

# **AN ASSESSMENT OF SPECIES-BASED, STRUCTURAL, AND FUNCTIONAL DIVERSITY AT THE TECK HIGHLAND VALLEY COPPER PARTNERSHIP MINE**

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## **ABSTRACT**

Mining companies in Canada, through corporate initiatives and their membership in the Mining Association of Canada, have implemented biodiversity conservation management programs. A valuable tool in assessing the success of these programs is the calculation of biodiversity indices. Biodiversity indices, when calculated alongside summary statistics of vegetation cover and plant-traits, provide useful descriptions of ecosystem composition, structure, and function.

Biodiversity indices were calculated for two separate databases at the Teck Highland Valley Copper Partnership (HVC) mine in south-central British Columbia. The two mine-site datasets analyzed included plot data collected for an ongoing reclamation-monitoring program and plot data from a Terrestrial Ecosystem Mapping (TEM) program. Both datasets contain data from forest harvesting and mining disturbances while only the TEM program dataset contains undisturbed or “naturally” disturbed (i.e., wildfire and insect infestation) ecosystem data. Comparisons of biodiversity indices between on-site and off-site plots in both datasets revealed information on ecosystem structure and function useful for reclamation planning and monitoring as well as in the assessment of ecosystem services.

## **KEYWORDS**

Biodiversity, ecosystem, function, monitoring, plant-traits, mine reclamation, and structure.

## **INTRODUCTION**

The mining industry, through various agencies such as the International Council on Mining and Metals (ICMM) (Johnson 2006) and the Mining Association of Canada (MAC) (MAC 2007), has acknowledged the importance of biodiversity conservation as an essential component of sustainable development. The Teck Highland Valley Copper Partnership (HVC) has both short- and long-term objectives for sustainability / biodiversity. The goals include (1) development of a Biodiversity Management Plan, (2) integration of biodiversity considerations into all stages of the mining life-cycle, and (3) corporate involvement in biodiversity research, education, and conservation (Teck 2015). The intent of this paper is to provide technical support for HVC’s goal of integrating biodiversity considerations into all stages of the mining life-cycle

Biological diversity (biodiversity) is defined as “the variety, distribution, and abundance of different plants, animals, and microorganisms, the ecological functions and processes they perform, and the genetic diversity they contain at local, regional or landscape levels of analysis” (Dunster and Dunster 1996). Franklin (1988) further identified three primary attributes of biodiversity – composition, structure, and function – that transcend these multiple levels of biodiversity. To address the assessment and monitoring

of biodiversity conservation efforts, Noss (1990) suggested that suitable indicators be identified and used that deal with the three primary attributes of biodiversity identified above.

The focus of this paper is plant-based biodiversity and the identification and application of suitable biodiversity indicators. Although not providing a full picture of all attributes of biodiversity, plant-based biodiversity can be used as a surrogate for animal-based diversity and for understanding, in part, the relationship between ecosystem functioning and biodiversity. Of particular interest is the use of plant-traits as indicators since they control ecosystem processes and define habitat and resources for other taxa. Trait-based approaches have been used at other mining operations in the world (Prach et al. 1997, Alday et al. 2011, Piekarska-Stachoiak et al. 2014).

## **OBJECTIVES**

The objectives of the study were to conduct assessments of plant species, structure, and functional diversity / ecosystem services based on two existing HVC vegetation datasets.

## **METHODS**

### Data Collection

Two datasets, one a component of an ongoing reclamation assessment (RA) program and one a component of a Mines Act Permit Application (MAPA), have been created at HVC by the Integral Ecology Group (IEG). The sampling system used in the RA program employs a stratified random approach to establish permanent sample sites for repeated-measures data collection with sites installed over multiple years. In contrast, the MAPA dataset was created during a single season (2013) using a stratified (pre-field stratification process based on slope, aspect, mesoslope position, parent materials, elevation, and site series) sampling system with subjective placement of plots in the field. The stratified / subjective-placement sampling system used in the MAPA program is typical for Terrestrial Ecosystem Inventory and Terrestrial Ecosystem Mapping (TEM) programs (RIC 1998). The sampling units for both datasets are different; the MAPA program used a standard single macroplot (20 m x 20 m) whereas the RA program uses a nested multiple plot sampling unit (total area 100 m<sup>2</sup>). Only the species-cover abundance and site-classification data for each dataset were used in the analyses performed for this paper.

