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Northwest

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Introduction

"Essentially, all life depends upon the soil … There can be no life without soil and no soil without life; they have evolved together." —Charles E. Kellogg (USDA 1938, p. 864).

Forests in the Northwest region (Washington, Oregon, and Idaho) represent a complex array of composition and structure. These complexities indicate the diverse range of soils and the physical environment which affect soil and plant interactions. In this region the textural classes range from gravel to heavy clay, many are skeletal (>35% rocks), and many are derived from volcanic materials (Isaac and Hopkins 1937). Today, these forests and soils are being impacted by warmer, drier years often associated with El Niño or the Pacific Decadal Oscillation (or both), below-average snowpack and streamflow, below-average forest growth, and an above-average risk of fire (Mote et al. 2005).

This regional summary describes the two distinct areas of the northwestern United States: the Pacific (coastal) Northwest and the Inland Northwest. It also provides an overview of some of the management challenges.

Description of the Region

The Northwest is characterized by a diversity of soil, climatic regimes, parent material, surficial deposits, and vegetation. Land uses and opportunities for soil conservation and ecosystem services from soil vary throughout this area. Proximity to the Pacific Ocean and large elevational gradients throughout the region contribute to unique soil and vegetation relationships. The region contains two distinct areas: (1) the wet, ocean-moderated coastal zone on the west side of the Cascade Mountains and (2) the Inland Northwest zone, which includes drier forests with long summer drought periods (Fig. A14).

The Pacific Northwest

The coastal forests of the Pacific Northwest are highly productive, a result of favorable climate, geology, and soil. The dominant commercial tree species is Douglas-fir (*Pseudotsuga menziesii*). Old-growth forests are dominated by Sitka spruce (*Picea sitchensis*) along the exceedingly wet coastline, by western hemlock (*Tsuga heterophylla*) and western redcedar (*Thuja plicata*) at mid-elevations, and by Engelmann spruce (*Picea engelmannii*), true firs (*Abies* spp.), and mountain hemlock (*Tsuga mertensiana*) at higher

