SOIL RESTORATION AND INVASIVE PLANTS
AT THE BLOCK P MILL AND TAILINGS SITE, MONTANA

by

John Gant Massey

A professional paper submitted in partial fulfillment
of the requirements for the degree

of

Master of Science

in

Land Resources and Environmental Sciences

MONTANA STATE UNIVERSITY
Bozeman, Montana

December 2019

ACKNOWLEDGEMENTS

Since beginning work on Block P Mill and Tailings site in 1999, I have received the support of many people, including:

- Tom Parker, who first invited me to Block P;
- The ecologists at Bitterroot Restoration, particularly Pat Burke and Len Ballek, who helped me understand the practice of environmental restoration;
- John Carter of The Doe Run Company and John Hunt at Barr Engineering, who patiently supported my ideas;
- The private landowners at and around Block P, who generously provided site access;
- The professionals with the USDA Forest Service and the Environmental Protection Agency, particularly those who supported this latest research effort; and
- The members of my committee and academic supporters at Montana State University (MSU), specifically Scott Powell and Bill Kleindl.

However, I would like to particularly acknowledge Dennis Neuman, Affiliate Professor of Land Resources and Environmental Science, Montana State University, as the godfather of this restoration work. I don't think that I could have gotten this done without his groups' development of the STARS protocols for adjusting soil pH on restoration sites, or without his ongoing cheerful support of both my career and my apparently never-ending academic interests.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

GLOSSARY

Both (Native and Introduced species): Ambiguity exists over whether a species is truly Native, introduced to a new local, or an indiscernible mix of Native and Introduced populations. For instance, a species such as dandelion (*Taraxacum officinale*) has some intra-taxa that are native but some that are introduced to this continent (United States Department of Agriculture [hereafter, USDA] PLANTS 2019a). As a result, it is categorized as Both (USDA PLANTS 2019d).

Introduced (species): Arrived in North America after Columbus from some other part of the world, invariably with human assistance. Introduced plants reproduce spontaneously in the wild without help from humans (USDA PLANTS 2019a).

Invasive (species): Successfully and aggressively spreading (Richardson et al., 2000).

Native (species): Naturally occurring in North America at the time of Columbus (USDA PLANTS 2019a).

Naturalized (species): Self-perpetuating in a new local (Richardson et al., 2000).

Non-native (species): <u>Not</u> naturally occurring in North America at the time of Columbus.

Novel assemblage(s): New combinations of species that arise through human action, environmental change, and the impacts of the deliberate and inadvertent introduction of species from other regions (Hobbs et al., 2006).

Pest (species): Causing or has the potential to cause severe economic or ecological harm (Richardson et al., 2000).

pH: The measure of the proton (H^+) activity and therefore of proton concentration in solution (Sorenson 1909).

Transformer (species): A species that is changing or has the potential to change the organization and functions of an ecosystem in a substantial way (Richardson et al., 2000).

Weed (species): A plant species that was non-native, but is now (simultaneously) naturalized, invasive, a transformer and a pest. Also, “A plant that has mastered every survival skill except for learning how to grow in rows (Larson n.d.).”

ABSTRACT

My case study considers the Block P Mill and Tailings Site (also, Block P or the Site), a derelict lead and zinc production facility in the Little Belt Mountains of Montana. Fifteen years after environmental restoration activities concluded at this heavily contaminated site, I analyzed whether the canopy cover of plant species correlates with soil pH conditions. Specifically, I investigated whether addressing acidic conditions during mine-site restoration encouraged the presence of oxeye daisy (*Leucanthemum vulgare*), a non-native invasive plant species. Fieldwork in June 2019 included collection of soil pH and vegetation canopy cover data from 36 quadrats (6 m x 6 m) arrayed across this 6.6-ha restoration site. A Canonical Correspondence Analysis (CCA) of these data shows no statistically significant relationship between soil pH and overall plant species' canopy cover values. Further, linear regression analysis shows no statistically significant relationship between soil pH and the canopy cover of oxeye daisy. Therefore, it is unlikely that differences in the soil pH across the Site unevenly affect the canopy cover of plant species or unduly encourages the presence of oxeye daisy. These results are a reminder, however, that if restoration returns fertility to a previously barren and inhospitable site, the presence of novel assemblages of non-native and native plant species also may be generally encouraged, including invasive species such as oxeye daisy. I therefore conclude that the treatment of invasive plants at restoration sites like the Block P are a required managerial choice, not a philosophical imperative.

INTRODUCTION

We live in the Anthropocene, a geological age in which human activities such as deforestation, fossil fuel combustion, and land-use changes constitute the dominant ecological drivers (Crutzen 2006). For example, mining directly disturbs an estimated 0.4 Mkm^2 of earth's surface (Hooke et al., 2012), an area greater in size than the state of Montana (United States Census Bureau 2019). The release of heavy metals and acid-rock drainage often exacerbates direct mining effects, leading to further losses of biodiversity and reductions in ecosystem services (Muthusaravanan et al., 2018; Murguía 2015; Kabata-Pendias 2001).

One response to such widescale disturbances is the development of a field of study dedicated to the science and practice of ecological restoration (Bullock et al., 2011; Jordan and Lubick 2011; Suding 2011). Due to the breadth and severity of impacts, the restoration of mine sites and their contaminated soils is of major emphasis in this field (Sonter et al., 2018, Wong 2003; Ye et al., 2000). In addition to soil chemistry issues, mine sites typically exhibit highly disturbed substrates (Bradshaw 1997; Munshower 1994), which are conducive to the presence of invasive plant species that share traits like rapid, early growth, and copious seed dispersal (Grime 1979; MacArthur 1972; Gurevitch et al., 2018). As a result, a key area of concentration in the study and practice of mine-site restoration focuses on the management or elimination of invasive plant species (Simberloff 2015). Without controls, invasive plants can come to dominate restoration sites, thwarting reestablishment of the historical ecological trajectory of a site or an ecosystem (Simberloff 2015; Murcia et al., 2014).

Given such potential problems, the treatment and control of non-native invasive species on mine restoration sites always would seem warranted, but in truth, presents an interesting ecological conundrum. If a heavily contaminated mine site had nothing growing on it before, is the presence after restoration of successfully growing, non-native invasive plant species a truly objectionable situation (Perring et al., 2014; Dooley and Audet 2013; Hobbs and Harris 2001)?

Indeed, ecologists regularly argue whether the presence of an unexpected plant on a restoration site is just an indication of ecologically acceptable, spontaneous succession (Prach and Hobbs 2008; Hobbs and Harris 2001). This contentious issue has become more complex, however, as novel assemblages of plants (groups of non-native plant species growing successfully in new habitats) are more common in the Anthropocene than in the past (Humair et al., 2014; Webber and Scott 2012; Davis et al., 2011). Some authors contend that the global spread of these novel assemblages renders moot the return of ecosystems or sites to their historic state or trajectory (Hobbs et al., 2009; Seastedt et al., 2008; Hobbs et al., 2006). Others counter that the impediments to controlling novel assemblages are only political and economic, not technological or scientific (Simberloff 2015) and that the defense of the novel plant assemblage concept is disingenuous at best and fatalistic at worst (Murcia et al., 2014; Simberloff et al., 2011). In short, the decision whether to control individual or clusters of non-native invasive plants on restoration sites is a current subject of significant philosophical and practical disagreement.

BACKGROUND

This case study examines soil and vegetation conditions at a 6.5 ha, severely disturbed mining location, the Block P Mill and Tailings Site, Montana. The case study considers the potential influence of post-restoration soil pH on the canopy cover of vascular plant species, with a focus on the non-native invasive plant species, oxeye daisy (*Leucanthemum vulgare*). Although this project concerns only a single, small mine site high in the Rocky Mountains, it affords a glimpse into the broader philosophical issues in restoration and novel assemblage ecology in a time of global, anthropogenic change.

Study Area: Block P Mill and Tailings Site

The Block P Mill and Tailings site (hereafter, Block P or the Site) is located at approximately 1683 m above mean sea level in the Little Belt Mountains of Cascade County, Montana, roughly 64 km southeast of Great Falls, Montana (Figure 1). The main body of the Site (approximately 5.6 ha; also often called the Block P Mill Tailings site) is positioned just upstream of the confluence of Galena Creek and the Dry Fork of Belt Creek and includes the historic mill location, the main tailings repository and the upper tailings impoundment (United States Department of Agriculture Forest Service [hereafter, USFS] 1995; Figure 1). The project area also includes an approximately 0.9 ha tailings impoundment/settling basin (also often called the Bender Creek Tailings or Bender Creek Streamside Tailings site) about 2.4 km downstream of the main body of the Site (USFS 1995; Figure 1).

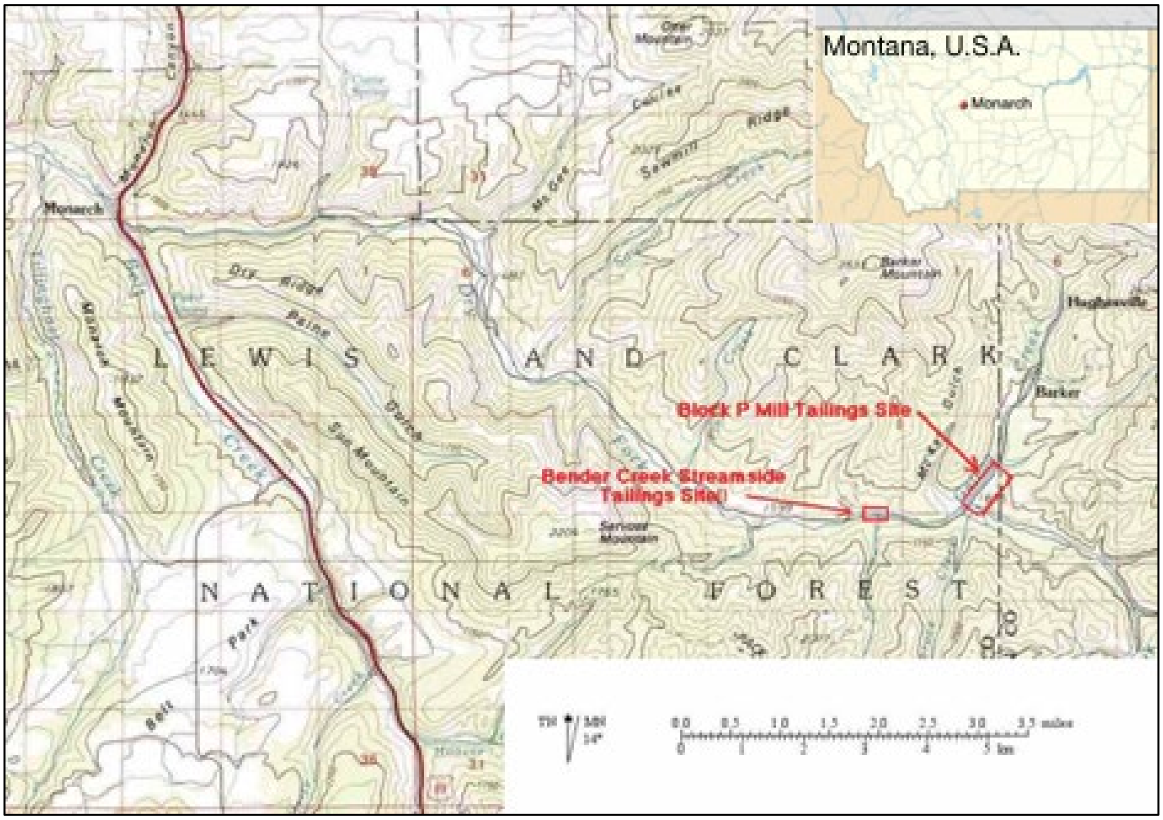

Figure 1. Block P location (Thompson and Massey 2005)

The approximate center of the Block P Mill Tailings Site is at 47.055938° N, -110.647855° W. The approximate center of the Bender Creek Streamside Tailings site is at 47.052269° N, -110.671184° W. Via Forest Service Road 120 (FS 120), the Site lies approximately 16 km east of U.S. Highway 89 at Monarch, Montana, the nearest permanent population center (Environmental Protection Agency [hereafter, EPA] 2002; Figure 1).

