Ni, Pb, and Zn (Walsh 2004). Copper, Ni, and Zn have also been detected in soils surrounding open burning/open detonation sites (Martin *et al.* 2012). Bullets are primarily comprised of Pb and Sb, but also contain Ag, As, Bi, and Ni, while bullet jackets are comprised predominantly of Cu and Zn (see Ahmad *et al.* 2012). Small arms ranges can receive Ag, As, Cr, Cu, Ni, Pb, Sb, and Zn, due to live fire exercises, although Ag and As are usually only present at lower

concentrations (Sanderson *et al.* 2012; Bandara and Vithanage 2016; Rodríguez-Seijo *et al.* 2016a).

Because metals are not biodegradable but can bioaccumulate, limiting their movement within and through the environment is often a key objective for managing adverse effects (Ali *et al.* 2013). Plant stabilization of metals is important in preventing surface and groundwater contamination (Conesa *et al.* 2012; Evangelou *et al.* 2012). Phytostabilization is one such technique, whereby plants are used to uptake and immobilize metals. Uptake and sequestration with root tissues minimize the likelihood of bioaccumulation in other organisms and both vertical and horizontal transport through and over the soil profile (Ali *et al.* 2013). With respect to phytostabilization, the most effective plant species will possess a high bioconcentration factor (BCF), the ratio of plant root concentration to soil concentration (Zhuang *et al.* 2007), while possessing a low translocation factor (TF), the ratio of shoot concentration to root concentration (Padmavathiamma and Li 2007). Thus, ideal plants for phytostabilization accumulate high concentrations of metals from the soil, keep the metals concentrated in root tissues, and prevent metal translocation to shoots.

Most research involving metal phytoremediation has focused on phytoextraction, or the accumulation of metals

in shoots for eventual harvest and removal (Pinto *et al.* 2015). A number of hyperaccumulators have been identified (Reeves *et al.* 2018). Unfortunately, few plant species have been investigated for their ability to stabilize metals from soils, and almost no species adapted to high latitude environments have been investigated. Vegetation occurring in soils where heavy metal deposition has occurred are ideal candidates for phytostabilization applications, largely due to the documented toxicity of heavy metals in soils (Pinto *et al.* 2015). Promising phytostabilization species have been identified in soils containing heavy metal contamination (Robinson *et al.* 2008; Álvarez-Ayuso *et al.* 2012; Selonen *et al.* 2012). However, many environmental variables influence metal phytostabilization, to include metal speciation and concentration, soil physical and biogeochemical characteristics, and climatic conditions (Pinto *et al.* 2015). How an individual plant species and/or a plant functional group may uptake a metal across an environmental gradient is not fully understood, and how Arctic and subarctic vegetation behaves relative to temperate and tropical vegetation is largely unknown. The objective of this study was to test the hypothesis that different functional groups of Arctic/subarctic vegetation differ in their abilities to accumulate metals from soils. To test this hypothesis, we quantified metal accumulation capacities for plant species and plant functional groups commonly occurring on Alaskan military training ranges where elevated soil metal concentrations were likely to occur. The research goal is to identify Arctic and subarctic region plant functional groups and species with potential for use in the phytostabilization of metals-affected soils.

Materials and methods

Study sites

Study sites were located at Fort Greely, AK (Figure S1, Supporting Material). The study area is a continental subarctic climate, with a mean annual temperature of -2.6°C , and receives 309 mm of precipitation annually, with approximately 1/3 occurring as snow. A number of sites were identified representing a variety of military training activities where metal deposition and accumulation were likely to occur. These sites included small arms firing ranges, munition target sites (impact areas), and explosive detonation sites where artillery propellant packets were ignited for disposal (Table 1).

Vegetation and soil sampling

Sample collection occurred the first week of August 2017. Dominant plant species with a minimum of three replicate individuals present at each site location were collected and identified to species (Hultén 1968; Welsh 1974) (Table 1). Three replicates of each plant species were then excavated to a depth of 15–20 cm to capture the majority of root material that interacted with surface deposition of metals. Soil collected with each excavation was placed into a high-density polyethylene tub, thoroughly mixed and quartered, and a

Table 1. List of sampling sites and locations and plant species sampled ($n = 3$) in each.

Site	Location	Species	Functional group
CO range	Berm	<i>Elymus macrourus</i> (Turcz.) Tzvelev	Grass
CO range	Berm	<i>Oxytropis campestris</i> (L.) DC.	Forb
CO range	Berm base	<i>Achillea borealis</i> Bong.	Forb
CO range	Berm base	<i>Elaeagnus commutata</i> Bernh. ex Rydb.	Shrub
OP7	Burn pan	<i>Elymus macrourus</i>	Grass
TX range	Berm1	<i>Achillea borealis</i>	Forb
TX range	Berm1	<i>Agrostis scabra</i> Willd.	Grass
TX range	Berm1	<i>Deschampsia cespitosa</i> (L.) P. Beauv.	Grass
TX range	Berm2	<i>Achillea borealis</i>	Forb
TX range	Berm2	<i>Agrostis scabra</i>	Grass
TX range	Berm2	<i>Deschampsia cespitosa</i>	Grass
WA flats	BIP1	<i>Potentilla multifida</i> Soják	Forb
WA flats	BIP1	<i>Taraxacum officinale</i> F.H. Wigg	Forb
WA flats	BIP2	<i>Hordeum jubatum</i> L.	Grass
WA flats	BIP2	<i>Salix setchelliana</i> C.R. Ball	Shrub
WA flats	Tank target	<i>Solidago decumbens</i> Greene	Forb
WA flats	TOW crater	<i>Elaeagnus commutata</i>	Shrub
WA flats	TOW target	<i>Oxytropis campestris</i>	Forb

composite soil sample collected for analysis. Soils were shaken from each root system, and plant roots and shoots were washed separately and thoroughly through vigorous shaking in three separate changes of 18 megaohm deionized water. Excess moisture was removed by placing plant samples in paper towels and gently patting them dry. Root and shoot samples were then placed in labeled paper bags for subsequent analyses.