### Data Analysis

Two matrices of each of the RA and MAPA datasets were created: species x plots and plant-traits x plots. The species by plots datasets were simply QA/QC versions of the raw data collected during the RA and MAPA field programs. To create the plant-traits x plots dataset, a species x plant-traits database was created using published literature (e.g., Klinkenberg 2013, eFlora 2015, USDA 2015, and NRCS 2015). All plant-traits used in the functional analyses are categorical (Table 1).

Species-cover abundance data were analyzed for species richness (S) and species diversity (Simpson's D') (Magurran 2004). Biodiversity profiles and permutation tests (Gardener 2014) were also calculated. Plots were assigned to ecosystem units broadly categorized according to the biogeoclimatic classification system (BEC) in British Columbia.

Species-diversity analyses were conducted in R (R Core Team 2016) while functional-diversity analyses were calculated in MS-Excel (2016) following Leps et al. (2006). Indicator Analysis (IA) was applied to the plant-traits x plots datasets using PC-ORD Version 6 (McCune and Mefford 2011). Summary statistics were calculated for each of the plant-traits.

## RESULTS AND DISCUSSION

HVC and the surrounding reference sites are situated within the Thompson Dry Cool Interior Douglas-Fir (IDFdk1), Thompson Dry Cool – Grassland Phase (IDFdk1a), Thompson Very Dry Hot Interior Douglas-Fir (IDFhx2), South Thompson Very Dry Cool Montane Spruce (MSxk2), and Thompson Very Dry Cold Engelmann Spruce Subalpine Fir (ESSFxc2) biogeoclimatic subzones (Lloyd et al. 1990). The datasets used in this paper include data points located in each of the subzones although HVC is situated primarily in the IDFdk1, IDFdk1a, and MSxk2 subzones. Due to the strong overlap in species composition between the IDFdk1 and the MSxk2, analyses and reporting did not discriminate between these BEC subzones.

Table 1. Plant Traits Categories.

Plant Trait	Functional Importance	Data Type	Number of Categories	Exclusivity	Coding Source
Raunkiaer Life-Form	Plant stature and position of buds for surviving harsh conditions	Categorical	11	Exclusive	Raunkiaer (1934)
Growth Habit	Shape, orientation, and occupation of biological space	Categorical	14	Exclusive	Pérez-Harguindeguy et al. (2013)
Root Architecture	Capacity to anchor and acquire resources	Categorical		Exclusive	Hickey and King (2000)
Rooting Depth	Soil moisture access/drought tolerance	Categorical	3	Exclusive	Woźniak et al. (2011)
Shade Tolerance	Intra- and interspecific responses to sunlight	Categorical	3	Exclusive	Dunster and Dunster (1996)
Leaf Shape	Light capture and decomposition	Categorical	2	Exclusive	Hickey and King (2000)
Leaf Duration	Plant resource allocation, soil organic matter, decomposability	Categorical	5	Exclusive	Hickey and King (2000)
Moisture-Use Strategy (MUS)	Pattern and distribution of plants along moisture gradients	Categorical	5	Exclusive	Dunster and Dunster (1996)
Nutrient-Uptake Strategy (NUS)	Assimilation of nutrients	Categorical	19	Non-exclusive	Pérez-Harguindeguy et al. (2013)
Ecological Life History (C-S-R)	Resource allocation and inter- and intra-specific interactions	Categorical	3	Non-exclusive	Grime (2002)
Sexual Reproduction	Genetic variation in offspring important to the survival and reproduction of population	Categorical	3	Exclusive	Pérez-Harguindeguy et al. (2013)
Asexual Reproduction/Clonality	Greater rate of plant establishment, advantageous for small populations	Categorical	10	Exclusive	Pérez-Harguindeguy et al. (2013)
Propagule Dispersal Mechanism	Efficacy of distribution and population maintenance	Categorical	9	Non-exclusive	Pérez-Harguindeguy et al. (2013)