Geology

An eastern outcrop of the Northern Rocky Mountains, the Little Belt Mountains comprise a broad, dome-shaped arch between Great Falls and Lewistown, Montana (Alt and Hyndman 1997). The mountain range consists of Archean gneisses and schists, underlain and folded with sedimentary rocks ranging in age from Cambrian to Cretaceous (Montana Department of Environmental Quality [hereafter, MT DEQ] 2019). Laccoliths (intrusive igneous outcrops) form a group of circular buttes in the northern part of the Little Belt Mountains. Such intrusions and the igneous conditions that formed them metamorphosized the surrounding sedimentary rocks (Alt and Hyndman 1997), leading in part to the presence of argentiferous (silver-bearing) galena (lead) ore for which the Hughesville Mining District is known (MT DEQ 2019).

Climate

The average temperature in Monarch, Montana, is 5.4°C, with average highs in August of 16.7°C and average lows in January of -5.0°C (Weatherbase.com 2019). The average precipitation in Monarch is 54 cm, with the greatest average precipitation occurring in June (90 mm) and the least in February (15 mm) (Weatherbase.com 2019). The average wind speed at Great Falls, Montana, the site of the closest major airport, is 18.5 km/h, typically from the southwest (Iowa Environmental Mesonet 2019).

Area Vegetation

Per Arno (1979), Block P lies within the Central Montana Forest Region, where forests at the Site's elevation are lodgepole pine (*Pinus contorta*) and Douglas-fir (*Pseudotsuga menzesii*). Non-forest uplands in this region are potentially grassland, dominated by bluegrass (*Agropyron* spp.) and fescue (*Festuca* spp.) species (Arno 1979). Woody riparian areas in the area are dominated by black cottonwood (*Populus balsamifera* L. ssp. *trichocarpa*) or shrubs such as mountain alder (*Alnus incana*), water birch (*Betula occidentalis*) or a variety of willows, including Drummond willow (*Salix drummondiana*), Bebb willow (*Salix bebbiana*), Booth willow (*Salix boothii*) and sandbar willow (*Salix exigua*) (Mincemoyer and Birdsall 2006). Major riparian grass species in the area include tufted hairgrass (*Deschampsia cespitosa*), beaked sedge (*Carex rostrata*), and bluejoint reedgrass (*Calamagrostis canadensis*) (Mincemoyer and Birdsall 2006).

Site History

Block P is a central point of the Barker-Hughesville Mining District of the Little Belt Mountains, Montana. Following the 1879 discovery of argentiferous lead-carbonate deposits in the Galena Creek drainage by E. A. "Buck" Barker and Patrick H. Hughes, hundreds of mining claims were established in the district (Weiser 2017). By the early 1900s, T. C. Power of Helena acquired the Barker, Grey Eagle, and Belt mines, operating the group under the name of the Block P Mine (MT DEQ 2019). Power built a mill at Barker in 1910-1911, subsequently selling it to St. Joseph Lead Company in 1927. By 1928, the St. Joseph Lead Company had replaced the earlier infrastructure with a 400-ton selective flotation mill, making the facility the largest producer of lead in the state by 1929 (MT DEQ 2019). By late 1930, however, the mill was shut down due to the economic effects of the Great Depression. Although functioning briefly in the early 1940s, the facility did not process minerals after 1943 (Weiser 2017).

The separation of zinc and lead ore from waste rock within the mills at Block P produced approximately 141,443 m^3 of tailings material (Barr Engineering Company 2010 and 2001). Such tailings were both strongly acidic (average pH of 3.3), and contained elevated levels of arsenic, cadmium, copper, lead, and zinc (EPA 2002). As a result of these substrate conditions, mine tailings at Block P remained unvegetated following mill closure in the 1940s, presenting ongoing threats to human health and the environment due to erosion and leaching of contaminants of potential concern (EPA 2002).

Given such problems, in 1995 the USFS initiated a time-critical CERCLA (Comprehensive Environmental Response, Compensation, and Liability Act of 1980) removal action (EPA 2002; USFS 1995). While conducting the time-critical phase of the clean-up, the USFS identified The Doe Run Company (hereafter, Doe Run), the direct corporate successor of the St. Joseph Lead Company, as the responsible party for this location. In response, between 1995 and 2001, Doe Run and its subcontractor, Barr Engineering, prepared an Engineering Evaluation and Cost Analysis (EE/CA) for an additional clean-up of this Site (EPA 2002). The USFS approved the EE/CA in 2002, and Doe Run implemented the recommended non-time critical removal action alternative between 2004 and 2006, including consolidation of tailings, re-routing of active runoffs, regrading, capping, soil amendments and revegetation (Barr Engineering Company 2010).

Soil Amendments, pH, and Revegetation

Bitterroot Restoration, Inc., designed the soil amendment and revegetation protocols in 2004-2005 (Thompson and Massey 2005) and subsequently performed the restoration work in 2005-2006, with subcontracting by Arrowhead Reclamation and oversight by Barr Engineering Company. For planning and implementation, the Site was broken into nine different Restoration Areas (Table 1; Figures 2 and 3) based on generalized habitat potential. Approximately 21% of the site was planned for riparian habitat, 51% mixed upland and riparian habitat, and 28% upland habitat (Thompson and Massey 2005).

Table 1. Restoration Areas at Block P (Thompson and Massey 2005)

Restoration Area	Hectares	Habitat
Galena Creek Riparian Zone	0.4	Riparian
Migrated Tailings Area south of Rd 120 (lower unit)	0.1	Riparian
Lower Diked Tailings Area	1.6	Mixed Upland/Riparian
Migrated Tailings Area north of Rd 120 (upper unit)	0.7	Mixed Upland/Riparian
New Stream Channel north of Repository	1.0	Mixed Upland/Riparian
Mill Foundation Area	0.2	Upland
Tailings Repository Cap	0.9	Upland
Skirt Slope and Haul Road	0.7	Upland
Bender Creek Tailings	0.9	Riparian

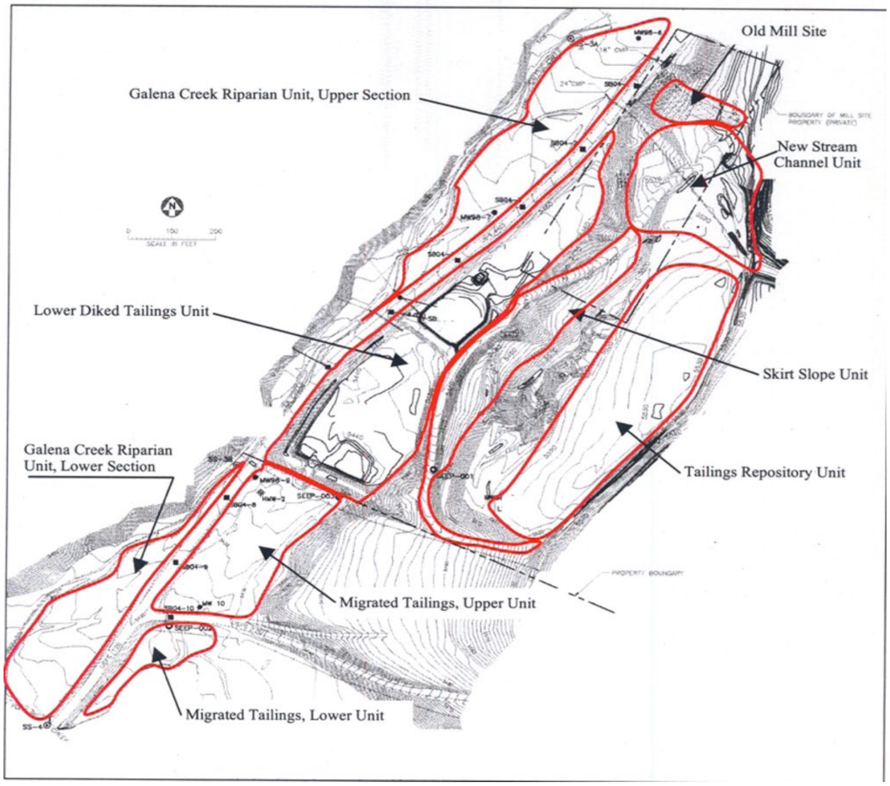

Figure 2. Restoration Areas at the main body of Block P (Thompson and Massey 2005)

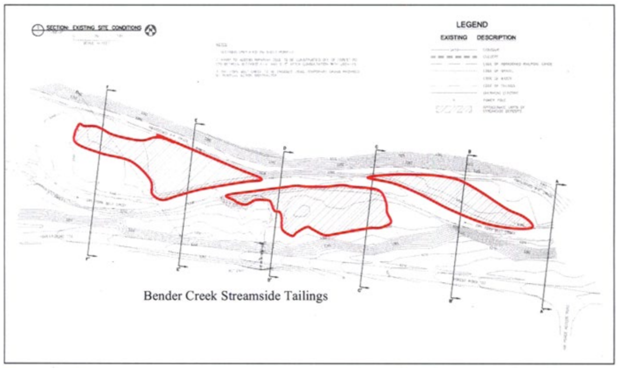

Figure 3. Bender Creek Tailings Restoration Area of Block P (Thompson and Massey 2005)

A primary goal of restoration at Block P was to create a growing zone amenable to plants. Other projects use stockpiled or borrowed topsoil for this purpose (Munshower 1994); however, topsoil was not available in sufficient quantities near Block P to permit this approach. Instead, the only available planting media were existing subsoils, plus crushed rock from the New Stream Channel area and another nearby borrow pit. Crushed rock was either placed onto or incorporated into the subsoils at the Block P Restoration Areas, yielding a range of planting media with a variety of potential problems, including low to neutral pH values (Table 2), plus existing (SMP lime buffer acidity [Shoemaker, McLean, and Pratt 1961]) acidity and potential (sulfur) acidity (Table 3). Other issues in the planting media included elevated heavy metal concentrations, lack of organic materials and a dearth of plant nutrients.