Sample analyses

Composite soil samples were air dried for 72 h, sieved to 2 mm, and bagged for chemical and physical property analysis. Plant root and shoot samples were oven-dried at 40°C for 72 h, ground and homogenized, and then stored in glass distillation vials for metal analysis. Soil and plant tissue samples were analyzed by the US Army Corps of Engineers Environmental Laboratory for metal concentrations following modifications of USEPA method 3050. Briefly, subsamples were acid digested using nitric acid with a concentration of 5% (v:v) (Sb had a prior digestion with 5 mL concentrated HCl) prior to analysis by inductively coupled plasma mass spectrometry using a Perkin Elmer NexION 300D ICP-MS following modifications of USEPA method 6020. Rhodium and Bi were added online as internal standards to correct for instrument drift. The instrument was calibrated on NIST-traceable heavy metal standards at 0, 1, 10, and $100\text{ }\mu\text{g L}^{-1}$. A second source calibration verification standard was analyzed immediately after instrument calibration to ensure the response function was accurate. A verification standard was run for every 10 unknown samples, and analyte recoveries were verified to within 10% of the expected concentration. Detection limits for all metals in soils were $<0.2\text{ mg kg}^{-1}$; $<0.4\text{ mg kg}^{-1}$ for Cr, Cu, and Pb in root and shoot samples, Ni in root samples, and Sb in shoot samples; $<0.6\text{ mg kg}^{-1}$ for Ni in shoots; $<0.8\text{ mg kg}^{-1}$ for Sb in roots; and 4 mg kg^{-1} for Zn in roots and shoots. Soil subsamples were then further analyzed for physical and plant nutritional properties by Midwest Laboratories (Omaha, NE).

Table 2. Mean total metal concentrations in sampling site soils and associated contaminant limits (mg kg⁻¹).

Site	Site Type	Location	Cr	Cu	Ni	Pb	Sb	Zn
CO range	Small arms range	1	13.3	173	12.2	4650	42	74.2
CO range	Small arms range	2	12.7	11.6	12	16.7	0.3	36.8
OP-7	Explosive detonation site	1	115.5	57.5	89.5	189.3	3	45.5
TX range	Small arms range	1	14.9	36.3	12.3	1090	6	37.1
TX range	Small arms range	2	13.1	10.6	11.1	61.1	0.7	30.9
WA flats	Munition target site	1	11.6	25.4	11.1	11	0.1	57.5
WA flats	Munition target site	2	10	13.1	9.6	7.3	0.2	43.1
WA flats	Munition target site	3	15.1	38.8	12.1	18.8	0.4	41.2
WA flats	Munition target site	4	12.1	29.8	13.7	11.1	0.1	38.8
WA flats	Munition target site	5	9.3	8.6	8.4	5.6	0.1	25.7
Maximum Contaminant Level (MCL) for Drinking Water ^a (μg L ⁻¹)			100	1300		15	6	
Regional Screening Level (RSL) for Industrial Soil ^b (mg kg ⁻¹)				47,000		800	470	35,000

^aUS EPA National Primary Drinking Water Regulations. United States Code of Federal Regulations 40 CFR 141.

^bUS EPA Regional Screening Levels Summary Table. www.epa.gov. Accessed 28 September 2018.

Statistical analyses

Means and standard errors were calculated for metal concentrations, BCF, and TF for all sampled plant species and functional groups across all the sites. Analysis of variance was conducted on the data using SAS (SAS Version 9.4, SAS Institute, Cary, NC). Metal concentration effects in both roots and shoots were analyzed between species in each functional group and across functional groups. Non-normal data were log-transformed to achieve normality. Mean separation for BCF and TF values between plant functional groups for each metal was conducted using Tukey's least-significant difference test in SAS.

Results

A total of 54 plant samples were collected from 10 different locations on 4 different training sites in interior Alaska (Table 1). Of these, 9 were from 2 shrub species, 24 were from 5 forb species, and 21 were from 4 grass species.

Metal concentrations in composite soils

Concentrations of total Cr, Cu, Ni, Pb, Sb, and Zn were detected in each of the composite site soils. The composite soil samples recovered from the small arms ranges contained the greatest concentrations of Pb and Sb, of which both were elevated in small arms range soils (Table 2). Composite soil samples recovered from the explosive detonation sites contained the greatest concentrations of Cr, Cu, and Ni (Table 2). Munition target site composite soils, *i.e.*, impact area soils, did not contain elevated concentrations of any sampled metal.

Metal concentrations in roots

Table 3 provides mean plant root heavy metal concentrations for the individual plant species assayed, as well as for the specific plant functional group. Grasses, as a mean functional group ($n = 21$), accumulated the greatest root concentrations of each metal assayed. Of the metals, the greatest root concentrations were observed for Pb, at a mean concentration of 482 mg kg⁻¹ and a maximum of 1568 mg kg⁻¹ in *Elymus macrourus* ($n = 6$). The lowest root metal

concentrations were observed for Sb, at a mean concentration of 8 mg kg⁻¹ non-detected for *Hordeum jubatum* ($n = 3$). Mean root concentrations of Cr, Cu, Ni, and Zn ranged from 8 to 68 mg kg⁻¹ with the *Elymus* sp. accumulating over 100 mg kg⁻¹ of Cu.

Forb species accumulated comparable concentrations of Cu, Pb, and Zn into roots (29, 21, and 40 mg kg⁻¹, respectively, $n = 24$). Cr, Ni, and Sb were accumulated at an order of magnitude lower concentrations (1–6 mg kg⁻¹). *Oxytropis campestris* ($n = 6$) accumulated the greatest root concentrations of Pb and Sb (43 and 2 mg kg⁻¹, respectively), whereas *Taraxacum officinale* ($n = 3$) accumulated the lowest root concentrations for these two metals (<2 mg kg⁻¹).

The two shrub species accumulated the lowest concentrations of Pb and Sb among the three functional groups assayed. Mean root concentrations ($n = 9$) of Pb and Sb were 6 and 0.6 mg kg⁻¹, respectively. The shrubs accumulated mean root concentrations of Cu and Zn at 21 and 50 mg kg⁻¹, respectively. *Salix setchelliana* accumulated greater root concentrations of all metals except Zn.

