

A comparative study of plant species diversity on three historic mining sites

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Abstract

In order to determine the degree of ecological damage inflicted as a result of mining operations around the Gothic area, three tailings piles were identified in Gothic and Crested Butte and an observational study of plant species on and around them carried out. It was found that both total numbers of species on our observed plots and total numbers of individual plants increased significantly with increasing distance from the tailings centrepoin, as well as the Simpson and Shannon indices derived from those numbers ($P < .0001$), indicating that revegetation has largely failed to occur on these tailings—despite a century or more of elapsed time since their deposition.

Introduction

The flora of an environment is a fairly good indicator of the overall ecological health of that environment—without a healthy autotrophic base, herbivores have nothing to feed upon and a more complex food web cannot develop. In polluted environments such as those of the sites of mining operations, ecological interactions can be damaged or completely disrupted (Custer *et al* 2009, Milton *et al* 2002, Shu *et al* 2005, Sorvari *et al* 2007), leading to an unhealthier, less-diverse ecosystem which may contain only pollution-tolerant species and in some cases, may be completely sterile.

The principal source of environmental damage from mining operations comes either from effects of the chemical techniques used to extract ore, or from their tailings. Mine tailings consist of pulverized waste rock not containing useful ore, typically in the form of a slurry or very fine dust. This finely-divided "soil" is too loose for many plant species to anchor themselves, and often can be piled up at too steep an angle to permit the establishment of *any* plant species (Mendez *et al* 2007, 2008). Tailings also contain unrecoverable portions of ore, toxic heavy metals such as Pb, As, Ni, Zn, and Cd, flotation agents and other chemicals used in the extractive process, highly acidic sulfides, and other noxious substances (Mendez *et al* 2007, 2008)—in short, an environment less than hospitable towards life.

A study by Weiersbye and Witkowski (2003) has shown that species of *Acacia* growing on the tailings of gold mining in South Africa exhibited lower seed vitality, were less likely to germinate, and contained higher levels of acid-soluble metals such as Fe and Co as compared to those on unpolluted soil. Another study by Boyd, Wall, and Jaffre (2006) has also shown that Ni-hyperaccumulating plants pass Ni on to insect species which pollinate or feed on them, including honey bees—which are known to suffer from increased mortality and a skewed sex ratio when introduced into areas of Zn pollution (Morón *et al* 2010).

The Rocky Mountain Biological Laboratory (RMBL) is located in Gothic, CO—once a silver-mining boomtown in the late 1800s. The area around the townsite and its surrounding valleys are honeycombed with the remains of old silver and coal mines, most of which proved fruitless and unprofitable, leading to the townsite's near-abandonment. The relatively undisturbed and highly diverse environment in the area eventually led to Gothic's resurrection as a biological field station.

However, despite the tremendous depth of fieldwork carried out at RMBL, surprisingly little research has been carried out on the reason for the town's existence: the mines. Historically, mine tailings were simply dumped wherever convenient—into the nearest stream or pit, into the mine once deposits were exhausted, or simply piled up and abandoned, as is the case at Gothic. It's not yet known whether or not the effects and byproducts of mining operations around Gothic continue to affect their surrounding environments, despite a century or more since the cessation of mining operations.

Extensive research *has* been done in the impact of mine tailings on the growth and reproductive fitness of plant species (Bagatto and Shorthouse 1999, Milton *et al* 2002, Weiersbye

and Witkowski 2003) and on the effect of heavy metal accumulation on herbivores (Boyd *et al* 2006, Milton *et al* 2002, Sorvari *et al* 2007), but comparatively little research exists on how mine-tailings ecosystems may regenerate *themselves* without human intervention—a situation which currently obtains on several of the mines around Gothic.

For these reasons, I have undertaken a comparative study of the flora on, around, and off the sites of three tailings piles in various locations near Gothic. Assuming that these tailings sites remain ecologically different from their surroundings, I hypothesize that both diversity of species, and individuals *of* those separate species, will increase noticeably with increasing distance from tailings—and as a corollary, diversity indices derived from that data will also increase. If, however, these tailings have become healed—showing little or no ecological difference compared to an undisturbed site—I should see no difference in any of those variables with increasing distance.

This type of pilot study does not appear to have been undertaken at RMBL previously, and could open the door to future studies of soil chemistry and more extensive studies of the plant community around these mines. This study may also have implications for future applied research on phytoremediation, revegetation, and phytomining endeavors around Gothic and across North America, as well as shedding some light onto the natural process of ecological recovery on mine tailings.

Methods

Description of sites:

Three mines were determined to be suitable for this study. Each research site was located on a pile of tailings at or near the entrance to each mine, with its centrepoin placed as close as was feasible to the centre of the barren area of each tailings pile. In the case of Peanut Mine, where the tailings pile studied was >25m in extent in all directions, I placed the centrepoin within about 10m of one margin of the pile. Sylvanite Mine, located on a mining road off the Copper Creek trail, was originally planned as the third site. However, time constraints in accessing it proved prohibitive.