Table 2. Soil pH conditions in planting media at Block P after removal actions but before amendments (Barr Engineering 2005; The Doe Run Company 2004)

	Soil pH		
Restoration Areas	Minimum	Average	Maximum
Galena Creek Riparian Zone	5.3	7.0	7.5
Migrated Tailings Area south of Rd 120 (lower unit)	n/a	6.1	n/a
Lower Diked Tailings Area	3.3	6.3	n/a
Migrated Tailings Area north of Rd 120 (upper unit)	2.9	5.0	7.0
New Stream Channel north of Repository	5.8	6.9	7.7
Mill Foundation Area	2.7	5.8	7.8
Skirt Slope and Haul Road	n/a	7.0	n/a
Tailings Repository Cap	5.8	6.6	7.7
Bender Creek Tailings	5.9	6.6	7.6
pH Values within Restoration Areas	4.9	6.3	7.3

Table 3. Existing and potential soil acidity in planting media at Block P after removal actions but before amendments (Barr Engineering 2005; The Doe Run Company 2004)

	SMP Lime Buffer tons/kton	HNO_3 Sulfur percent	Residual Sulfur percent	HCl Sulfur percent
Galena Creek Riparian Zone	1.60	0.19	0.03	0.02
Migrated Tailings Area south of Rd 120 (lower unit)	3.50	1.18	0.10	0.04
Lower Diked Tailings Area	2.40	0.18	0.02	0.03
Migrated Tailings Area north of Rd 120 (upper unit)	5.00	0.14	0.01	0.01
New Stream Channel north of Repository	0.55	0.00	0.00	0.00
Mill Foundation Area	2.60	0.72	0.18	0.11
Tailings Repository Cap	0.55	0.00	0.00	0.00
Skirt Slope and Haul Road	5.00	0.14	0.01	0.01
Bender Creek Tailings	1.30	0.05	0.01	0.03

To address both general and spot-specific concentrations of soil acidity, the restoration plan (Thompson and Massey 2005) called for an amendment of planting media to 20-31 cm in all Restoration Areas using lime (calcium carbonate). The goal was to ameliorate both existing and potential acidity, ending with growth medium pH values in the range of 6.5 to 7.0 standard units, which presents good growing conditions for many plants (Boul et al., 1989). pH was chosen as a central guide for soil amendments as this characteristic is a "master variable" in soils (McBride 1994). pH is a measure of the proton (H^+) activity, and therefore of proton concentration in solution (Sorenson 1909). As such, it helps to control ion mobility, precipitation and dissolution equilibria, precipitation and dissolution kinetics, and oxidation-reduction equilibria (Bloom 2000). pH both influences soil nutrient availability and has direct effects on plants (Small 1954; Boul et al., 1989; Marschner 1995). It also has a direct effect on heavy metal chemical form and bioavailability (Bolan et al., 2003). Scientists often analyze soil pH as a continuous environmental variable. However, plant effects also can be related to different categories of soil pH (Boul et al., 1989; Table 4).

Table 4. Categorical pH effects in soils (Boul et al., 1989)

pH Level	Soil Conditions
3.5 and less	Extreme acidity, acid sulfates present
3.5 - 4.5	Acidity, plus high values of exchangeable aluminum
4.5 - 5.8	Sufficient exchangeable aluminum to affect plant growth, and low percentage base saturation
5.8 - 6.5	Sufficient protonated hydrogen to influence acid-sensitive plants
6.5 - 8.5	Soil strongly base saturated and limited exchangeable aluminum, good conditions for many plants
8.5 - 10.0	Significant presence of soluble salts, high electrical conductivity, influence on salt-sensitive plants
10.0 and greater	Sodium saturated (alkali), good conditions only for tolerant plants

Protocols for addressing acidic soils at Block P followed lime amendment rates from the Streambank Tailings and Revegetation Treatability Study (STARS) developed by Schafer and Associates and the Reclamation Research Unit of Montana State University [hereafter, SA and RRU] 1989). Lime (calcium carbonate) was surface-spread at different rates for each Restoration Area (Table 5) and then disked and harrowed to a common depth of 20-31 cm. Additional soil amendments added at the same time as liming included compost and Biosol, a slow-release organic fertilizer (Thompson and Massey 2005).

Table 5. Soil liming prescriptions at Block P (Massey 2006)

Restoration Area	Lime Addition (metric ton/ha)
Galena Creek Riparian Zone	56
Migrated Tailings Area south of Rd 120 (lower unit)	291
Lower Diked Tailings Area	119
Migrated Tailings Area north of Rd 120 (upper unit)	164
New Stream Channel north of Repository	3
Mill Foundation Area	211
Skirt Slope and Haul Road	39
Tailings Repository Cap	4
Bender Creek Tailings	26

Following soil amendments, the Restoration Areas were seeded using different herbaceous (grass and forb) mix for the riparian and upland areas, and a combined palette for the mixed habitat areas (Thompson and Massey 2005). The Restoration Areas then were planted using site-specific combinations of containerized woody plants and graminoid plug seedlings (Thompson and Massey 2005). Restoration activities occurred at Block P in fall 2005 and summer 2006. In no cases, however, was oxeye daisy included as a part of the soil amendment, seeding, planting, or other restoration prescriptions. Yet, by 2007 this non-native, invasive plant species already had gained a muted, but widespread foothold at the Site. Concerns about the expanded presence of this species at Block P through 2019 led to this study.

Oxeye Daisy

Oxeye daisy, a member of the Asteraceae family, is a perennial herb, sporting white ray florets and yellow disc florets (Figure 4). The plant is part of a large species complex that ranges through most of Europe and western Asia. Mitich (2000) describes the oxeye daisy as "beloved by prince and peasant in the Orient and the Western world." For example, for her marriage in 1445 to Henry VI, Margaret of Anjou reputedly had oxeye daisies embroidered on her robes and those of her entourage (Haughton 1978).

Figure 4. Oxeye daisy (*Leucanthemum vulgare*) (source: Howard [Smithsonian Institution] 2019 in USDA PLANTS 2019b)

However, early European horticultural societies also identified the oxeye daisy as an undesirable, aggressively spreading species (Sanders 1993). Each oxeye daisy plant can produce about 26,000 achenes under optimal conditions (Salisbury 1942), although production under more-typical conditions is 251 seeds per inflorescence (Coulson et al., 2001) or 1,300-4,000 seeds per plant (Dorph-Petersen 1925). Due to its fecundity, oxeye daisy had become established across much of North America by as early as 1800 (Clements et al., 2004). Botanists first reported the presence of oxeye daisy in the Montana Territory in 1883 (Consortium of Pacific Northwest Herbaria 2019). Currently in the state of Montana, the species occupies roadsides, seeded pastures, meadows, and forest openings, ranging from valleys to mountainous settings (Lesica 2012, Olson et al., 1997).

The plant's large seed production, long seedbank viability, perennial mature-plant presence, and phenotypic plasticity provide oxeye daisy its competitive advantage as an invasive species. Disturbance conditions that lead to the removal of existing vegetation particularly can result in the development of dense stands of oxeye daisy (Burke and Grime 1996). In livestock pastures, this presence can be long-term, as this species is less desirable as a grazing species than other forage plants (Gilkey 1957). Even if oxeye daisy populations ultimately succumb to competition by grasses and other species, however, a substantial seed bank is left behind, permitting re-emergence if future disturbance occurs (Clements et al., 2004).

As a result of such characteristics, oxeye daisy is listed as a Priority 2B weed in Montana (The State of Montana 2019), abundant and widespread in many counties, requiring eradication or containment where less abundant (Montana Department of Agriculture 2019). To date, the species occurs at 23 reported locations in Cascade County, Montana (EDDMapSWest 2019). In Cascade County, oxeye daisy is considered a Category 3 Noxious weed, i.e., so well established and spread to such an extent that eradication in the county is no longer possible, although the county considers preventing the spread of this weed to new sites as both feasible and desirable (Cascade County 2018).

Most critical to concerns at Block P, some authors have found oxeye daisy growing most commonly on slightly basic or somewhat neutral soils, versus strongly acidic soils (Howarth and Williams 1968). In its native, central European habitats, oxeye daisy often occurs on calcareous pastures with basic soil pH conditions (Hess et al., 1972; Oberprieler 2011). Similarly, Cole (1998) found oxeye daisy growing on pasture lands in western Alberta in soil pH ranges of 5.9 to 6.1. USDA PLANTS (2019b) describes the soil pH growth range for oxeye daisy as extending from 5.2 to 7.0, but Ferdinandsen (1918), who first classified the oxeye daisy as a basophile (base soil pH loving plant), suggested a tighter pH range of 6.5 to 7.0 for optimal growth. Also pertinent to its presence at Block P, some ecologists suggest that oxeye daisy is not tolerant of soils that are heavily contaminated by heavy metals (Ryser and Emerson 2007), indicating that the species would not appear where reclamation was unsuccessful.

As a result, restoration activities at Block P may have prepared optimal conditions for the growth of oxeye daisy. As previously discussed, the primary purpose of soil amendments was to create a planting medium with a pH within the range of 6.5 to 7.0 standard units, exactly the soil pH range (6.5 to 7.0) suggested by Ferdinandsen (1918) for optimal oxeye daisy growth. Additionally, lime addition catalyzed these soil chemistry changes, also creating calcareous conditions that mimic the soils of oxeye daisy’s native, central European habitats. Further, disking and harrowing soils to a depth of 20-31 cm removed competition and created substantial disturbance conditions highly amenable to invasive plant species such as oxeye daisy.

Given these factors, in addition to the oxeye daisy’s ubiquity in Cascade County (EDDMapSWest 2019; Cascade County 2018), there should be no surprise that oxeye daisy subsequently has grown in multiple Restoration Areas at the Site (Massey 2007). In recent seasons, however, oversight officials with the EPA and the USFS observed a worrisome expansion of this species at Block P (Hoogerheide, pers. com. 2019; Opp, pers. com. 2019). In great part, such concerns about the spread of oxeye daisy on Site led to this research paper.

HYPOTHESES

In this case study, I investigate two ecological issues at Block P. First, does soil pH affect the canopy cover of plant species on the Site? Second, does soil pH affect the canopy cover of oxeye daisy on the Site? These two questions are addressed, respectively, with the following two sets of hypotheses:

- $H1_o$: At Block P, plant species canopy cover values are not significantly correlated with soil pH at an alpha = 0.05
- $H1_a$: Not $H1_o$

- $H2_o$: At Block P, oxeye daisy canopy cover is not significantly correlated with soil pH at an alpha = 0.05
- $H2_a$: Not $H2_o$

METHODS

Field sampling occurred at Block P from June 16-21, 2019. Both vegetation and soil sampling took place at the same quadrat locations as those used in multiple vegetation inventories beginning in 2007 (Massey 2008 and 2007, Massey and Thompson 2010 and 2009).