Metal concentrations in shoots

Across the three functional groups, grasses contained the greatest mean concentrations of Pb and Sb, 29 and 1 mg kg⁻¹, respectively (Table 3). The greatest shoot concentrations of both Pb and Sb were observed in *E. macrourus*. The lowest shoot concentrations of Pb and Sb were observed in *H. jubatum* (<7 mg kg⁻¹). Accumulation of Cr, Cu, Ni, and Zn ranged from a mean of 3 mg kg⁻¹ for Ni to a high of 28 mg kg⁻¹ for Zn.

Bioconcentration and translocation

The bioconcentration factor (BCF) is the ratio of plant concentration to soil concentration, whereas the translocation factor (TF) is the ratio of shoot concentration to root concentration. Forbs were the only functional group able to accumulate high concentrations of Cu in their roots compared with soils, having a mean root BCF greater than 1 (Figure 1, Table 4). Mean Zn concentrations in forb roots were similar to soils (BCF = 1), but all other metals were not accumulated in forb roots in higher concentrations from the soils (BCF < 1). Grasses accumulated

Table 3. Mean metal concentrations in roots and shoots of all sampled plant species and plant functional groups across all sites.

	Roots (mg kg ⁻¹)					
	Cr	Cu	Ni	Pb	Sb	Zn
Forb species						
<i>Achillea borealis</i>	2.51 (0.34)	25.04 (3.29)	5.43 (0.90)	22.54 (10.84)	0.40 (0.05)	41.77 (9.65)
<i>Oxytropis campestris</i>	3.71 (2.18)	24.53 (1.75)	8.20 (1.28)	43.24 (20.81)	2.15 (0.40)	21.05 (2.43)
<i>Potentilla multifida</i>	1.60 (0.28)	31.43 (6.26)	5.38 (0.67)	6.13 (1.63)	BDLa	81.43 (13.42)
<i>Solidago decumbens</i>	11.81 (3.98)	60.40 (12.21)	7.35 (2.39)	4.70 (0.55)	0.52 (NA)b	50.17 (0.39)
<i>Taraxacum officinale</i>	1.03 (0.07)	17.37 (2.58)	1.63 (0.19)	1.48 (0.30)	BDL	18.93 (1.36)
Forb Mean	3.67 (0.94)	29.17 (3.21)	5.88 (0.66)	20.80 (7.00)	1.07 (0.36)	39.74 (5.54)
Grass Species						
<i>Agrostis scabra</i>	6.97 (2.69)	15.12 (0.31)	11.85 (0.68)	10.01 (1.97)	0.50 (0.03)	17.87 (1.41)
<i>Deschampsia cespitosa</i>	6.79 (2.46)	17.54 (2.25)	12.64 (1.20)	28.64 (17.24)	0.70 (0.22)	27.48 (6.38)
<i>Elymus macrourus</i>	11.46 (2.19)	163.00 (61.70)	11.50 (1.69)	1568.70 (306.40)	23.62 (11.11)	82.47 (10.64)
<i>Hordeum jubatum</i>	9.81 (1.70)	66.50 (21.29)	13.07 (1.13)	5.39 (0.86)	BDL	97.17 (10.97)
Grass Mean	8.79 (1.22)	67.78 (22.98)	12.13 (0.61)	481.60 (184.60)	8.27 (4.68)	50.40 (8.11)
Shrub Species						
<i>Elaeagnus commutata</i>	5.96 (1.76)	22.78 (7.65)	5.93 (0.78)	7.29 (3.86)	0.60 (0.22)	23.97 (4.22)
<i>Salix setchelliana</i>	1.15 (0.13)	18.33 (5.00)	2.93 (0.74)	2.76 (0.83)	BDL	101.30 (0.33)
Shrub Mean	4.35 (1.39)	21.30 (5.20)	4.93 (0.74)	5.78 (2.61)	0.60 (0.22)	49.76 (13.18)
Shoots (mg kg⁻¹)						
Forb Species						
<i>Achillea borealis</i>	9.49 (3.73)	13.02 (1.21)	5.19 (1.44)	12.39 (4.65)	0.26 (0.04)	25.99 (2.44)
<i>Oxytropis campestris</i>	3.49 (0.30)	10.25 (1.61)	4.57 (0.84)	23.09 (10.76)	0.79 (0.21)	20.33 (0.99)
<i>Potentilla multifida</i>	1.86 (0.15)	9.30 (0.34)	2.70 (0.19)	4.19 (1.79)	BDL	68.47 (15.69)
<i>Solidago decumbens</i>	9.37 (3.77)	15.40 (12.25)	2.75 (0.50)	1.22 (0.30)	BDL	66.17 (6.28)
<i>Taraxacum officinale</i>	1.14 (0.07)	23.63 (2.68)	2.12 (0.05)	BDL	BDL	109.80 (26.17)
Forb Mean	5.93 (1.58)	13.51 (1.15)	3.96 (0.60)	11.13 (3.54)	0.49 (0.14)	45.39 (7.22)
Grass Species						
<i>Agrostis scabra</i>	5.46 (3.41)	5.43 (0.51)	3.98 (0.40)	4.87 (1.33)	0.19 (0.04)	16.67 (1.77)
<i>Deschampsia cespitosa</i>	9.30 (3.89)	5.00 (0.58)	3.76 (0.39)	7.06 (2.41)	BDL	16.27 (1.61)
<i>Elymus macrourus</i>	4.47 (1.59)	17.26 (5.94)	0.97 (0.18)	79.32 (21.02)	1.71 (0.44)	33.18 (6.45)
<i>Hordeum jubatum</i>	5.16 (2.02)	16.97 (1.39)	2.71 (0.45)	6.85 (NA)	BDL	61.20 (2.97)
Grass Mean	6.23 (1.53)	10.33 (2.08)	2.97 (0.33)	29.17 (10.19)	0.95 (0.39)	27.63 (3.95)
Shrub Species						
<i>Elaeagnus commutata</i>	1.50 (0.17)	5.79 (0.42)	3.09 (0.19)	0.90 (0.19)	0.22 (NA)	18.08 (2.46)
<i>Salix setchelliana</i>	1.31 (0.10)	10.51 (1.78)	2.45 (0.08)	0.43 (NA)	BDL	132.13 (16.79)
Shrub Mean	1.44 (0.12)	7.36 (0.98)	2.87 (0.16)	0.82 (0.18)	0.22 (NA)	56.10 (19.68)

Standard errors are in parentheses.