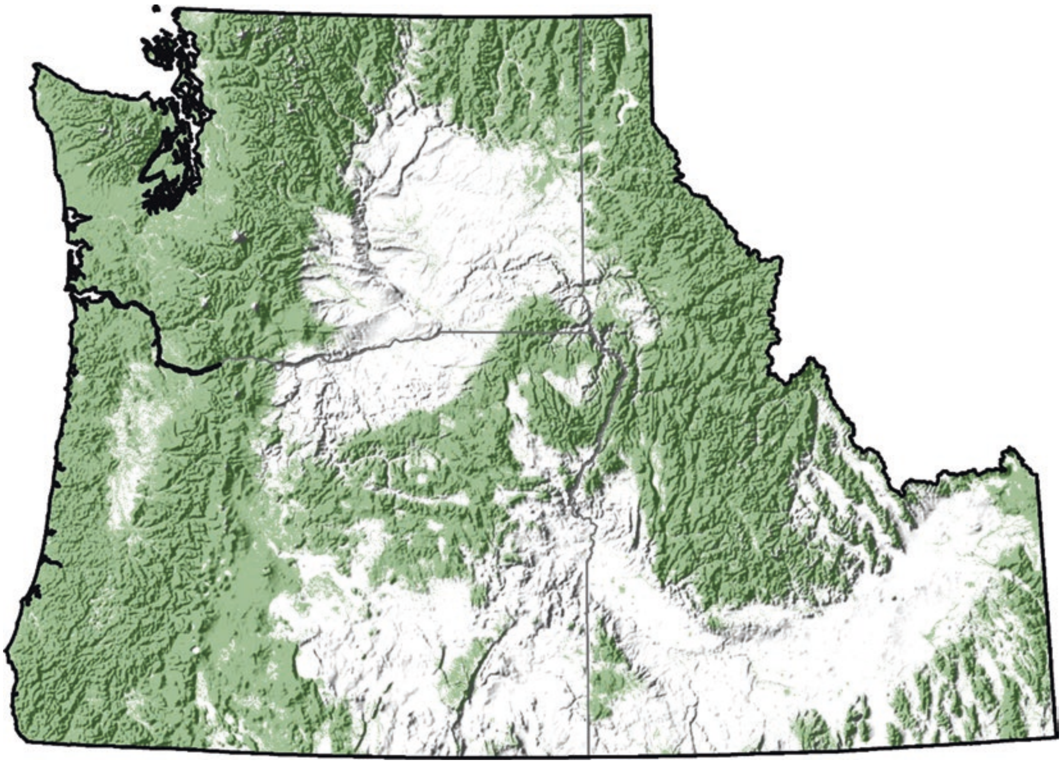

Fig. A14 Map of the Pacific Northwest and Inland Northwest

elevations. These forests grow primarily on steep mountainous areas, which might suggest young, thin soils (Waring and Franklin 1979); however, the soils are at least as deep and fertile as other temperate forests. This area experiences wet, mild winters, and warm, dry summers (Shumway 1979), which allow many conifers to flourish.

The dominant soils of the Cascade Range and Olympic Mountains are Andisols and Spodosols (Bockheim 2017). Almost 35% of the soil particle-size families are ashy or medial (Table A3), reflecting the influence of volcanic ash parent materials and the weathering processes associated with andic soils. Spodosols occur at the higher elevations, which have a greater amount of effective precipitation. On the drier east side of the Cascades, Inceptisols are extensive (Southard et al. 2017).

Soils in the Pacific Northwest include all textural classes—from heavy clay to gravel—but the most common textural class is loam. In the southern part of the coastal area, soils are primarily derived from basalt (Mangum 1913), and in the northern portion, many soils are derived from sedimentary gravels, sands, and silts from past glacial activity (Isaac and Hopkins 1937). In addition, many soils of this region have a high coarse-fragment content, which has been shown to have a strong negative effect on tree growth (Table A4). Skeletal soils have at least 35% rock-fragment content on a volume basis, contributing to reduced water holding capacity and lower rooting volume compared to nonskeletal soils.

Table A3 Relative abundance of soil particle-size classes in the Pacific (coastal) Northwest (Soil Survey Staff 2017, 2018)

Soil textural class[a]	Abundance (%)
Ashy or medial	34.9
Loamy skeletal	23.5
Loamy or silty	21.4
Clayey, fine, or very fine	15.3
Sandy or sandy skeletal	2.6
Cindery or pumiceous	2.1

[a]Textural classes are derived from the textural family either in its entirety or from the first element of multipart textural families. Approximately 720 000 ha were evaluated, and no data were excluded

Table A4 Relative abundance of soils with or without a skeletal feature in textural control section in the Pacific (coastal) Northwest (Soil Survey Staff 2017, 2018)

Soil feature	Abundance (%)
All skeletal[a]	43.8
All nonskeletal	56.2

[a]Skeletal soils have >35% rock fragments in some part of the particle size control section (1 m depth). Approximately 720 000 ha were evaluated, and no data were excluded

On the west side of the Cascades, the soils are primarily porous and most precipitation infiltrates rapidly as long as the site has not been impacted by compaction, rutting, or displacement of the forest floor (Heninger et al. 2011). More

Table A5 Occurrence of soil depth classes in the Pacific (coastal) Northwest (Soil Survey Staff 2017, 2018)

Soil feature[a]	Abundance (%)
Very deep to restriction	43.7
Deep to restriction	17.9
Moderately deep to restriction	33.5
Very shallow and shallow	1.8

[a]Depth classes are very shallow and shallow <50 cm, moderately deep 50–99 cm, deep 100–150 cm, very deep >150 cm. Approximately 720 000 ha were evaluated, and no data were excluded. Percentages do not add up to 100 because of the occurrence of rock outcrops or water features

than 95% of the soils in the Pacific Northwest are moderately deep to very deep to any kind of layer that restricts root growth or the movement of water (Table A5).

Because rapid regrowth generally occurs on the coastal Northwest, there is very little bare soil after management activities. Therefore, the dominant erosion process here is landslides, which move large masses of the soil mantle downslope.