Monitoring

In July 2007, monitoring teams established a total of 36 quadrats (6 m x 6 m), randomly distributed across nine Restoration Areas at Block P (Massey 2007). The six smallest Restoration Areas received one set of three quadrats, and the remaining received two sets of three quadrats to allow for more sampling in larger Restoration Areas (Table 6).

Table 6. Revegetation monitoring locations at Block P (2007-2019) (Thompson and Massey 2005)

Restoration Areas	Quadrat Sets	Total Quadrats
Galena Creek Riparian Zone	1	3
Migrated Tailings Area south of Rd 120 (lower unit)	1	3
Lower Diked Tailings Area	2	6
Migrated Tailings Area north of Rd 120 (upper unit)	1	3
New Stream Channel north of Repository	1	3
Mill Foundation Area	1	3
Tailings Repository Cap	2	6
Skirt Slope and Haul Road	1	3
Bender Creek Tailings	2	6
TOTALS	12	36

Except where constrained by Restoration Area shape, the monitoring teams established three quadrats (6 m x 6 m) in Restoration Areas along randomly placed 50-m transects, beginning at the randomly selected points of 5, 28, and 42 m. The monitoring teams randomly placed quadrats to a selected side of the transect (Figure 5). The teams marked the origin point of the quadrats along the transects with a labeled stake and quadrats were documented via GPS and photographs. These marking stakes were still present in all Restoration Areas in 2019.

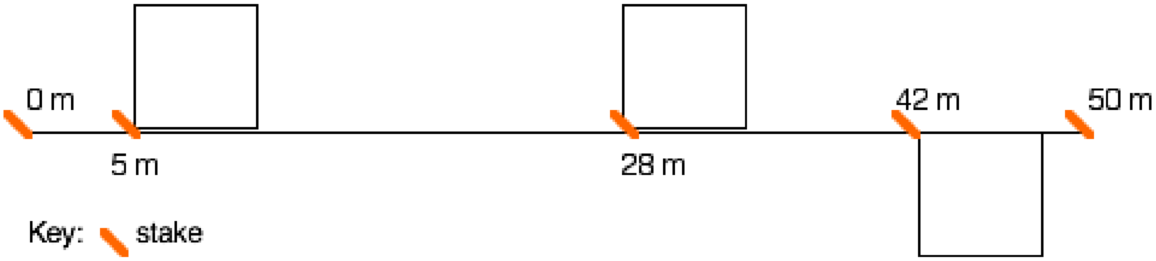

Figure 5. Typical transect layout at Block P (Massey 2007)

Due to the small sizes and non-homogenous shapes of Restoration Areas within the Galena Creek and Migrated Tailings Area South of Route 120, it was not possible to establish transects or quadrats consistent with the other units. Instead, within the Galena Creek area, monitoring teams distributed quadrats (6 m x 6 m) randomly within three major subareas of soil amendment and planting. Within the Migrated Tailings Area South of Route 120, monitoring teams established one quadrat (2 m x 18 m) parallel to Forest Road 120 at the southern end of the Restoration Area, and two quadrats (6 m x 6 m) at the north end of the Restoration Area.

Vegetation Monitoring

Within all quadrats, the canopy cover of individual plant species were visually estimated by category per Daubenmire (1959) and the USDA ECODATA program (USFS 1989). When field identification was not possible, plant samples were collected. Subsequent plant species identification followed Lesica (2012) and Cronquist et al. (2012).

Soils Analysis and Monitoring

As part of the 2019 monitoring effort, soil pH was determined within each quadrat by dibbling a 20-cm deep hole in the soil, filling the hole with distilled water, and then, after approximately 5 minutes equilibration, directly testing the pH in the hole using a Hanna (HI12922) HALO™ pH Probe (Hanna Instruments 2019). Within each of the 36 quadrats, pH readings were collected in this fashion from 6 holes at an approximately 1-m grid spacing.

Data Analyses

All statistical analyses were conducted using R version 3.6.1 (The R Foundation for Statistical Computing 2019). Statistical methods included Canonical Correspondence Analysis (CCA) (Palmer 1993; ter Braak 1986) and linear regression analysis (Sheskin 2011). All analyses used an alpha = 0.05 level threshold for determination of statistical significance (Cochran and Cox 1992).

CCA is a form of direct gradient analysis based on multiple regression (Palmer 1993; ter Braak 1986). CCA permits the investigation of the effect of independent variable on multiple dependent variables, such as the effect of soil pH on the canopy cover of multiple species considered in this case study. CCA is used in part because its results are not beset by the arch effects found in Correspondence Analysis (CA) or Detrended Correspondence Analysis (DCA) that are due to data self-correlation (Jongman et al., 1995). A major weakness of CCA, however, is that the number of independent variables investigated must be fewer than the number of dependent variables (Jongman et al., 1995). Given that only a single independent variable is being tested (soil pH) versus a large number of multiple dependent variables (the canopy cover of over 130 plant species present on Site), this weakness is not pertinent to the analysis in this study.

Simple linear regression (SLR) analysis investigates the relationship between two variables (Sheskin 2011), such as the relationship between soil pH and the canopy cover value of oxeye daisy considered in this case study. Violations of data linearity or the constant variance assumption can cause problems in the use of SLR (Ramsey and Schaefer), however, SLR was used due to its simplicity and its robustness in the face of data normality or independence issues (Ramsey and Schafer 2013).

RESULTS/DISCUSSION

Soil pH

Fifteen years after amendment, soils at Block P exhibited an average pH of 7.65 (Table 7), with 96% of individual sample points across Block P showing a soil pH in the range of 6.5 to 8.5 standard units. While there are a few, isolated pockets with soil pH values lower than 6.5 (Table 7), current soil pH conditions at Block P were mostly within the range that presents good growing conditions for many plants (Boul et al., 1989), but slightly above the soil pH range (6.5 to 7.0) suggested by Ferdinandsen (1918) for optimal oxeye daisy growth.

Table 7. Soil pH values by Restoration Areas at Block P (2019)

Restoration Areas	Min	Average	Max
Galena Creek Riparian Zone	7.07	7.84	8.11
Migrated Tailings Area south of Rd 120 (lower unit)	6.82	7.62	8.08
Lower Diked Tailings Area	3.41	7.54	8.00
Migrated Tailings Area north of Rd 120 (upper unit)	5.88	7.79	8.26
New Stream Channel north of Repository	7.68	8.02	8.29
Mill Foundation Area	7.02	7.49	7.80
Skirt Slope and Haul Road	4.55	6.80	7.90
Tailings Repository Cap	7.11	7.98	8.37
Bender Creek Tailings	6.87	7.63	8.50
pH Values within Restoration Areas	6.27	7.65	8.15

Plant Species Statistics

The following section presents vascular plant species (hereafter, plant species) data collected at the 36 quadrants of Block P in 2019. The identity of plants as Native, Introduced, or Both follows USDA Plants (2019a) categorizations (Note: Both are species that are possibly Introduced, but also possibly Native [USDA PLANTS 2019a]). I could not identify seven discernably different forb samples to specific genus and species, so both their identity and their native origin are Unknown (Tables 8 and 9). All of these Unknown samples, however, exhibited a canopy cover of 1% per quadrat or less, so their influence on the overall results is minimal.

Plant Species Richness

Across Block P in 2019, 135 different plant species were present, with forbs accounting for nearly two-thirds of plant species present, followed distantly by graminoids, shrubs, and then trees (Table 8). Native plants accounted for more than two-thirds of the count of species present, although Introduced plants accounted for more than one-fifth of species present (Table 8).

Table 8. Average plant species count by native status at Block P (2019)

Native Status	Trees	Shrubs	Graminoids	Forbs	Total
Native	6	17	18	51	92
Both	0	0	2	5	7
Introduced	0	0	7	22	29
Unknown	0	0	0	7	7
Totals	6	17	27	85	135

Plant Species Canopy Cover

In 2019, total canopy cover by plant species averaged 84% across all Restoration Areas at Block P, with graminoids accounting for more than 50% of plant canopy cover present, followed distantly by the canopy cover of forbs, shrubs and then trees (Table 9).

Native plants accounted for approximately two-thirds of the total canopy cover present, with Introduced/Both species together accounting for approximately one-third of total canopy cover present (Table 9).

Table 9. Summed plant species canopy cover (percent) by native status at Block P (2019)

Native Status	Trees	Shrubs	Graminoids	Forbs	Total
Native	6	9	28	7	50
Both	0	0	5	2	7
Introduced	0	0	21	5	27
Unknown	0	0	0	0.4	0.4
Totals	6	9	54	15	84

In the past 15 years since restoration, total vegetation canopy cover at Block P has increased steadily from 2007 to the present (Table 10). Even more strikingly, the average 84% canopy cover at Block P represents an enormous increase from the depauperate conditions found at the Site before restoration, when vegetative canopy cover was essentially 0 (zero) due first to the presence of contaminated mine tailings and then to restoration-related construction activities.

Table 10. Summed plant species canopy cover (percent) by Restoration Area at Block P (2019)

Restoration Areas	2007	2008	2009	2010	2019
Galena Creek Riparian Zone	53	57	67	67	78
Migrated Tailings Area south of Rd 120 (lower unit)	86	106	83	70	109
Lower Diked Tailings Area	60	57	75	53	80
Migrated Tailings Area north of Rd 120 (upper unit)	63	56	83	63	77
New Stream Channel north of Repository	20	38	53	67	76
Mill Foundation Area	30	24	73	60	79
Skirt Slope and Haul Road	20	26	50	63	82
Tailings Repository Cap	15	17	40	50	77
Bender Creek Tailings	85	83	90	65	97
Averages	48	49	67	62	84

CCA Results: Soil pH versus Plant Species Canopy Cover

Although the post-restoration increase in vegetative canopy cover at Block P is encouraging, the open questions from this paper remain, namely whether plant species canopy cover (in general and specifically those of oxeye daisy) are correlated with post-reclamation soil pH conditions. The following section addresses the first question, presenting the results from a gradient analysis (CCA) of soil pH and total canopy cover data from Block P in 2019. Figure 6 displays the results as joint plots of CCA species' scores and the eigenvector for soil pH. As this analysis examines only one environmental variable, the x-axis along CCA1 (Axis 1) indicates the response of plant species' canopy cover values to soil pH values. The absence of a cluster of plants along this soil pH vector (Figure 6) suggests that species canopy cover values are not significantly responding to this environmental gradient.