^aBDL = metal concentration was below detection limit for all replicate samples.^bNA = metal concentration was below detection limit for all but one sample so standard error was incalculable.**Table 4.** Mean root metal bioconcentration factors (BCF, ratio of root concentration to soil concentration) of all sampled plant species and plant functional groups across all sites.

	Cr	Cu	Ni	Pb	Sb	Zn
	Root:Soil					
Forb Species						
<i>Achillea borealis</i>	0.19 (0.02)	1.91 (0.40)	0.47 (0.08)	0.16 (0.06)	0.58 (0.20)	1.20 (0.27)
<i>Oxytropis campestris</i>	0.30 (0.16)	1.64 (0.68)	0.84 (0.17)	0.38 (0.16)	0.05 (0.01)	0.66 (0.17)
<i>Potentilla multifida</i>	0.14 (0.02)	1.24 (0.25)	0.49 (0.06)	0.56 (0.15)	BDLa	1.42 (0.23)
<i>Solidago decumbens</i>	0.78 (0.26)	1.56 (0.32)	0.61 (0.20)	0.25 (0.03)	1.43 (NA)b	1.22 (0.01)
<i>Taraxacum officinale</i>	0.09 (0.01)	0.68 (0.10)	0.15 (0.02)	0.13 (0.03)	BDL	0.33 (0.02)
Forb Mean	0.27 (0.06)	1.56 (0.23)	0.54 (0.07)	0.27 (0.06)	0.49 (0.19)	0.98 (0.13)
Grass Species						
<i>Agrostis scabra</i>	0.49 (0.18)	0.92 (0.23)	1.02 (0.07)	0.10 (0.05)	0.45 (0.22)	0.54 (0.06)
<i>Deschampsia cespitosa</i>	0.49 (0.19)	0.91 (0.26)	1.07 (0.11)	0.07 (0.03)	0.40 (0.14)	0.79 (0.16)
<i>Elymus macrourus</i>	0.35 (0.11)	1.10 (0.29)	0.52 (0.20)	3.42 (1.62)	0.60 (0.24)	1.13 (0.21)
<i>Hordeum jubatum</i>	0.98 (0.17)	5.08 (1.63)	1.36 (0.12)	0.74 (0.12)	BDL	2.25 (0.26)
Grass Mean	0.52 (0.09)	1.60 (0.41)	0.93 (0.09)	1.19 (0.57)	0.48 (0.11)	1.01 (0.16)
Shrub Species						
<i>Elaeagnus commutata</i>	0.48 (0.14)	1.15 (0.25)	0.46 (0.06)	0.49 (0.22)	1.95 (1.10)	0.63 (0.11)
<i>Salix setchelliana</i>	0.12 (0.01)	1.40 (0.38)	0.31 (0.08)	0.38 (0.12)	BDL	0.63 (0.11)
Shrub Mean	0.36 (0.11)	1.23 (0.20)	0.41 (0.05)	0.45 (0.15)	1.95 (1.10)	1.21 (0.30)

Standard errors are in parentheses.

^aBDL = metal concentration was below detection limit for all replicate samples.^bNA = metal concentration was below detection limit for all but one sample so standard error was incalculable.

higher mean concentrations of Cu and Pb compared to soils, similar concentrations of Ni and Zn, and low concentrations of Cr and Sb, a BCF ≤ 0.5 (Figure 1, Table 4). Shrubs accumulated higher mean concentrations of Cu and Sb compared to soils, similar concentrations of Zn, and

low concentrations of Cr, Ni, and Pb (Table 4). Between functional groups, grasses had a higher mean root Cr BCF value than forbs and a higher mean root Ni BCF value than both forbs and shrubs (Figure 1). Shrubs had a higher mean root Sb BCF value than both forbs and grasses. No

Table 5. Mean metal translocation factors (TF, ratio of shoot concentration to root concentration) of all sampled plant species and plant functional groups across all sites.

	Shoot:Root					
	Cr	Cu	Ni	Pb	Sb	Zn
Forb Species						
<i>Achillea borealis</i>	5.73 (2.54)	0.67 (0.17)	1.03 (0.16)	0.76 (0.15)	0.58 (0.02)	0.89 (0.20)
<i>Oxytropis campestris</i>	1.88 (0.42)	0.41 (0.04)	0.66 (0.13)	0.53 (0.07)	0.37 (0.04)	1.03 (0.12)
<i>Potentilla multifida</i>	1.22 (0.16)	0.32 (0.07)	0.53 (0.11)	0.86 (0.38)	BDL ^a	0.84 (0.10)
<i>Solidago decumbens</i>	0.75 (0.18)	0.29 (0.09)	0.42 (0.07)	0.28 (0.11)	BDL	1.32 (0.12)
<i>Taraxacum officinale</i>	1.11 (0.03)	1.40 (0.19)	1.33 (0.14)	0.58 (0.21)	BDL	5.67 (1.11)
Forb Mean	2.93 (1.00)	0.60 (0.10)	1.29 (0.46)	0.63 (0.08)	0.45 (0.06)	1.57 (0.35)
Grass Species						
<i>Agrostis scabra</i>	0.54 (0.17)	0.54 (0.17)	0.34 (0.03)	0.48 (0.06)	0.31 (0.05)	0.97 (0.14)
<i>Deschampsia cespitosa</i>	2.48 (1.26)	0.27 (0.04)	0.30 (0.05)	0.38 (0.09)	BDL	0.75 (0.15)
<i>Elymus macrourus</i>	0.38 (0.11)	0.28 (0.14)	0.09 (0.02)	0.06 (0.02)	0.07 (0.02)	0.40 (0.04)
<i>Hordeum jubatum</i>	0.48 (0.14)	0.31 (0.09)	0.22 (0.05)	1.40 (NA) ^b	BDL	0.64 (0.06)
Grass Mean	0.97 (0.36)	0.31 (0.05)	0.24 (0.03)	0.36 (0.08)	0.16 (0.06)	0.70 (0.08)
Shrub Species						
<i>Elaeagnus commutata</i>	0.33 (0.06)	0.34 (0.07)	0.56 (0.07)	0.28 (0.16)	BDL	0.81 (0.10)
<i>Salix setchelliana</i>	1.17 (0.16)	0.74 (0.35)	0.98 (0.30)	0.36 (NA)	BDL	1.31 (0.17)
Shrub Mean	0.61 (0.15)	0.48 (0.13)	0.70 (0.12)	0.29 (0.13)	BDL	0.97 (0.12)

Standard errors are in parentheses.