Avery Mine is located northeast of Trail 401, at the end of a switchbacked mining road. This road is reachable by following Trail 401 north from Gothic until reaching a private cabin and wire fence—follow this fence for a time until the remnants of the road become apparent. Its tailings pile appeared to be composed mostly of shattered shale and dark grey stone, as well as dust of the same composition.

Copper Creek Mine could not be located in the historical records as having a name, so I've given it a name corresponding to its location. It can be reached from the Copper Creek trail by following the trail until the first river crossing from Gothic. Before the crossing, a small path leads obliquely to the left through stands of aspen and willow. The mine and its tailings pile are located in a meadow bordering a forest, with a ruined cabin nearby. Its tailings were composed of a lighter shade of rock, with an average fragment size rather larger than that of Avery Mine.

Peanut Mine is located in Crested Butte, near the Lower Loop multi-use trail. Historically this mine undertook both coal and hard-rock mining activities—today, much of the area has been reclaimed as the result of a very successful EPA project (EPA 2005, Renner 2009). According to historical data outlined in Renner (2009), much of the site was once severely polluted, suffering from copious acid rock drainage and anthracite-coal waste prone to spontaneous combustion. This study focuses on one tailings pile which has not yet been reclaimed, with similar composition to the tailings of Avery Mine.

Description of methods:

Each research site consisted of four 25m transects, with a mutual centrepoin. The angle of

separation between each transect was not precisely 90°, due to issues with the surrounding terrain—particularly steep slopes, tangled vegetation, stream crossings—interfering with accurate angle-taking. Every effort was made to preserve linearity, but most transects were not perfectly linear for their 25m length. GPS data was collected at the centrepoint and 25m points for all transects.

At the centrepoint, and every 5m thereafter, markers were placed and a 1x1m square plot was laid out, using the marker as its centrepoint. In situations where accessing the plots required trampling vegetation, and therefore potentially affecting species and individual counts, the marker was used as the midpoint of one of the plot's edges.

On each plot, counts of every species present within were made, and all individuals of those species identified and counted. This study focuses on vascular plants—but on the very few occasions where mosses were present, they were also counted. Identification was accomplished in the field and with high-resolution photos out of the field, but could not be completed for every plant on each site. "Colorado Flora: Western Slope" by Weber and Wittmann (2001), and the aid of Robin Bingham, were both instrumental in identification.

Plant species known to reproduce clonally, such as *Veratrum tenuipetalum* and *Populus tremuloides* had each individual stem counted as an individual—there was no way to be certain a particular stem was one ramet of a colony, or an individual in its own right. Stoloniferous plants such as *Fragaria virginiana* had all stolons counted as part of one individual, *unless* a plantlet from such a stolon had begun to take root. Any such plantlets were counted as separate individuals.

Data analysis

Data from each individual plot was fed into an online calculator at http://alyoung.com/labs/biodiversity_calculator.html, and values for the Shannon index (ln type) and Simpson dominance index (expressed as 1-**D**) were retrieved. Data analysis was through JMP version 7, and R 2.13.1, using four least-squares regression models. Any plot containing no species, or a single species, does not have an associated Shannon or Simpson index; the equations governing their calculation require two or more.

Response variables were one of either total species, total individuals, Shannon index, or Simpson index; explanatory variable was distance from centrepoint, with a random effect of transect (nested within site) added to account for any variation within transects at each site. These analyses use the entire dataset.

Results

Table 1: Linear regression statistics for four variables, as a function of distance-from-centre

Variable name	R2 value	P-value	Beta value
Total species	0.53	< .0001	.3117306 ± 0.047481
Total individuals	0.38676	< .0001	2.6813843 ± 0.48104
Shannon index	0.63041	< .0001	.0421292 ± 0.009287
Simpson index	0.39211	< .0001	.0129278 ± 0.003596

We found that both the total number of species and individuals present on a plot increased significantly with distance from the centrepoint of tailings (Table 1). The diversity indices derived from these values also increased significantly with increasing distance. To illustrate: while the centrepoint plots were mostly or entirely barren, plots 20 or 25m from centre exhibited considerable diversity, with up to fourteen individual species and 175 individuals in the most diverse plot.

Those species falling on plots closest to the centrepoint (0, 5, or 10 m) were typically grasses (*Poaceae spp.*), *Ribes spp.*, unidentifiable species consisting mostly or entirely of a tiny basal rosette of leaves, and *Fragaria virginiana*. Peanut Mine was also host to *Artemisia tridentata*, which was not present at the other sites—possibly due to higher elevation and greater tree cover at those sites. Plots 15-25m from the centrepoint typically exhibited a greater diversity of species, with much greater ground cover in comparison to plots 0-10 m away.