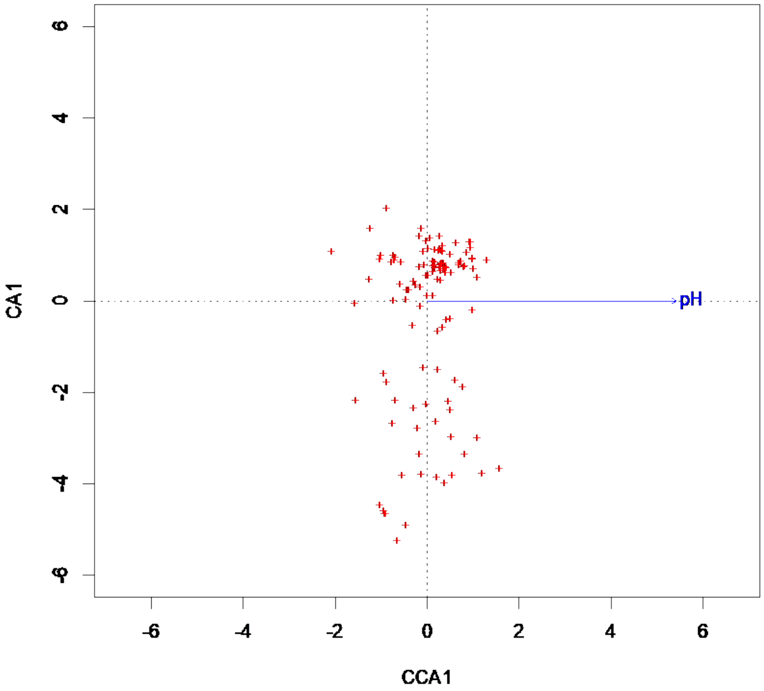

Figure 6. 2D joint plot: CCA of soil pH and plant species canopy cover at Block P (2019)

The apparent lack of a strong relationship between soil pH and plant canopy cover is revealed further in Table 11, which presents the quantitative results of the CCA per Jongman et al. (1995) and ter Braak (1988). These data clearly show that plant canopy cover does not significantly trend with soil pH (Axis 1: CCA1). Indeed, soil pH alone explains very little (only approximately 3.4%) of the variability of plant species' canopy cover data at Block P in 2019 (Table 11). Otherwise, the proportion explained by CCA1 (Axis 1) would be higher, and the plant species canopy cover values would be more strongly clustered along the soil pH vector shown in Figure 6.

Table 11. CCA results: soil pH and plant species canopy cover at Block P (2019)

		Inertia[1]	Proportion[2]
Total		6.679[3]	1.00000
Constrained[4]		0.227	0.03398
Unconstrained[4]		6.452	0.96602
	Axis 1	**Axis 2**	**Axis 3**
Eigenvalue[5]	0.22697	0.7622	0.5596
Proportion explained	0.03398	0.1141	0.0838
Cumulative proportion	0.03398	0.1481	0.2319

[1] Inertia is analogous to the variance in the data (Palmer 2019). In this analysis, inertia is scaled Chi-square (The R Foundation for Statistical Computing 2019).

[2] Proportion is the amount of the inertia explained (de Leeuw and Mair 2009).

[3] Total inertia corresponds to the Pearson chi-square statistic for independence of the Table F with Df=(n-1)(m-1) (de Leeuw and Mair 2009)

[4] Constrained refers to the amount of the inertia that is affected by environmental variables; unconstrained refers to the amount of the inertia that is not affected by environmental variables (Palmer 2019).

[5] In mathematics, the ordination axes of a CCA are called eigenvectors. Each eigenvector has an eigenvalue, equal to the dispersion of species scores on the ordination axis and thus a measure of the importance of the ordination axis (Jongman et al., 1995). The greater the eigenvalue relative to the total inertia, the greater the importance.

Further weakening these results, ANOVAs based on multiple permutations examined, respectively, the significance of the CCA model, the significance of terms (the environmental variables), and the significance of CCA axes (Table 12). None of these analyses resulted in significant p-values at alpha = 0.05 (Table 12), indicating that the CCA model of soil pH and plant species canopy cover did not generate statistically convincing or even suggestive outcomes.

Table 12. CCA post-hoc analyses: ANOVAs of soil pH and plant species canopy cover at Block P (2019)

	Df	Chi Square	F	Pr(>F)
Permutation test for significance of CCA (999 permutations)				
Model	1	0.227	1.196	0.209
Residual	34	6.452		
Permutation test for significance of terms (999 permutations)				
Model	1	0.227	1.196	0.216
Residual	34	6.452		
Permutation test for significance CCA axes (999 permutations)				
Model	1	0.227	1.196	0.242
Residual	34	6.452		

These results strongly suggest that there is no correlation between soil pH and plant canopy cover. This also suggests that I cannot disprove the first null hypothesis ($H1_o$) of this professional paper and accept the first alternative hypothesis ($H1_a$). Simply, there is no statistically-significant evidence that post-restoration soil pH is driving overall plant species' canopy cover values at Block P.

Oxeye Daisy at Block P: Canopy Cover and Soil pH

Oxeye daisy was present at the beginning of restoration monitoring at Block P and has continued to spread across the Site (Table 13) (Massey and Thompson 2010 and 2009; Massey 2008 and 2007). Over the last 15 years, oxeye daisy was found on all Restoration Areas and is currently observed in eight out of nine Restoration Sites and 64% of sampled quadrats. Although it had only a 3% average canopy cover in 2019, this species can rapidly spread, for instance, increasing its canopy cover by 10% at the Mill

Foundation Area between 2009 and 2010 (Table 13 and Figure 7; Massey and Thompson 2010 and 2009). Further, the Migrated Tailings Area south of Rd 120 (lower unit) currently shows the highest canopy cover of this species since monitoring began in 2007 (Table 13).

Table 13. Oxeye daisy canopy cover (percent) by Restoration Area at Block P (2007-2019) (Massey and Thompson 2010 and 2009; Massey 2008 and 2007)

Restoration Areas	2007	2008	2009	2010	2019
Galena Creek Riparian Zone	1.3	0.3	1.3	2.2	0.3
Migrated Tailings Area south of Rd 120 (lower unit)	4.5	1.2	6.8	5.3	16.7
Lower Diked Tailings Area	0.0	0.0	0.1	0.1	1.2
Migrated Tailings Area north of Rd 120 (upper unit)	0.0	0.0	0.0	0.0	0.2
New Stream Channel north of Repository	0.0	0.0	0.2	3.7	3.7
Mill Foundation Area	3.0	0.5	4.5	14.3	0.2
Skirt Slope and Haul Road	0.2	0.2	0.0	0.2	0.0
Tailings Repository Cap	0.2	0.3	1.7	3.3	3.0
Bender Creek Tailings	0.0	0.0	0.0	0.0	0.7
Averages	1.0	0.3	1.7	3.3	3.0

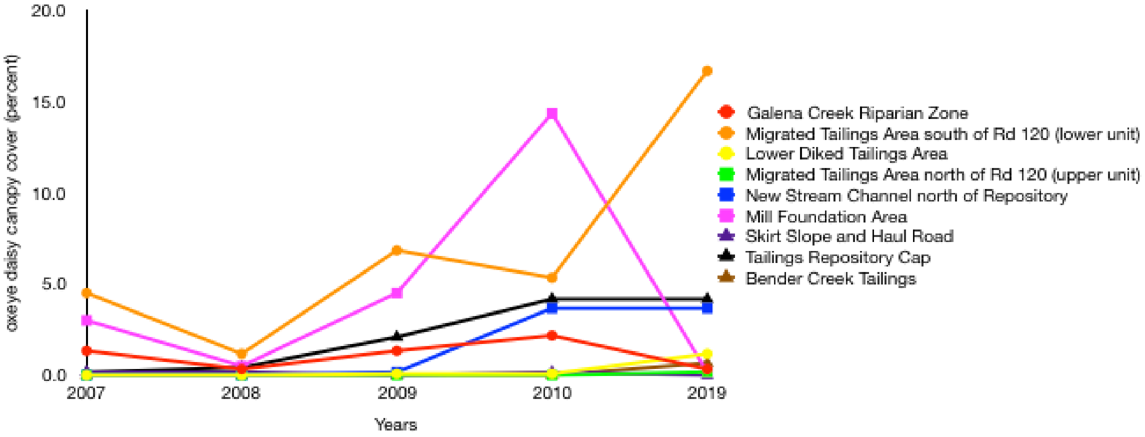

Figure 7. Oxeye daisy canopy cover (percent) by Restoration Area at Block P (2007-2019) (Massey and Thompson 2010 and 2009; Massey 2008 and 2007)

The remaining question from this paper, however, regards whether oxeye daisy canopy cover is correlated with post-reclamation soil pH conditions. The following section presents the results from a linear regression analysis of soil pH and oxeye daisy canopy cover data from Block P in 2019. As shown in Figure 8, the final predictive model was:

Equation 1. oxeye daisy canopy cover = (2.016 x soil pH) - 12.684.

However, oxeye daisy canopy cover only has a very low correlation (R^2=0.0264) with soil pH, strongly suggesting that the two factors are not correlated.

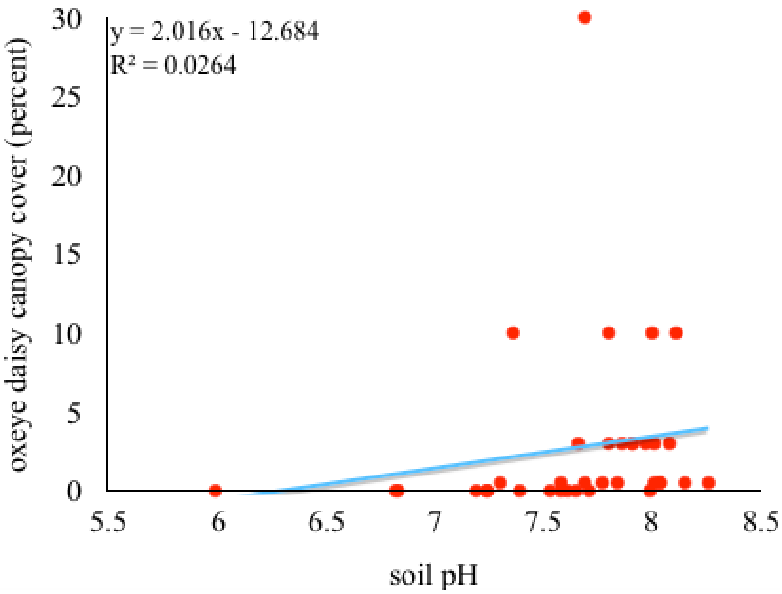

Figure 8. Soil pH versus oxeye daisy canopy cover (percent) at Block P (2019)

Further, the linear model (Table 14) was not statistically significant (F[1,34]=0.922; p-value=0.3437). In addition, soil pH did not significantly predict oxeye daisy canopy cover (β1= 2.016; p-value=0.344). These results strongly suggest that there is no significant relationship between soil pH and oxeye daisy canopy cover. This also suggests that I cannot disprove the second null hypothesis ($H2_o$) of this professional paper and accept the second alternative hypothesis ($H2_a$). Simply, there is no statistically-significant evidence that post-restoration soil pH is driving oxeye daisy's canopy cover values at Block P.