^aBDL = metal concentration was below detection limit for all replicate samples.

^bNA = metal concentration was below detection limit for all but one sample so standard error was incalculable.

Figure 1. Mean root metal bioconcentration factors (BCF, the ratio of root concentration to soil concentration) for grasses, forbs, and shrubs sampled from Alaskan military lands. A high BCF (>1) indicates higher root concentration compared to the soil. Mean BCF values for each metal with the same letter are not significantly different at an $\alpha = 0.05$.

Figure 2. Mean metal translocation factors (TF, the ratio of shoot concentration to root concentration) for grasses, forbs, and shrubs sampled from Alaskan military lands. A high TF (>1) indicates higher translocation to shoots compared to roots. Mean TF values for each metal with the same letter are not significantly different at an $\alpha = 0.05$.

differences were observed in mean BCF values between grasses, forbs, and shrubs for Cu, Pb, and Zn.

Forbs allowed translocation of high concentrations of Cr, Ni, and Zn to shoots (TF > 1), while accumulated Cu, Sb, and Pb were retained in roots (Figure 2, Table 5). Grasses allowed a similar concentration of Cr to be translocated to shoots from roots, while all other metals were retained in roots (Figure 2, Table 5). Shrubs did not allow high concentrations of any metal to be translocated to shoots, while mean Zn concentration was similar between shrub roots and shoots (Figure 2, Table 5). Between functional groups, forbs had a higher mean TF value for Cu, Pb, Sb, and Zn compared to grasses (Figure 2). Both forbs and shrubs had higher mean TF values for Ni compared to grasses. No differences existed between grasses, forbs, and shrubs for mean Cr TF (Figure 2).

Discussion

Vegetation adapted to Arctic and subarctic environments are not adequately characterized with respect to interactions with metal deposition in soils. As permafrost thaw continues, coupled with increasing human activity in this locale, greater understanding of these interactions is necessary to maintain environmental quality. Our results indicate that vegetation indigenous to this environment possesses the potential for use in phytoremediation applications, but greater knowledge of species' differences and effects of environmental variation on performance is needed to effectively utilize phytoremediation technology for metal stabilization in high latitude environments.

In this study, the indigenous Alaska training range plants were highly variable in their accumulation of soil metals,

concurrent with similar depositional trends worldwide. Forbs generally did not accumulate high concentrations of metals, in either roots or shoots. Any metal that was accumulated into the roots was also translocated to shoots, resulting in an even metal distribution across the plant. Of the forbs, only *Solidago decumbens* exhibited potential as a phytostabilizer, particularly for Sb. This plant species exhibited a BCF > 1 and a TF of < 0.5 . *Solidago canadensis*, a congener to *S. decumbens*, has been previously shown to be an accumulator of Cd (Fu *et al.* 2017).

Shrubs generally did not accumulate high concentrations of metals in this study, but also did not translocate metal concentrations to shoots. Our shrub results further support the growing evidence that woody vegetation has high potential to concentrate Sb in roots and prevent translocation to shoots, which is important for stabilizing shooting range soils (Busby *et al.* 2018). *Salix* (willow) species are well known for their metal phytoextraction abilities (Gasronski *et al.* 2011). However, *S. setchelliana* was more effective at phytostabilization than phytoextraction, as indicated by the accumulation of metals in roots and lower shoot metal concentrations, *i.e.*, low translocation. However, the *S. setchelliana* samples collected in this study were growing in soil with low metal concentrations and previous research has indicated that metal accumulation in *Salix* tissues is highly dependent on soil metal concentrations (Tózsér *et al.* 2017).

Grasses, overall, accumulated the greatest root concentrations of metals and little evidence of translocation to shoots was observed. Of the grasses, *E. macrourus* and *H. jubatum* accumulated the highest concentrations of metals. Grasses are well documented for their ability to grow in soils high in metals and are one of the most important plant families for metal phytoremediation (Gasronski *et al.* 2011). Related species that have been previously investigated include *Agrostis capillaris*, which exhibited significant phytostabilization potential from a shooting range soil in Spain (Rodríguez-Seijo *et al.* 2016b), and *Hordeum vulgare*, which exhibited high root bioconcentration of metals and low translocation to shoots (Soriano-Disla *et al.* 2014).

Elymus macrourus has good potential as a metal phytostabilizer, accumulating the greatest root concentrations of Cu, Pb, and Sb and substantial amounts of Cr, Ni, and Zn. It also possessed, by far, the highest root Pb BCF of all sampled plant species. Low TF values for all analyzed metals were measured for *E. macrourus*. Unfortunately, because sampled plants were from a variety of soils with variable chemical and physical properties and levels of metal concentrations, a definitive conclusion that *E. macrourus* outperforms all other studied plant species for all analyzed metals cannot be made. However, samples of *E. macrourus* included samples from the soil with the highest Pb and Sb concentrations. In this soil, it accumulated greater root Pb and Sb concentrations compared to the other plant species, and with little apparent translocation of the metals to shoots. A controlled comparison between multiple plant species with *E. macrourus* in identical soils and varying levels of metal deposition would be needed to fully determine its potential as a phytostabilizer.

The soils sampled in this study varied considerably in metal concentrations. The impact area soils contained low concentrations of sampled metals, indicating that the management of metals at these sites is likely not necessary. However, the explosive detonation site soil and small arms range soils contained elevated levels of metals (Cr, Cu, Ni, and Pb in the detonation site soil and Cu, Pb, Sb, and Zn in the range soils). Of the sampled plant species exhibiting the greatest phytostabilization potential, only *E. macrourus* occurred in the soils with elevated metals; all others were only identified and sampled in the impact area soils. Overall, *E. macrourus* accumulated the highest concentrations of metals in its roots. Other species accumulating high root concentrations of at least one metal were *S. decumbens*, *H. jubatum*, and *Salix setchelliana*. These species also had root BCF values greater than 1 for at least one metal, while *Elaeagnus commutata* had the highest root BCF value for Sb. These species also possessed low metal TF values.