Fourteen plots, out of the 63 laid out in this experiment, were completely barren—all but two located on the centrepoint, or 5 to 10 meters away. Those two exceptions were located 15m away. Eleven plots contained only 1 or 2 species, with a distribution across all distances from the centre. In total, 25 of 63 (~40%) of the plots examined in this experiment were barren or nearly so, and of those, the majority fell within ten meters of the centrepoint across all sites.

Table 2: The six most common species across all sites; grasses excluded

Species name/description	Species ID#s (#A, #C, #P)	Avery?	Copper Creek?	Peanut?	Plots observed on
<i>Epilobium angustifolium</i>	#A4, #C7	Y	Y	N	15
<i>Fragaria virginiana</i>	N/A, N/A, #P9	Y	Y	Y	15
<i>Aquilegia caerulea</i>	#A7, #C4	Y	Y	N	15
<i>Ligusticum porteri</i>	#A10	Y	N	N	11
<i>Populus tremuloides</i>	N/A, N/A	Y	Y	N	11
<i>Taraxacum officinale</i>	N/A, #P12	N	Y	Y	11

Table 3: The five most common species observed on each site

Site name	Species ID#	Species name/description	Plots observed on
Avery	#A10	<i>Ligusticum porteri</i>	11
Avery	#A3	Poaceae sp. #1	9
Avery	#A8	Poaceae sp. #2	8
Avery	#A4	<i>Epilobium angustifolium</i>	7
Avery	N/A	<i>Heracleum sphondylium</i> ssp. <i>montanum</i>	7
Copper Creek	#C4	<i>Aquilegia caerulea</i>	9
Copper Creek	N/A	<i>Fragaria virginiana</i>	8
Copper Creek	N/A	<i>Populus tremuloides</i>	8
Copper Creek	#C7	<i>Epilobium angustifolium</i>	7
Copper Creek	#C6	A milk-vetch species; name unknown	5
Peanut	#P3	The shortest Poaceae sp. observed at Peanut	9
Peanut	#P7	A low shrub with spirally-arranged leaves.	7
Peanut	#P2	<i>Artemisia tridentata</i>	7
Peanut	#P9	<i>Fragaria virginiana</i>	5
Peanut	#P5	Unknown; a tiny basal rosette of spoon-like leaves. Flowers are miniscule; reddish.	5

Discussion

Statistical analysis and observational data clearly shows a significant effect is exerted by these mine tailings on the numbers of species and individuals capable of surviving on these tailings. The effect becomes less with increasing distance from the tailings, allowing the survival of more diverse plant communities.

On most 5m plots that contained any species at all, the dominant species were all grasses (*Poaceae spp.*). This may be due to the documented ability of grasses to tolerate wide pH ranges and high heavy-metal concentrations (Byrne-Kelly *et al* 2001, Gregory & Bradshaw 1965, Porter & Peterson 1970) or due to their propensity for colonizing finely-divided soils similar in particle size to mine tailings, such as sand (Hewett 1970, Peters 1984).

Other plants commonly present nearest, or on, the centrepoinTs include *Fragaria virginiana* (wild strawberry) and *Taraxacum officinale* (dandelion). Avery Mine also was host to a number of ramets of *Populus tremuloides* very near the centrepoinT; this is likely due to vegetative spreading of an existing colony, and not new individuals sinking their own roots. *Ligusticum porteri* (osha or bear root) was also observed on Avery Mine, albeit only on plots far from the tailings. *T. officinale* is a known alien weed across North America (Weber and Wittmann 2001), with a cosmopolitan distribution; the toxicity of these tailings is apparently not enough to dissuade its growth.

Conclusions

It is plain both from visual observation and statistical analysis of the collected data that there are still very significant differences in plant communities on and off these tailings—in effect, none have truly "healed" themselves *without* human intervention, despite a century or more of time in which to do so. This has distressing implications for mines of similar nature worldwide: we cannot expect the pollution generated by mining operations to simply go away, even over generations of time. It may be possible that over geological timescales, the effects of such pollution may be mitigated or eliminated—but such speculation is quite beyond the scope of this very simple study.

Judging from the success of the EPA reclamation efforts on Peanut Mine, remediation of these sites would likely be a fairly easy matter. A number of conventional treatments were used to restore Peanut Mine (Renner 2009) and these treatments would likely work well for reclaiming Avery and Copper Creek mines as well (Byrne-Kelly *et al* 2001, Peters 1984, Renault *et al* 2003). However, the small size and isolated location of these mines, as well as their location in protected wilderness, may mean a lack of political will to spend anything on their reclamation.

Considerable opportunity still exists here for more extensive surveying of these sites, and for manipulative experiments to determine the extent of pollution on these sites—and the resultant effects on ecological conditions rather more complicated than something as simple as species diversity. Further studies on these locations might explore the effect of tailings-grown plants have on insect and/or mammal herbivory, heavy metal uptake of tailings-grown plants, or the effects any such heavy metal uptake may have on growth and reproduction.

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