The Inland Northwest

Inland Northwest soils are much drier because of the rain shadow effect of the Cascades. The bulk of the precipitation is dropped by westerlies as they approach the mountain crests along the eastern boundaries. Although the mountains of the Okanogan Highlands in northeastern Washington rise as high as the Selkirk and Cabinet Mountains, which lie successively east of them, they are less massive and considerably drier. In the Okanogan Highlands, forests and soils are typically xerophytic, even near the mountain summits. In the Selkirk and Cabinet, however, typical vegetation is mesophytic to the valley floor (Daubenmire and Daubenmire 1968). Parent materials consist of igneous, sedimentary, and metamorphic rocks. Glacial till and outwash deposits are common north of the Columbia River and Spokane-Rathdrum Prairies. An extensive mantle of mixed volcanic ash and loess overlies the local tills, colluvium, and residuum.

The dominant forest soils of the Inland Northwest are Andisols, Inceptisols, and Alfisols. Andisols and andic subgroups of Inceptisols and Alfisols account for 37% of the particle-size classes in the region (Table A6), underscoring the importance of volcanic ash as a parent material. Spodosols are found at higher elevations in northeastern Washington, northern Idaho, and northwestern Montana, where colder temperatures, greater snowpack, and abundant organic compounds derived from coniferous litter promote the podzolization process (Valerio et al. 2016). Mollisols are transitional soils associated with drier forest communities.

Geologic history and climate have led to strong mechanical weathering of the mountain slopes where most forest lands occur. This has produced extensive areas of soils high in rock fragments, especially at higher elevations (Table A7). Deeply weathered soils with fewer fragments do occur, however. These are most common in the unglaciated low mountains and foothills south of Lake Coeur D'Alene and north of the Idaho Batholith.

Table A6 Relative abundance of soil particle-size classes in the Inland Northwest (Soil Survey Staff 2017, 2018)

Soil texture[a]	Abundance (%)
Ashy or medial	37.1
Loamy skeletal	29.9
Loamy or silty	19.0
Clayey, fine, or very fine	9.0
Sandy or sandy skeletal	4.9
Cindery or pumiceous	0.1

[a]Textural classes are derived from the textural family either in its entirety or from the first element of multipart textural families. Approximately 11 600 000 ha were evaluated, and no data were excluded

Table A7 Relative abundance of soils with or without a skeletal feature in textural control section in the Inland Northwest (Soil Survey Staff 2017, 2018)

Soil feature[a]	Abundance (%)
All skeletal	53.7
All nonskeletal	46.3

[a]Skeletal soils have >35% rock fragments in some part of the particle size control section (1 m depth). Approximately 11 600 000 ha were evaluated, and no data were excluded.

Skeletal soils are abundant across the region, accounting for more than half of all soils in the Inland Northwest (Table A7). Because of this, the mantle of volcanic ash greatly enhances the plant-available water holding capacity of many forest soils. A 40-cm-thick layer of weathered volcanic ash can typically provide 12–16 cm of plant available water, 2–3 times as much as underlying horizons (McDaniel et al. 2005). This difference can be critical to forest community composition and productivity in the seasonally dry landscapes of the region. Although most soils of the Inland Northwest are deep or very deep (Table A8), many of the benefits associated with deep soils may be offset by the abundance of skeletal soils. Rock fragments within skeletal soils occupy a significant volume of mineral soil, making less room for root growth and moisture storage.

Impacts on the Soil Resource

Harvesting and Site Preparation

Stand harvesting and site preparation alter the inputs of soil organic matter into the soil. Soil organic matter is critical for maintaining site productivity because of its role in supporting nutrient availability, gas exchange, and water supply (Blake and Ruark 1992; Henderson 1995; Jurgensen et al. 1997; Powers et al. 1990). Organic matter is also essential to microflora and macrofauna active in nutrient cycling, soil aggregation, and disease incidence or prevention (Harvey et al. 1987). Recent changes in land management now com-

Table A8 Occurrence of soil depth classes in the Inland Northwest (Soil Survey Staff 2017, 2018)

Soil feature[a]	Abundance (%)
Very deep to restriction	46.7
Deep to restriction	17.3
Moderately deep to restriction	26.0
Very shallow and shallow	10.0

[a]Depth classes are very shallow and shallow <50 cm, moderately deep 50–99 cm, deep 100–150 cm, very deep >150 cm. Approximately 11 600 000 ha were evaluated, and no data were excluded.