The plants analyzed in this study, on average, contained lower concentrations of Cr, Ni, and Zn but higher concentrations of Cu, Pb, and Sb compared to a meta-analysis of global mean metal concentrations in plants (Kumar *et al.* 2017). Of the metals assayed, Cu, Ni, and Zn are plant micronutrients and are present in low concentrations in healthy plants. The normal range of concentrations for shoot Cu is 5–20 mg kg⁻¹, although many exceptions exist (Kabata-Pendias and Pendias 2001). The normal Ni content of most plant species is less than 5 mg kg⁻¹ (Kabata-Pendias and Pendias 2001). Concentrations of 10–100 mg kg⁻¹ Ni are considered toxic for most plant species. Normal Zn concentrations in grasses range from 12 to 47 mg kg⁻¹ worldwide, with clovers ranging from 24 to 45 mg kg⁻¹ (Kabata-Pendias and Pendias 2001). Most of the sampled plant species in this study did not exceed the normal concentration for these micronutrients, when examining shoot concentrations. However, root concentrations were often higher than the published normal ranges (Kabata-Pendias and Pendias 2001), which does coincide with the elevated metal concentrations observed in these training range soils.

Globally, few plant species have been investigated for their potential use to mitigate metal deposition in shooting range soils (Bandara and Vithanage 2016). Of those that have been studied, most are for phytoextraction, rather than phytostabilization, and most are not adapted to grow under conditions found in interior Alaska. Of a number of plants growing in soil containing elevated concentrations of Sb and Pb in Spain, a single grass species was identified as exhibiting phytostabilization capacity for Pb (Álvarez-Ayuso *et al.* 2012). On shooting range soils in Switzerland, a number of grass and forb shoots were analyzed for heavy metals, with only one forb species containing a high concentration of shoot Pb (Evangelou *et al.* 2012). In another Swiss shooting range soil with much higher concentrations of heavy metals, some of the same plant species analyzed by Evangelou *et al.* (2012) accumulated high shoot concentrations that would be considered toxic to livestock (Robinson *et al.* 2008). However, roots were not analyzed in these studies so the

phytostabilization potentials of these plants cannot be discussed.

In a boreal forest environment in Finland, Pb from shooting range soils resulted in increased Pb concentrations in multiple organisms, Pb leaching from organic soil layers, and reduced abundances of numerous soil dwelling organisms (Selonen *et al.* 2012, 2014; Selonen and Setälä 2017). Grass litter with higher Pb concentrations decomposed more slowly in this environment (Selonen and Setälä 2015). This indicates phytostabilization of such soils would reduce the potential for Pb migration, as the Pb that accumulates in the stabilizers would decompose slowly and be held in the organic matter where it was taken up.

A combination of grasses, forbs, and shrubs that are most capable of metal phytostabilization would be most beneficial to the ecosystem as a whole, as plant functional diversity improves ecosystem functioning and resilience (Hooper and Vitousek 1997; Walker *et al.* 1999). The best performing grass, forb, and shrub could be utilized together across their adapted range to better ensure metal stabilization across a range of environmental conditions. Unfortunately, none of the most capable studied species possesses a circumpolar distribution (Hultén 1968; Welsh 1974). The native range of *E. macrourus* does stretch into Siberia, but its North American range is confined to Alaska and northwest Canada, where it occurs in tundra, woodlands, and riverbanks on sandy and gravelly soils. *S. decumbens* occurs in meadows and open woods across the United States and Canada, while *E. commutata* occurs on dry slopes, gravel bars, and open woods across the United States and Canada. *H. jubatum* is considered a weed in many locations and has been introduced outside its native range of northern North America and Siberia to most continents, and its metal phytostabilization capacity was lesser than *E. macrourus*.

In conclusion, grasses indigenous to interior Alaska were most effective at metal accumulation in roots, in particular *Elymus macrourus*. Forbs were not effective at metal accumulation and did not restrict translocation to shoots. Shrubs did not accumulate high metal concentrations, but what was accumulated remained in roots, in particular Sb. It is recommended that a combination of the best performing grass, forb, and shrub species be used in combination for metal stabilization in interior Alaska to enhance functional diversity while maximizing metal stabilization.

Funding

This research was funded by the United States Army Environmental Quality 6.2 Applied Research Program.