Table 14. Linear regression analysis of soil pH and oxeye daisy canopy cover at Block P (2019)

	Estimate	Standard Error	t-value	Pr(>|t|)
Intercept	-12.684	16.101	-0.788	0.436
pH	2.016	2.100	0.960	0.344

Residual standard error: 5.618 on 34 degrees of freedom
Multiple R-squared: 0.0264; Adjusted R-squared: -0.002233
F-statistic: 0.922 on 1 and 34 DF, p-value: 0.3437

CONCLUSIONS

I began this research hypothesizing that the canopy cover of plant species at Block P, particularly the non-native invasive plant, oxeye daisy, follow soil pH conditions. Instead, I found no statistically significant evidence that plant canopy cover trends with soil pH at the Site either in general or in the specific instance of oxeye daisy. These results indicate that the processes to address acidic soil conditions at this Site did not unevenly affect the canopy cover of plant species or encourage the presence of oxeye daisy. Sampling shows that lime amendments at Block P have created consistent soil pH values across the entire Site, currently presenting good conditions for the growth of many plant species (Boul et al., 1989), including oxeye daisy.

Additional future areas of research into soil effects on the distribution and canopy cover of plant species at Block P could include moisture, calcium concentrations, organic material composition, and residual metal/metalloid presence. Soil pH, however, should not just be discarded in future research efforts at Block P. The STARS liming rates used to guide soil amendments at the Site are based in part upon potential acidity due to the molecular presence of sulfur (SA and RRU 1989). The 15 years after soil amendments have not yet exhausted the acid-neutralizing effects of lime. A longer period of physical, chemical, and biological weathering of sulfur-containing materials must pass for soil pH values to equilibrate to their final condition (Munshower 1994; Stevenson 1986). Monitoring of soil pH should continue at the Site, particularly as there are known pockets of acidity at Block P, as well as the potential migration of acidity into the Restoration Areas from the continued presence of upstream tailings deposits. In the absence of these sources of contamination, however, and based upon the STARS protocols for liming, potential acidity ultimately should be exhausted (SA and RRU 1989) and soil pH at Block P should remain in a range compatible to a variety of flora (Boul et al., 1989), including the oxeye daisy.

This future condition raises an interesting philosophical question, namely whether the post-restoration presence of a successfully growing, non-native invasive plant species is truly undesirable? This question is complicated by what defines a non-native, invasive plant species. The presence of Kentucky bluegrass (*Poa pratensis*) at Block P provides a clear example of this conundrum. As with oxeye daisy, the soil amendment, seeding, planting, or other restoration prescriptions at Block P did not include Kentucky bluegrass. Like oxeye daisy, this graminoid currently grows in a majority of quadrats at the Site (69% constancy for Kentucky bluegrass versus 64% constancy for oxeye daisy). In 2019, the two plant species also share a similar average canopy cover at Block P (5% for Kentucky bluegrass versus 3% for oxeye daisy).

However, unlike oxeye daisy, Kentucky bluegrass is defined as a Both species (USDA PLANTS 2019c), i.e., possibly Introduced, but also possibly Native (USDA PLANTS 2019a). However, many areas of the United States welcome Kentucky bluegrass as a desirable forage species (Uchytil 1993), unlike oxeye daisy (Olson et al., 1997; Gilkey 1957). Some ecologists, however, characterize Kentucky bluegrass as “a fairly aggressive colonizer…that can most readily immigrate into fairly undisturbed native dry-site vegetation (Lesica 2012).” Because of these aggressive traits, Kentucky bluegrass is listed as an invasive weed in Wisconsin, Nebraska, and the Great Plains

(United States Department of Agriculture Natural Resources Conservation Service 2004), as well as, ironically, in Kentucky (Kentucky Exotic Pest and Plant Council 2013). However, Kentucky bluegrass is not on the State of Montana's Noxious Weed List (Montana Department of Agriculture 2019) nor Cascade County's weed list (Cascade County 2018) due to its utility as forage. Given these issues, should Kentucky bluegrass be welcomed and accepted at Block P, or should it be worthy of negative management attention and control, like the oxeye daisy?

Even without the complication of determining whether a plant species is Native or Introduced, such management decisions about the control of invasive plants are becoming even more philosophically complex. We live in an age in which the spread of both individual and groups of invasive plants are increasingly the norm. In the Anthropocene, more than 13,000 individual vascular plant species have successfully nativized into habitats distant from their ancestral homes (van Kleunen et al., 2015). Further, novel assemblages of non-native plants are increasingly present on landscapes worldwide, with some authors stating that these new combinations of species are the ecological New World Order (Davis et al., 2011; Hobbs et al., 2009; Hobbs et al., 2006). Such perspectives bring into question foundational issues about the philosophy and practice of ecological restoration. If conditions on our planet are changing so fundamentally that historical patterns about what is a Native plant and what is an Introduced plant are no longer a useful guide, should any invasive species or group of invasive species be unwelcomed at a restoration site? Specifically, at Block P, should we love the daisy less than the bluegrass?

Some authors argue that the ultimate goal of restoration is to reestablish the historical trajectories of ecosystems before they are derailed by anthropogenic influences (Simberloff 2015). I would argue, however, that simply repairing damage to ecological functions or ecosystem services is a reasonable goal in environmental restoration (Hobbs and Harris 2001). Even if native habitats and native plant restoration techniques served as guidelines for restoration planning at Block P (Thompson and Massey 2005), the greater issue in restoration planning at the Site was to reduce the off-site transport of contaminants through revegetating the surface areas (EPA 2002). With an 84% canopy cover of plants, this goal has been achieved. Further, I would argue whatever natural trajectory that was present at the Site disappeared with the advent of mining and smelting. The miracle of Block P is that anything can grow in an area that was phytotoxically barren for over 60 years, even if the Site has been reborn without a completely perfect native plant palette.

This does not mean that I am wholly unconcerned about the presence of oxeye daisy at Block P. The arguments for or against novel plant assemblages of plants aside (Davis et al., 2011; Simberloff et al., 2011), I believe that oxeye daisy will require monitoring and control as continuing aspects of long-term site management at the Site. The control of weedy species such as the oxeye daisy is not just a good idea, it is the law for public lands (Federal Plant Protection Act 2000; Federal Noxious Weed Act of 1974 [1975]), including parts of the Block P footprint. Further, preventing the spread of oxeye daisy to new sites is prescribed under the State of Montana’s and Cascade County’s weed management guidelines (Montana Department of Agriculture 2019; Cascade County

2018). Moreover, oxeye daisy has no management utility, and is a pest, with the potential to cause severe economic or ecological harm (Richardson et al., 2000). Its presence at Block P should be controlled.

Given this, oxeye daisy should receive a combination of herbicide treatment (USFS 2017) and fertilizer application (Cole et al., 1999, Olson and Wallander 1999) at Block P. Such ongoing intensive management will require patience. The soil pH at the Site will take decades to decline as sulfur-containing minerals in the soils and subsoils slowly break down and neutralize the residual lime presence. Nonetheless, oxeye daisy already has made its long-term seed deposits at the Block P. I suspect that future monitoring data will show that as soil conditions mature, oxeye daisy's current investment into the soil bank will yield, and thus require long-term interest.

Kentucky bluegrass may not gain much from these future changes in soil conditions, as its optimal soil pH range already broadly extends from 5.8 to 8.2 (Uchytil 1993). As such, without active control, Kentucky bluegrass should continue its uninvited presence at this Site. However, Kentucky bluegrass makes a reasonable forage (Uchytil 1993) and is not covered by the punitive guidelines devised for species like the oxeye daisy. As a result, this graminoid should not be treated as a malignant interloper at Block P.

The managerial choice to not control Kentucky bluegrass but to actively control oxeye daisy at Block P may seem arbitrary and capricious, and dependent on human needs, not science or natural law. Nonetheless, world circumstances force me to defend a utilitarian perspective regarding environmental restoration and management. Humans are in the process of disrupting the old, ecological world order (Hobbs et al., 2009; Crutzen 2006). Globally, mining alone already has created a disturbance footprint larger than the entire state of Montana (United States Census Bureau 2019; Hooke et al., 2012). Places with soil contaminant issues like Block P are common across the planet (Kabata-Pendias 2001; Adriano 1986). Given this level of disruption, E.O. Wilson's call to make this "the age of restoration in ecology" (1992) is not just a hopeful aphorism, it is a worldwide imperative. If we are to restore what we can of our planet, we will have to accept the practical limitations inherent in such efforts. As such, ecological utilitarianism is the philosophical choice of this author, even if it leaves us with imperfect environmental results.

In defense of this position, some perspective is in order. One should remember that between 1943 and 2005, Block P was a phytotoxic wasteland; now, plants cover 84% of the Site. To me, there is a clear lesson that bringing plant life back to barren ground is both possible and necessary. In relative comparison, the need to choose between plants like Kentucky bluegrass and oxeye daisy is a post-restoration, site-management luxury. In this case, I will defer to the practical and love the daisy less than the bluegrass.

REFERENCES CITED

Adriano, D.C. 1986. Trace elements in the terrestrial environment. Springer-Verlag, New York, New York, U.S.A. 533p.

Alt, David and Donald W. Hyndman. 1997. Roadside geology of Montana. Mountain Press Publishing Company, Missoula, Montana, U.S.A. 427p.

Arno, Stephen F. 1979. Forest regions of Montana. United States Department of Agriculture Forest Service Research Paper INT-218. U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station. Ogden, Utah, U.S.A. 39p.

Barr Engineering Company. 2010. Engineering evaluation/cost analysis-Block P Mine Complex, Monarch, Montana. Prepared for The Doe Run Company. Minneapolis, Minnesota, U.S.A. 52p.

Barr Engineering. 2005. Soil quality-revegetation parameters: Block P Mill Tailings Site. June 13, 2005. np.

Barr Engineering Company. 2001. Final–engineering evaluation/cost analysis, Block P Mill Tailings Site, Barker, Montana. Prepared for The Doe Run Company, June 2001. Minneapolis, Minnesota, U.S.A. n.p.

Bloom, Paul R. 2000. Soil pH and pH buffering. In: Handbook of soil science. Edited by Malcom E. Sumner. CRC Press, Boca Raton, Florida, U.S.A. n.p.

Bolan, Nathi S., Domy C. Adriano and Denis Curtin. 2003. Soil acidification and liming interactions with nutrient and heavy metal transformation and bioavailability. Advances in agronomy 78:215-272.

Boul, S. W., F. D. Hole and R. J. McCracken. 1989. Soil genesis and classification. 3rd edition. Iowa State University Press, Ames, Iowa, U.S.A. 446p.

Bradshaw, Anthony. 1997. Restoration of mined lands-using natural processes. Ecological engineering 8:255-269.

Bullock, J. M., J. Aronson, A. C. Newton, R. F. Pywell and J. M. Rey-Benayas. 2011. Restoration of ecosystem services and biodiversity: conflicts and opportunities. Trends in ecology and evolution 26:541–549.

Burke, M. J. W. and J. P. Grime. 1996. An experimental study of plant community invasibility. Ecology 77:776–790.

Cascade County. 2018. Cascade County noxious weed management plan: January 1, 2018-December 31, 2019. Cascade county weed and mosquito division. Great Falls, Montana, U.S.A. 12p.

Clements, David R., Dan E. Cole, Stephen Darbyshire, Jane King and Alec McClay. 2004. The biology of Canadian weeds. 128. *Leucanthemum vulgare* Lam. Canadian journal of plant science 84:343-363.