monly favor restoration of fire regimes or watershed health and precommercial thinnings to restore ecological function. Loss of soil organic matter from periodic stand disturbances (e.g., repeated thinning) could have negligible short-term impacts (Sanchez et al. 2006) or more significant impacts, depending on soil type, tree species, ecosystem, or climatic regime (Grigal and Vance 2000; Henderson 1995). Removal of logging slash for bioenergy, rather than leaving the harvest residues on site, can change nutrient availability (Sinclair 1992), soil temperature, water availability, and biological activity (Covington 1981; Harvey et al. 1976). Conversely, excess biomass left after stand harvesting or thinning may negatively impact soil quality by providing fuel for uncharacteristically severe wildfire (Page-Dumroese et al. 2010) or impair natural regeneration potential (Jurgensen et al. 1997). Traditional harvest methods (e.g., feller bunchers, harvesters, skyline logging, forwarders), when used with care, can cause less than 10% soil displacement and compaction (McIver et al. 2003). Newer logging systems (e.g., tethered logging) have yet to be tested for their soil impacts. For example, tethered logging has been used in New Zealand on steep terrain (>40% slope) and is now being used in a few locations in the Pacific Northwest and Inland Northwest. It is unclear how much compaction or soil displacement may be generated from this type of logging and how that may alter site productivity.

Fire

Current forest structure in the Northwest is a result of a successful fire suppression program that began after the 1910 fires (Pyne 1982). Since that time, vegetation and surface fuels have been slowly accumulating, and we are faced with many ecological issues associated with overstocked forests (Keane 2008; Keane et al. 2002). When wildfires burn today, they do so with greater intensity and severity during a longer fire season (Jolly et al. 2015). Wildfires have the potential to shift lifeform dominance across large areas (Moreira et al. 2011; Odion et al. 2010), which can result in shifting microbial populations, carbon stocks, and nutrients. Soil carbon is critical for maintaining soil physical properties, supporting hydrologic function, providing clean water, and circulating greenhouse gases, but these are at risk after high-severity wildfires or prescribed burns (Busse et al. 2014). In addition to affecting soil carbon and other nutrients, wildfire impacts the soil fungal community structure. The impacts are mixed and are dependent on site or fire severity (or both). Usually, there are greater impacts in the surface horizons than deeper in the profile, and they are more pronounced in areas of frequent burning (Cairney and Bastias 2007). These mixed results of wildfire or prescribed burning underscore the importance of understanding individual soil and vegetation relationships as well as changes at the landscape scale.

Although wildfire is a concern on many Pacific and Inland Northwest sites, another management concern is the threat of a reburn, where dead trees remain and eventually fall to create "jackstraw" conditions. These intersecting points of downed logs can create hotspots when the site reburns (Passovoy and Fulé 2006). Reburns can be difficult to suppress, have the potential to kill any regeneration (Kemp 1967), and can impact soil carbon stocks (Page-Dumroese et al. 2015). For example, in the Scapegoat Wilderness in northwestern Montana, soil carbon in the 0–30 cm depth declined 9–16%; the change depended on the number of reburns and time since the last fire (Page-Dumroese et al. 2015).

It is important to understand the management options for areas with many dead or dying trees. One method to lower the fuel load is prescribed burning. This tool can manipulate the amount of woody residues on the soil surface and can control the amount of damage to plants and soil (Brown et al. 2003). Salvage logging is another option on sites with numerous snags. This method can reduce the amount of coarse wood on the soil surface and reduce insect populations (Simon et al. 1994). However, Page-Dumroese et al. (2006) note that salvage logging can produce a considerable amount of soil disturbance (>15% of the harvest unit) unless care is taken to limit logging to winter or dry soils and equipment is matched to site conditions.

Climate Change

Changes in twenty-first-century climate are projected to increase wildfire in many ecosystems (Flannigan et al. 2009), which may adversely affect the terrestrial carbon sink and cascade to affect soil biodiversity. Both the Pacific Northwest and Inland Northwest have many ecosystems that are tightly coupled with fire. These ecosystems have been sensitive to past climatic shifts because of their strong seasonal warm-wet winters and hot-dry summers. These seasonal conditions are projected to become amplified in most climate models (Mote and Salathé 2010; Rogers et al. 2011). Currently, the global soil carbon (C) pool is 3.3 times that of the atmospheric pool (Lal 2004). It is predicted that semiarid biomes in the Pacific and Inland Northwest could have increases in biomass production and C sequestration despite changing climate and fire regimes because of increased productivity during nonsummer months (Rogers et al. 2011). However, forests in the Pacific Northwest may become more vulnerable to summer drought and fire, resulting in less soil C (Rogers et al. 2011).