References

- Ahmad M, Loo SS, Moon DH, Yang JE, Ok YS. 2012. A review of environmental contamination and remediation strategies for heavy metals at shooting range soils. In: Malik A, Grohmann E, editors. Environmental protection strategies for sustainable development: strategies for sustainability. Dordrecht (DE): Springer. p. 437–451.
- Ali H, Khan E, Sajad MA. 2013. Phytoremediation of heavy metals—concepts and applications. *Chemosphere*. 91(7):869–881. doi:10.1016/j.chemosphere.2013.01.075.
- Álvarez-Ayuso E, Otones V, Murciego A, García-Sánchez A, Santa Regina I. 2012. Antimony, arsenic and lead distribution in soils and plants of an agricultural area impacted by former mining activities. *Sci Total Environ*. 439:35–43. doi:10.1016/j.scitotenv.2012.09.023.
- Bandara T, Vithanage M. 2016. Phytoremediation of shooting range soils. In: Ansari AA, Gill SS, Gill R, Lanza GR, Newman L, editors. *Phytoremediation: management of environmental contaminants*. Vol. 3. Cham (CH): Springer. p. 469–488.
- Brown D, Jorgenson MT, Douglas TA, Romanovsky VE, Kielland K, Hiemstra C, Euskirchen ES, Ruess RW. 2015. Interactive effects of wildfire and climate on permafrost degradation in Alaskan lowland forests. *J Geophys Res Biogeosci*. 120(8):1619–1637. doi:10.1002/2015JG003033.
- Busby RR, Barbato RA, Jung CA, Morozova KA, Bednar AJ, Bray AL, Milam JM, Smith JC, Indest KJ. 2018. Photoperiod and soil nutrient constituent effects on phytoaccumulation and rhizosphere interactions in boreal vegetation. *Water Air Soil Pollut*. 229(12):380. doi:10.1007/s11270-018-4027-3.
- Conesa HM, Evangelou MWH, Robinson BH, Schulin R. 2012. A critical review of current state of phytotechnologies to remediate soils: still a promising tool?. *Sci World J*. 2012:1. doi:10.1100/2012/173829.
- Douglas T, Jones MC, Hiemstra CA, Arnold JR. 2014. Sources and sinks of carbon in boreal ecosystems of interior Alaska: a review. *Elementa-Sci Anthropol*. 12:2. doi:10.12952/journal.elementa.000032.
- Evangelou MWH, Hockmann K, Pokharel R, Jakob A, Schulin R. 2012. Accumulation of Sb, Pb, Cu, Zn, and Cd by various plants species on two different relocated military shooting range soils. *J Environ Manage*. 108:102–107. doi:10.1016/j.jenvman.2012.04.044.
- Frey KE, McClelland JW. 2009. Impacts of permafrost degradation on arctic river biogeochemistry. *Hydrol Process*. 23(1):169–182. doi:10.1002/hyp.7196.
- Fu W, Huang K, Cai HH, Li J, Zhai DL, Dai ZC, Du DL. 2017. Exploring the potential of naturalized plants for phytoremediation of heavy metal contamination. *Int J Environ Res*. 11(4):515–521. doi:10.1007/s41742-017-0045-z.
- Gasronski SW, Greger M, Gawronska H. 2011. Plant taxonomy and metal phytoremediation. In: Sherameti I, Varma A, editors. *Detoxification of heavy metals*. Berlin (DE): Springer-Verlag. p. 91–109.
- Hooper DU, Vitousek PM. 1997. The effects of plant composition and diversity on ecosystem processes. *Science*. 277(5330):1302–1305. doi:10.1126/science.277.5330.1302.
- Hultén E. 1968. *Flora of Alaska and neighboring territories*. Stanford (CA): Stanford University Press.
- Kabata-Pendias A, Pendias H. 2001. *Trace elements in soils and plants*. Boca Raton (FL): CRC Press.
- Kumar V, Sharma A, Dhunna G, Chawla A, Bhardwaj R, Thukral AK. 2017. A tabulated review on distribution of heavy metals in various plants. *Environ Sci Pollut Res Int*. 24(3):2210–2260. doi:10.1007/s11356-016-7747-1.
- Martin WA, Felt DR, Larson SL, Fabian GL, Nestler CC. 2012. Open burn/open detonation (OBOD) area management using lime for explosives transformation and metals immobilization. Vicksburg (MS): United States Army Corps of Engineers Environmental Laboratory Technical Report TR-12-4.
- O'Donnell JA, Jorgenson MT, Harden JW, McGuire AD, Kanevskiy MZ, Wickland KP. 2012. The effects of permafrost thaw on soil hydrologic, thermal, and carbon dynamics in Alaskan peatland. *Ecosystems*. 15(2):213–229. doi:10.1007/s10021-011-9504-0.

- Padmavathiamma PK, Li LY. 2007. Phytoremediation technology: hyper-accumulation metals in plants. *Water Air Soil Pollut.* 184(1–4):105–126. doi:[10.1007/s11270-007-9401-5](https://doi.org/10.1007/s11270-007-9401-5).
- Pinto AP, de Varennes A, Fonseca R, Teixeira DM. 2015. Phytoremediation of soils contaminated with heavy metals: techniques and strategies. In: Ansari AA, Gill SS, Gill R, Lanza GR, Newman L, editors. *Phytoremediation: management of environmental contaminants*. Vol. 1. Cham (CH): Springer. p. 133–155.
- Reeves RD, Baker AJM, Jaffré T, Erskine PD, Echevarria G, van der Ent A. 2018. A global database for plants that hyperaccumulate metal and metalloid trace elements. *New Phytol.* 218(2):407–411. doi:[10.1111/nph.14907](https://doi.org/10.1111/nph.14907).
- Robinson BH, Bischofberger S, Stoll A, Schroer D, Furrer G, Roullet S, Gruenwald A, Attinger W, Schulen R. 2008. Plant uptake of trace elements on a Swiss military shooting range: uptake pathways and land management implications. *Environ Pollut.* 153(3):668–676. doi:[10.1016/j.envpol.2007.08.034](https://doi.org/10.1016/j.envpol.2007.08.034).
- Rodríguez-Seijo A, Alfaya MC, Andrade ML, Vega FA. 2016a. Copper, chromium, nickel, lead, and zinc levels and pollution degree in firing range soils. *Land Degrad Develop.* 27(7):1721–1730. doi:[10.1002/ldr.2497](https://doi.org/10.1002/ldr.2497).
- Rodríguez-Seijo A, Lago-Vila M, Luisa Andrade M, Vega FA. 2016b. Pb pollution in soils from a trap shooting range and the phytoremediation ability of *Agrostis capillaris* L. *Environ Sci Pollut Res.* 23(2):1312–1323. doi:[10.1007/s11356-015-5340-7](https://doi.org/10.1007/s11356-015-5340-7).
- Sanderson P, Naidu R, Bolan N, Bowman M, Mclure S. 2012. Effect of soil type on distribution and bioaccessibility of metal contaminants in shooting range soils. *Sci Total Environ.* 438:452–462. doi:[10.1016/j.scitotenv.2012.08.014](https://doi.org/10.1016/j.scitotenv.2012.08.014).
- Selonen S, Liiri M, Setälä H. 2014. Can the soil fauna of boreal forests recover from lead-derived stress in a shooting range area? *Ecotoxicology.* 23(3):437–448. doi:[10.1007/s10646-014-1210-1](https://doi.org/10.1007/s10646-014-1210-1).
- Selonen S, Liiri M, Strömmer R, Setälä H. 2012. The fate of lead at abandoned and active shooting ranges in a boreal pine forest. *Environ Toxicol Chem.* 31(12):2771–2779. doi:[10.1002/etc.1998](https://doi.org/10.1002/etc.1998).
- Selonen S, Setälä H. 2015. Soil processes and tree growth at shooting ranges in a boreal forest reflect contamination history and lead-induced changes in soil food webs. *Sci Total Environ.* 518–519:320–327. doi:[10.1016/j.scitotenv.2015.03.018](https://doi.org/10.1016/j.scitotenv.2015.03.018).
- Selonen S, Setälä H. 2017. Nutrient leaching, soil pH and changes in microbial community increase with time in lead-contaminated boreal forest soil at a shooting range area. *Environ Sci Pollut Res.* 24(6):5415–5425. doi:[10.1007/s11356-016-8278-5](https://doi.org/10.1007/s11356-016-8278-5).
- Soriano-Disla JM, Gómez I, Navarro-Pedreño J, Jordán M. 2014. The transfer of heavy metals to barley plants from soils amended with sewage sludge with different heavy metal burdens. *J Soils Sediments.* 14(4):687–696. doi:[10.1007/s11368-013-0773-4](https://doi.org/10.1007/s11368-013-0773-4).
- Tózsér D, Magura T, Simon E. 2017. Heavy metal uptake by plant parts of willow species: a meta-analysis. *J Hazard Mater.* 336:101–109. doi:[10.1016/j.jhazmat.2017.03.068](https://doi.org/10.1016/j.jhazmat.2017.03.068).
- Walker B, Kinzig A, Langridge J. 1999. Plant attribute diversity, resilience, and ecosystem function: the nature and significance of dominant and minor species. *Ecosystems.* 2(2):95–113. doi:[10.1007/s100219900062](https://doi.org/10.1007/s100219900062).
- Walsh ME. 2004. Field-portable X-ray fluorescence (FP-XRF) determinations of metals in post-blast ordnance residues. Hanover (NH): United States Army Corps of Engineers Cold Regions Research and Engineering Laboratory Technical Report TR-04-5.
- Welsh SL. 1974. Anderson's flora of Alaska and adjacent parts of Canada. Provo (UT): Brigham Young University Press.
- Zhuang P, Yang Q, Wang H, Shu W. 2007. Phytoextraction of heavy metals by eight plant species in the field. *Water Air Soil Pollut.* 184(1–4):235–242. doi:[10.1007/s11270-007-9412-2](https://doi.org/10.1007/s11270-007-9412-2).