Cochran, W. G. and G. M. Cox. 1992. Experimental designs. 2nd ed. John Wiley and Sons, Inc., New York, New York, U.S.A. 611p.

Cole, D. E., J. R. King, J. R. and J. Lickacz. 1999. Integrated control of ox-eye daisy (*Chrysanthemum leucanthemum* L.) in pastures and hay land. Alberta Agricultural Research Institute Project #96M038 Final Report. 74p.

Cole, D. E. 1998. Effect of competition on growth of ox-eye daisy (*Chrysanthemum leucanthemum* L.) in pastures and hay land. M.Sc. Thesis, University of Alberta, Edmonton, Alberta, Canada. 156p.

Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA). 1980. Public Law 96-510. 42 U.S.C. 9601 et seq.; 94 Stat. 2767, enacted December 11, 1980.

Consortium of Pacific Northwest Herbaria. 2019. *Leucanthemum vulgare* in Montana by date. http://www.pnwherbaria.org/data/results.php?ExcludeCultivated=Y&SearchAllHerbaria=Y&QueryCount=1&State1=Montana&IncludeSynonyms1=Y&Genus1=Leucanthemum&Species1=vulgare&Zoom=4&Lat=55&Lng=-135&PolygonCount=0&GroupBy=ungrouped&SortBy=Year&SortOrder=ASC (August 23, 2019).

Coulson, S. J., J. M. Bullock, M. J. Stevenson and R. F. Pywell. 2001. Colonization of grassland by sown species: dispersal versus microsite limitation in responses to management. Journal of applied ecology 38:204–216.

Cronquist, A., A. H. Holmgren, N. H. Holmgren, J. L. Reveal and P. K. Holmgren. 2012. Intermountain flora. Vascular plants of the intermountain west. New York botanical garden press. New York, New York, U.S.A. n.p.

Crutzen, Paul J. 2006. The “Anthropocene”. Pages 13-18 In: Earth system science in the Anthropocene: Emerging issues and problems. Springer, Heidelberg, Germany. 268p.

Daubenmire, R. F. 1959. A canopy-coverage method of vegetational analysis. Northwest science 33:43-66.

Davis, Mark, Matthew K. Chew, Richard J. Hobbs, Ariel E. Lugo, John J. Ewel, Geerat J. Vermeij, James H. Brown, M. L. Rosenzweig, M.R. Gardener, S. P. Carroll and K. Thompson. 2011. Don't judge species on their origins. Nature 474(7350):153-154.

de Leeuw, Jan, and Patrick Mair. 2009. Simple and canonical correspondence analysis using the R package anacor. American statistical association, Journal of statistical software 31(5):1-18.

The Doe Run Company. 2004. UAO Implementation Monthly Progress Report: Block P Mill Tailings Site, Barker, Montana, December 7, 2004. np.

Dooley, David and Patrick Audet. 2013. Adopting novel ecosystems as suitable rehabilitation alternatives for former mine sites. Ecological processes 2:22.

Dorph-Petersen, K. 1925. Examination of the occurrence and vitality of various weed seed species under different conditions, made at the Danish State Seed Testing Station during the years 1886–1923. Report of the 4th International Seed Testing Congress 4:128–138.

EDDMapSWest. 2019. Oxeye daisy (*Leucanthemum vulgare*). Early detection and distribution mapping system (EDDMapS). https://www.eddmaps.org/west/distribution/uscounty.cfm?sub=5937&map=distribution (August 23, 2019).

Environmental Protection Agency (EPA). 2002. Action memorandum: Block P Tailings Site Removal Action within the Barker-Hughesville Mining District Superfund Site. April 10, 2002. Lewis and Clark National Forest, Belt Creek Ranger District, Cascade County, Montana, U.S.A. 53p., plus map.

Federal Noxious Weed Act of 1974. 1975. Public Law 93-629. 7 U.S.C. 2801 et seq.; 88 Stat. 2148, enacted January 3, 1975.

Federal Plant Protection Act. 2000. Public Law 106-224. 7 U.S.C. 7701 et seq.; enacted June 20, 2000.

Ferdinandsen, C. 1918. Undersögeber over danske Unkrudsformationes paa Mineraljorder. Tidssk. Pl. Avl. 28: 629. In: Clements, David R., Dan E. Cole, Stephen Darbyshire, Jane King and Alec McClay. 2004. The biology of Canadian weeds. 128. *Leucanthemum vulgare* Lam. Canadian journal of plant science 84:343-363.

Gilkey, H. M. 1957. Weeds of the Pacific Northwest. Oregon State College, Corvallis, Oregon, U.S.A. 441p.

Grime. J. P. 1979. Plant strategies and vegetation processes. John Wiley and Sons, New York, New York, U.S.A. 456p.

Gurevitch, Jessica, Samuel M. Scheiner and Gordon A. Fox. 2018. The ecology of plants, Sinaur Associates, Inc. Sunderland, Massachusetts, U.S.A. 574p.
Hanna Instruments. 2019. The ultimate guide to testing soil pH. Hanna Instruments Blog. http://blog.hannainst.com/soil-ph-testing (February 24, 2019).

Haughton, C. L. 1978. Green immigrants. Harcourt Brace Jovanovich, New York, New York, U.S.A. 450p.

Hess, H. E., E. Landolt and R. Hirzel. 1972. Flora der Schweiz und angrenzender Gebiete. Band 3: Plumbaginaceae bis Compositae. Birkhauser Verlag, Basel und Stuttgart. In: Roche, Ben F., Gary L. Piper and Cindy Jo Talbott, 1986. Knapweeds of Washington. EB1393. Washington state cooperative extension. Washington state university, Pullman, Washington, U.S.A. 41p.

Hobbs, R. J. and J. A. Harris. 2001. Restoration ecology: repairing the earth's ecosystems in the new millennium. Restoration ecology 9(2):239-246.

Hobbs, R. J. E. Higgs and J. A. Harris. 2009. Novel ecosystems: implications for conservation and restoration. Trends in evolutionary ecology 24:599-605.

Hobbs, Richard J., Salvatore Arico, James Aronson, Jill S. Baron, Peter Bridgewater, Viki A. Cramer, Paul R. Epstein, John J. Ewel, Carlos A. Klink, Ariel E. Lugo, David Norton, Dennis Ojima, David M. Richardson, Eric W. Sanderson, Fernando Valladares, Montserrat Vilà, Regino Zamora and Martin Zobel. 2006. Novel ecosystems: theoretical and management aspects of the new ecological world order. Global ecology and biogeogeography 15:1–7.

Hoogerheide, Roger. 2019. Environmental Protection Specialist, Environmental Protection Agency, Helena, Montana, U.S.A. Personal conversation with author.

Hooke, Roger LeB., José F. Martín-Duque and Javier Pedraza. 2012. Land transformation by humans: a review. GSA Today 22(12):4-10.

Howard, Richard A. 2019. Oxeye daisy, Smithsonian Institute, hosted by United States Department of Agriculture PLANTS Database. 2019. *Leucanthemum vulgare* Lam. oxeye daisy. https://plants.usda.gov/core/profile?symbol=LEVU# (August 21, 2019).

Howarth, S. E. and J. T. Williams. 1968. Biological flora of the British Isles. *Chrysanthemum leucanthemum* L. Journal of ecology 56:585–595.

Humair, Franziska, Peter J. Edwards, Michael Siegrist and Christoph Kueffer. 2014. Understanding misunderstandings in invasion science: why experts don’t agree on common concepts and risk assessments. NeoBiota 20:1-30.

Iowa Environmental Mesonet. 2019. Great Falls International Airport Windrose Plot. https://mesonet.agron.iastate.edu/sites/windrose.phtml?station=GTF&network=MT_ASOS (August 11, 2019).

Jongman, R. H.G., C.J.F. ter Braak and O.F.R. van Tongeren. 1995. Data analysis in community and landscape ecology. Cambridge University Press, New York, New York, U.S.A. 299p.

Jordan, William R. and George M. Lubick. 2011. Making nature whole: a history of ecological restoration. Island Press, Washington, D.C., U.S.A. 272p.

Kabata-Pendias, Alina. 2001. Trace elements in soil and plants, Third Edition. CCR press, Boca Raton, Florida, U.S.A., 413p.

Kentucky Exotic Pest and Plant Council. 2013. Exotic invasive plants of Kentucky (3rd Edition). https://www.se-epc.org/ky/KYEPC_2013list.pdf (September 8, 2019).

Larson, Doug. n.d. https://www.goodreads.com/author/quotes/4341759.Doug_Larson (September 10, 2019).

Lesica, Peter. 2012. Manual of Montana vascular plants. Botanical Research Institute of Texas. Fort Worth, Texas, U.S.A. 771p.

MacArthur. R. H. 1972. Geographical ecology. Princeton University Press, Princeton, New Jersey, U.S.A. 288p.

Marschner, Horst. 1995. Mineral nutrition of higher plants. 2nd ed. Academic Press, Harcourt Brace and Company, New York, New York, U.S.A. 889p.

Massey, J. Gant. 2008. 2008 Monitoring, Block P. Memorandum to John Hunt, Barr Engineering. Ecological Solutions Group LLC, Stevensville, Montana, U.S.A. 35p.

Massey, J. Gant. 2007. 2007 Monitoring, Block P. Memorandum to John Hunt, Barr Engineering. Ecological Solutions Group LLC, Stevensville, Montana, U.S.A. 22p.

Massey, J. Gant. 2006. Status of Block P Project, December 20, 2005 (revised March 23, 2006). Prepared for by Bitterroot Restoration, Inc., on behalf of John Hunt, Barr Engineering. Bitterroot Restoration, Inc., Corvallis, Montana, U.S.A. 6p.

Massey, J. Gant. and William Thompson. 2010. 2010 Monitoring, Block P. Memorandum to John Hunt, Barr Engineering. Ecological Solutions Group LLC, Stevensville, Montana, U.S.A. 22p.

Massey, J. Gant and William Thompson. 2009. 2009 Monitoring, Block P. Memorandum to John Hunt, Barr Engineering. Ecological Solutions Group LLC, Stevensville, Montana, U.S.A. 39p.

McBride, Murray B. 1994. Environmental chemistry of soils. Oxford University Press, New York, New York, U.S.A. 406p.

Mincemoyer, Scott A. and Jennifer L. Birdsall. 2006. Vascular flora of the Tenderfoot Creek Experimental Forest, Little Belt Mountains, Montana. Madrono 53(3):211-222.

Mitich, L. W. 2000. Oxeye daisy (*Chrysanthemum leucanthemum* L.), the white-flowered gold flower. Weed technology 14:659–662.

Montana Department of Agriculture. 2019. Montana noxious weed list (Effective: June 21, 2019). https://agr.mt.gov/Portals/168/Documents/Weeds/2019%20Montana%20Noxious%20Weed%20List.pdf?ver=2019-07-02-095540-487&timestamp=1566575797863 (September 7, 2019).

Montana Department of Environmental Quality (MT DEQ). 2019b. The Hughesville District. Historic Context: aka Barker. Montana.gov (official state website). http://deq.mt.gov/Land/abandonedmines/linkdocs/90tech (August 21, 2019).