Another consequence of a changing climate is the decline in winter snowpack and snow water equivalent, particularly below 1800 m elevation (Mote 2003). Seasonal snow cover has decreased by 7% between 1973 and 1998 and is correlated with increasing air temperatures (Edwards et al. 2007). Reduced snow cover leads to a decline in soil C stocks (Neilson et al. 2001); nitrogen (N) leaching from increased snowmelt (Hazlett et al. 1992); increased freeze-thaw cycles, which result in more damaged roots (Weih and Karlsson 2002); and changing soil biota (Sjursen et al. 2005).

Soil Restoration

There are many methods for reducing the risk of wildfire on forest and range wildlands. These methods include restoration activities such as prescribed fire and mechanical practices (e.g., thinning, mastication, or chipping). They are used to reduce the wildfire hazard, limit the spread of fire, protect life and property, and restore forest or rangeland soil and site health (Busse et al. 2014). Each site treatment method is not without soil impacts, however, and managers will need to determine what ecosystem services are most important to maintain and then monitor the effectiveness of these treatments (Page-Dumroese et al. 2009). For example, restoration fire and thinning in ponderosa pine (*Pinus ponderosa*) resulted in similar litter depths and mycorrhizal fungi after 15 years as compared to the unharvested control, indicating that some forest sites are resilient (Hart et al. 2018). This resilience provides management flexibility to restore forest sites. However, repeated stand entries may produce a considerable amount of soil disturbance or compaction; the degree and extent of this may impact microbial and vegetative biodiversity, C sequestration, water quantity or quality, and nutrient cycling (Page-Dumroese et al. 2010). Some ecosystem services may not be compatible with restoration activities and therefore managers will have to balance maintaining soil productivity with managing for other site properties or desired outcomes (Burger et al. 2010).

The increased use of prescribed fire for restoration of rangeland sites may increase runoff and erosion in both the short term and the long term, leading to damage to soil and water resources. Increased runoff and erosion are a result of the loss of ground cover, aggregate stability, and soil roughness, and an increase in soil hydrophobicity (water repellency) (Pierson et al. 2011). Among long-term responses to burning in sagebrush-grassland ecosystems was a rebound of microbial community structure to preburn levels after 7 years (Dangi et al. 2010). Frequent rangeland fires, fuel accumulation from invasive species (e.g., cheatgrass; *Bromus tectorum*), and postfire annual weed dominance coupled with a low decomposition rate of plant materials (Knapp 1996) promote the alien grass-fire cycle (Brooks et al. 2004) that perpetuates nonnative species and can often lead to intensifying efforts to restore belowground processes.

Problems and Limitations

Management of forests and rangelands in the Pacific Northwest and Inland Northwest will continue to get more complex as rural communities seek to harvest timber or conduct restoration activities while conservationists push to protect wildlands. These issues are exacerbated when combined with a changing climate. Many policies, Federal agencies, and Congress have noted a forest health crisis in the Pacific and Inland Northwest that is arising mostly in overstory vegetation. Impaired health is usually related to dense overstories caused by fire suppression, numerous dead trees caused by drought or insect and disease outbreaks, or even-aged stand compositions that lack resistance to insect and disease invasions (DellaSalla et al. 1995; O'Laughlin et al. 1993).

Current solutions for these problems are to increase harvesting by thinning stands or salvage logging dead trees. However, there is a great need to expand the scope of the discussions about forest health to include whole ecosystem processes that involve changes to belowground properties as they relate to management and restoration goals. Understanding the role of forest and rangeland soil properties in hydrologic function, nutrient cycling, C sequestration, and resilience to climate change is critical to both ongoing harvesting and restoration activities. In areas where forest productivity has declined, it is often because of soil displacement, compaction, puddling (smearing of surface pores), and losses of organic matter (Heninger et al. 1997). In addition, taking land out of production due to roads and harvest landings contributes to the decline in forest productivity potential.