0 16 km
0 10 mi

REPORT DOCUMENTATION PAGE				Form Approved OMB No. 0704-0188	
Public reporting burden for this collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing this collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden to Department of Defense, Washington Headquarters Services, Directorate for Information Operations and Reports (0704-0188), 1215 Jefferson Davis Highway, Suite 1204, Arlington, VA 22202-4302. Respondents should be aware that notwithstanding any other provision of law, no person shall be subject to any penalty for failing to comply with a collection of information if it does not display a currently valid OMB control number. PLEASE DO NOT RETURN YOUR FORM TO THE ABOVE ADDRESS.					
1. REPORT DATE August 2021		2. REPORT TYPE Final		3. DATES COVERED (From - To)	
4. TITLE AND SUBTITLE Metal accumulation capacity in indigenous Alaska vegetation growing on military training lands				5a. CONTRACT NUMBER	
				5b. GRANT NUMBER	
				5c. PROGRAM ELEMENT NUMBER	
6. AUTHOR(S) Ryan R. Busby, Thomas A. Douglas, Joshua J. LeMonte, David B. Ringelberg, and Karl J. Indest				5d. PROJECT NUMBER	
				5e. TASK NUMBER	
				5f. WORK UNIT NUMBER	
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) See next page.				8. PERFORMING ORGANIZATION REPORT NUMBER ERDC MP-21-10	
9. SPONSORING / MONITORING AGENCY NAME(S) AND ADDRESS(ES) U.S. Army Corps of Engineers Washington, DC 20314				10. SPONSOR/MONITOR'S ACRONYM(S)	
				11. SPONSOR/MONITOR'S REPORT NUMBER(S)	
12. DISTRIBUTION / AVAILABILITY STATEMENT Approved for public release; distribution is unlimited.					
13. SUPPLEMENTARY NOTES This article was originally published online in the <i>International Journal of Phytoremediation</i> on 23 February 2020. This research was funded by the U.S. Army Environmental Quality 6.2 Applied Research Program.					
14. ABSTRACT Permafrost thawing could increase soil contaminant mobilization in the environment. Our objective was to quantify metal accumulation capacities for plant species and functional groups common to Alaskan military training ranges where elevated soil metal concentrations were likely to occur. Plant species across multiple military training range sites were collected. Metal content in shoots and roots was compared to soil metal concentrations to calculate bioconcentration and translocation factors. On average, grasses accumulated greater concentrations of Cr, Cu, Ni, Pb, Sb, and Zn relative to forbs or shrubs, and bioconcentrated greater concentrations of Ni and Pb. Shrubs bioconcentrated greater concentrations of Sb. Translocation to shoots was greatest among the forbs. Three native plants were identified as candidate species for use in metal phytostabilization applications. <i>Elymus macrourus</i> , a grass, bioconcentrated substantial concentrations of Cu, Pb, and Zn in roots with low translocation to shoots. <i>Elaeagnus commutata</i> , a shrub, bioconcentrated the greatest amounts of Sb, Ni, and Cr, with a low translocation factor. <i>Solidago decumbens</i> bio-concentrated the greatest amount of Sb among the forbs and translocated the least amount of metals. A combination of forb, shrub, and grass will likely enhance phytostabilization of heavy metals in interior Alaska soils through increased functional group diversity.					
15. SUBJECT TERMS Boreal forest; <i>Elymus macrourus</i> ; phytoremediation; phytostabilization					
16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT	b. ABSTRACT	c. THIS PAGE			19b. TELEPHONE NUMBER (include area code)
Unclassified	Unclassified	Unclassified	UU	15	

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)

Construction Engineering Research Laboratory
U.S. Army Engineer Research and Development Center
2902 Newmark Drive
Champaign, IL 61822

Cold Regions Research and Engineering Laboratory
U.S. Army Engineer Research and Development Center
Fort Wainwright, AK

Cold Regions Research and Engineering Laboratory
U.S. Army Engineer Research and Development Center
72 Lyme Road
Hanover, NH 03755

Environmental Laboratory
U.S. Army Engineer Research and Development Center
3909 Halls Ferry Road
Vicksburg, MS 39180