Munshower, Frank. 1994. Practical handbook of disturbed land revegetation. CRC Press, Inc., Boca Raton, Florida, U.S.A. 288p.

Murcia, C. J. Aronson, G.H. Kattan, D. Moreno-Mateos, K. Dixon and D. Simberloff. 2014. A critique of the “novel ecosystem” concept. Trends in ecology and evolution 29:548-53.

Murguía, Diego I. 2015. Global area disturbed and pressures on biodiversity by large-scale metal mining. Kassel University press, Kassel, Germany. 350p.

Muthusaravanan, S., N. Sivarajasekar, J. S. Vivek, T. Paramasivan, Mu Naushad, J. Prakashmaran, V. Gayathri and Omar K. Al-Duaij. 2018. Phytoremediation of heavy metals: mechanisms, methods and enhancements. Environmental chemistry letters 16(4):1339-1359.

Oberprieler, C, C. Eder, J. Meister and R. Vogt. 2011. AFLP fingerprinting suggests an allopolyploid origin of two members of the *Leucanthemum vulgare* aggregate (Compositae, Anthemideae) in central Europe. Nordic journal of botany 37:370-377.

Olson, B. E. and R. T. Wallander. 1999. Oxeye daisy. Pages 282–289 in R. L. Sheley and J. K. Petroff, eds. Biology and management of noxious rangeland weeds. Oregon State University Press, Corvallis, Oregon, U.S.A. 464p.

Olson, Bret E., Roseann T. Wallander, and Peter K. Fay. 1997. Intensive cattle grazing of oxeye daisy (*Chrysanthemum leucanthemum*). Weed technology 11(1):176-181.
Opp, Steve. 2019. Minerals and Geology Program Manager, United States Forest Service, Helena, Montana, U.S.A. Personal conversation with author.

Palmer, Michael. 2019. Variance explained and variance partitioning. http://ordination.okstate.edu/varpar.html (November 17, 2019).

Palmer, Michael W. 1993. Putting things in even better order: the advantages of canonical correspondence analysis. Ecology 74(8):2215-2230.

Perring, Michael P., Patrick Audet and David Lamb. 2014. Novel ecosystems in ecological restoration and rehabilitation: innovative planning or lowering the bar? Ecological processes 3:8.

Prach, Karel and Richard J. Hobbs. 2008. Spontaneous succession versus technical reclamation in the restoration of disturbed sites. Restoration ecology 16(3):363-366.

Ramsey, Fred L. and Daniel W. Schafer. 2013. The statistical sleuth: A course in the methods of data analysis, Third edition. Brooks/Cole, CENAGE Learning. Boston, Massachusetts, U.S.A. 760p.

Richardson, David M., Petr Pysek, Marcel Rejmanek, Michael G. Barbour, F. Dane Panetta and Carol J. West. 2000. Naturalization and invasion of alien plants: concepts and definitions. Diversity and distributions 6(2):93-107.

Ryser, Peter and Phil Emerson. 2007. Growth, root and leaf structure, and biomass allocation in *Leucanthemum vulgare* Lam. (Asteraceae) as influenced by heavy-metal-containing slag. Plant and soil 301:315-324.

Salisbury, E. J. 1942. The reproductive capacity of plants: Studies in quantitative biology. G. Bell and Sons Ltd., London, United Kingdom. 244p.

Sanders, J. 1993. Hedgemaids and fairy candles. The lives and lore of North American wildflowers. Ragged Mountain Press, Camden, Maine, U.S.A. 232p.

Schafer and Associates and Reclamation Research Unit of Montana State University (SA and RRU). 1989. Streambank Tailings and Revegetation Study-Phase I. Montana Department of Health and Environmental Sciences Final Report. Bozeman, Montana, U.S. A. n.p.

Seastedt T. R., R. J. Hobbs and K. N. Suding. 2008. Management of novel ecosystems: are novel approaches required? Frontiers in ecology and the environment 6(10):547-553.
Sheskin, David A. 2011. Handbook of parametric and nonparametric statistical procedures. CRC Press, Boca Raton, Florida, U.S.A. 1886p.

Shoemaker, H. E., E. O. McLean, and P. F. Pratt. 1961. Buffer methods of determining lime requirements of soils with appreciable amounts of extractable aluminum. Soil Science Society of America Proceedings 25:274-277.

Simberloff, Daniel. 2015. Non-native invasive species and novel ecosystems. F1000 prime reports 7(47):1-7.

Simberloff, Daniel, J. Alexander, F. Allendorf, J. Aronson, P.M. Antunes, S. Bacher, R. Bardgett, S. Bertolino, M. Bishop, T.M. Blackburn and A. Blakeslee. 2011. Non-natives: 141 scientists object. Nature 475(7354):36.

Small, James. 1954. Modern aspects of pH. D. Van Norstrand Company, Inc. New York, New York, U.S.A. 247p.

Sonter, Laura J., Saleem H. Ali and James E. M. Watson. 2018. Mining and biodiversity: key issues and research needs in conservation science. Proceedings of the Royal Society B. 285:20181926.

Sorenson, S. P. L. 1909. Enzyme studies: II. The measurement and importance of the hydrogen ion concentration in enzyme reaction. Compt. Rend. Trav. Lab. Carlsberg, Germany 8:1-168.

The State of Montana. 2019. Montana field guide: species status codes.
http://fieldguide.mt.gov/statusCodes.aspx#noxious
(August 22, 2019).

Stevenson, F. J. 1986. Cycles of soil: carbon, nitrogen, phosphorus, sulfur, micronutrients. John Wiley and Sons, New York, New York, U.S.A. 380p.

Suding, Katharine N. 2011. Toward an era of restoration in ecology: successes, failures, and opportunities ahead. Annual review of ecology and evolutionary systems 42:465-487.

ter Braak, C. J. F. 1988. CANOCO. Agricultural mathematics group. Technical report LWA-88-A. Wageningen, Netherlands. 95p.

The R Foundation for Statistical Computing. 2019. R version 3.6.1 (2019-07-05) -- "Action of the Toes" R 3.6.1 GUI 1.70 El Capitan build (7684). http://www.R-project.org.

Thompson, William H. and Gant Massey. 2005. Block P Mill Tailings Site Revegetation Plan. For: Barr Engineering Company and The Doe Run Company. Bitterroot Restoration, Corvallis, Montana, U.S.A. 19p.

Uchytil, Ronald J. 1993. *Poa pratensis*. In: Fire Effects Information System, [Online]. United States Department of Agriculture, Forest Service, Rocky Mountain Research Station, Fire Sciences Laboratory (Producer). https://www.fs.fed.us/database/feis/plants/graminoid/poapra/all.html (September 8, 2019).

United States Census Bureau. 2019. Quick Facts: Montana. https://www.census.gov/quickfacts/MT. (October 28, 2019).

United States Department of Agriculture Forest Service (USFS). 2017. Field guide for managing oxeye daisy in the southwest. Technical report: TP-R3-16-33. United States Department of Agriculture, Forest Service, Southwest region, Albuquerque, New Mexico, U.S.A. 6p.

United States Department of Agriculture Forest Service (USFS). 1995. Action memorandum: Time-critical CERCLA Removal Action Commenced at Block P Tailings. January 6, 1995. United States Department of Agriculture, Forest Service, Region 1, Missoula, Montana, U.S.A. 12p.

United States Department of Agriculture Forest Service (USFS). 1989. Ecosystem classification handbook: ECODATA. United States Department of Agriculture Forest Service, Northern Region, Missoula, Montana, U.S.A. n.p.

United States Department of Agriculture PLANTS (USDA PLANTS). 2019a. Help: What do you mean by native and introduced? United States Department of Agriculture, Natural Resources Conservation Service, PLANTS Database, https://plants.usda.gov/faq.html#native (September 7, 2019).

United States Department of Agriculture PLANTS (USDA PLANTS). 2019b. *Leucanthemum vulgare* Lam. oxeye daisy. United States Department of Agriculture, Natural Resources Conservation Service, PLANTS Database, https://plants.usda.gov/java/charprofile?symbol=LEVU (August 21, 2019).

United States Department of Agriculture PLANTS (USDA PLANTS). 2019c. *Poa pratensis* L. Kentucky bluegrass. United States Department of Agriculture, Natural Resources Conservation Service, PLANTS Database, https://plants.usda.gov/core/profile?symbol=POPR (October 13, 2019).

United States Department of Agriculture PLANTS (USDA PLANTS). 2019d. *Taraxacum officinale* F.H. Wigg. common dandelion. United States Department of Agriculture, Natural Resources Conservation Service, PLANTS Database, https://plants.usda.gov/core/profile?symbol=taof (September 9, 2019).

United States Department of Agriculture Natural Resources Conservation Service. 2004. Plant guide: Kentucky bluegrass *Poa pratensis* L. https://plants.usda.gov/plantguide/pdf/pg_popr.pdf (September 8, 2019).

van Kleunen, Mark, Wayne Dawson, Franz Essl, Jan Pergl, Marten Winter, Ewald Weber, Holger Kreft, Patrick Weigelt, John Kartesz, Misako Nishino, Liubov A. Antonova, Julie F. Barcelona, Francisco J. Cabezas, Dairon Cárdenas, Juliana Cárdenas-Toro, Nicolás Castaáo, Eduardo Chacón, Cyrille Chatelain, Aleksandr L. Ebel, Estrela Figueiredo, Nicol Fuentes, Quentin J. Groom, Lesley Henderson, Inderjit, Andrey Kupriyanov, Silvana Masciadri, Jan Meerman, Olga Morozova, Dietmar Moser, Daniel L. Nickrent, Annette Patzelt, Pieter B. Pelser, María P. Baptiste, Manop Poopath, Maria Schulze, Hanno Seebens, Wen-sheng Shu, Jacob Thomas, Mauricio Velayos, Jan J. Wieringa and Petr Pysek. 2015. Global exchange and accumulation of non-native plants. Nature 525:100-103.

Weatherbase.com. 2019. Monarch, Montana. https://www.weatherbase.com/weather/weather.php3?s=800642&cityname=Monarch-Montana-United-States-of-America&units=us (August 15, 2019).

Webber, Bruce L. and John K. Scott. 2012. Rapid global change: implications for defining natives and aliens. Global ecology and biogeography 21:301-311.

Weiser, Kathy. 2017. Barker & Hughesville, Montana – Ghost Camps in the Little Belt Mountains. Legends of America. https://www.legendsofamerica.com/mt-barkerhughesville/ (August 11, 2019).

Wilson, E. O. 1992. The diversity of life. Norton Publisher, New York, New York, U.S.A. 444p.

Wong, M.H. 2003. Ecological restoration of mine degraded soils, with emphasis on metal contaminated soils. Chemosphere 50:775-780.

Ye, Z. H., W. C. Wong and M. H. Wong. 2000. Vegetation response to lime and manure compost amendments on acid lead/zinc mine tailings: a greenhouse study. Restoration ecology 8(3):289-295.