Controlling the amount of disturbance relies on integrated decision-making processes that guide harvest methods. This process requires monitoring to determine soil disturbance after management and relating that information to best management practices and operational ratings (Heninger et al. 1997; Page-Dumroese et al. 2010). Greater collaboration to remove barriers among agencies, universities, scientists, and land managers is critical for continuing to move forward on training efforts, monitoring protocols, and joint research efforts to restore or maintain soil processes and hydrologic function.

Key Findings

- Since the early twentieth century, wildfires in the Northwest have burned with greater intensity and severity. These catastrophic fires may shift forest community composition and structure, which in turn can lead to shifts in C stocks, soil nutrient availability, and microbial populations. There is a need for documentation of wildfire effects on belowground processes and microbial community structure and function.

- Vegetation and surface fuels have been slowly accumulating in the Northwest during the last century, increasing the risk of wildfire and reburns. We need long-term data on the impacts of fuel reduction treatments in low-elevation semiarid forests, including the impacts of using biochar, biosolids, or mastication to build surface and mineral soil organic matter.
- Forests in the Pacific Northwest are vulnerable to summer drought and fire. Areas undergoing aridification (long-term drought) need to be identified and monitored so that we can define the soil changes that lead to vegetation shifts.
- Ongoing harvesting and restoration activities affect forest and rangeland soil properties that impact C sequestration. Frequent rangeland fires, fuel accumulation from invasive plant species, and postfire annual weed dominance contribute to a cycle that perpetuates nonnative species and may require intensified efforts to restore belowground processes. We need a better understanding of how to protect and promote forest and rangeland soil and vegetation productivity to encourage C sequestration and limit invasive species.
- Careful use (e.g., logging on dry soils, limited off-trail travel) of traditional harvest methods such as feller bunchers and forwarders can have limited soil impacts, but data are needed on the impacts of new logging systems (e.g., tethered logging) on soil productivity, C sequestration, and stand sustainability.
- Land management is increasingly focusing on restoration of ecological function. We need to determine the long-term impacts of forest, rangeland, riparian area, and mine site development, as well as energy exploration and development, on our ability to restore soil processes. Applications of this research include helping managers (1) determine how a changing climate impacts restoration objectives, (2) use monitoring techniques to ensure objectives are met, and (3) understand whether and how ecosystems are progressing toward the desired restoration goal (active vs. passive restoration).

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Alaska

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Introduction

Alaska is by far the largest state in the United States but is often discussed within the same context as other states in reviews of natural resources. Regardless of the size of a state or region, it is a difficult task to disseminate all available information that will adequately address many aspects of a soil resource evaluation in one overview. This summary provides key references to soil resource inventory, soil vulnerability, and basic soil landscape information for obtaining additional soils information needed for specific uses. An overview of Alaska soil resources is presented within the context of several major functional groupings including permafrost, fire, and landscape position.

Current Condition of Alaska Soils

The areal coverage and diversity of soils in Alaska are extremely large. Alaska soils represent 7 of the 12 recognized soil orders (Ping et al. 2017; Soil Survey Staff 2014) and a large component of endemic soil taxonomic units (Carpenter et al. 2014). Alaska contains approximately 18% (1 717 900 km^2) of the total land and water area of the United States, covering a wide range of soil ecosystems (Fig. A15). Alaska soils can be broadly characterized by three key metrics: presence or absence of permafrost, presence or absence of fire, and landscape position as an upland or lowland. These attributes are the primary controls on dominant soil-forming factors that are related to the soil geography of the state. Permafrost manifests itself regionally with more prevalence from north to south, and fire dominates the boreal forest in the central part of the state. Uplands and lowlands are general landscape descriptors that distinguish areas of freely flowing matrix water (uplands) and areas of water accumulation (lowlands).

Alaska soils are subject to current climate disturbance as northern latitudes are expected to have more dramatic climate change than lower latitudes (Bekryaev et al. 2010). Alaska regions are also subject to extreme climate normal. Temperature oscillations include seasonal temperature changes of 48 $^{\circ}$C in interior Alaska. Precipitation is extreme in the coastal forest region, where total rainfall can reach 5 m annually. The state contains a disproportionate area susceptible to change, including wetlands and permafrost. Changes in soils should be of great concern in Alaska due to the influence of soils on the stock and flow of carbon (C), stability of structures, and both animal and human habitat, including