### Phylogenetic / Floristic-Based Diversity

A total of 206 species (5 trees, 25 shrubs, 109 forbs, 26 grasses, 4 sedges, 1 rush, 12 mosses, and 24 lichens) were recorded in the RA dataset while a total of 255 species (7 trees, 27 shrubs, 109 forbs, 35 grasses, 13 sedges, 2 rushes, 2 fern-allies, 1 cattail, 3 liverworts, 29 mosses, and 27 lichens) were recorded in the MAPA dataset. The difference in the total number of species and proportions of plant growth forms is due to the difference in the objectives of the two sampling programs. The focus of the RA project is to monitor convergence of reclaimed mine disturbances with comparable off-site reference conditions (Melaschenko et al. 2014) whereas the MAPA dataset was created for a TEM project designed to support the description and mapping of the ecosystems within the MAPA project study area. Sampling effort for the RA project limited data heterogeneity to improve the power of statistical analyses (Melaschenko et al. 2014) by constraining sampling to a select number of ecosystems. In contrast, the MAPA project was designed to capture the variability of the ecosystems on the landscape. The MAPA project is therefore more comprehensive in representing the phylogenetic diversity within HVC and the surrounding area.<sup>6</sup>

The proportion of numbers of native species to total number of observed species in both datasets is very high (MAPA=94.9%, RA=91.7%). As expected, species composition in non-mine sites was dominated by native species while introduced (agronomic) species dominated reclaimed mine plots. The proportion of non-invasive species in the datasets range between 90.8% (RA) and 93.7% (MAPA). A total of 5.1% of the species in the MAPA dataset and 8.7% in the RA dataset are invasive while 0.5% of the RA dataset and 1.2% of the MAPA dataset are considered noxious.

Frequency-of-occurrence plot data representing non-mining disturbed sites were pooled in both the MAPA and RA datasets, as were the plot data representing reclaimed mining disturbances. Taxonomic distinctness indices (see footnote above for definition) were calculated for each “treatment” and dataset. For the MAPA dataset, the non-mining disturbed data distinctness index was 3.876 whereas the reclaimed plot data had an index of 3.677. The reclaimed plot data in the RA dataset had a distinctness index of 3.872 compared with 3.665 for the non-mining disturbed data. Based on the taxonomic distinctness calculations, the reclaimed and non-mining disturbed “treatments” were considered different. Further analyses using biodiversity permutation tests with 8 diversity metrics (see preceding text) revealed floristically, as expected, that the non-mining plots and reclaimed mining plots in both datasets were significantly different (permutation  $p_{\text{equal}} = \text{MAPA}=0.0068, \text{RA}=0.0001$ ). In the MAPA dataset, common

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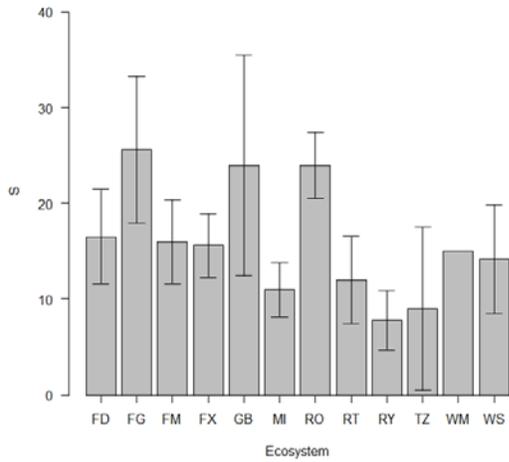
<sup>6</sup> The taxonomic distinctness index (Clarke and Warwick 1998) which describes the average taxonomic “distance” through phylogenetic relationships (e.g., order, family, and genus) by species in a dataset was applied comparatively to species-frequency data derived from the two datasets. Although the taxonomic distinctness (MAPA=3.866, RA=3.824) and the biodiversity profiles (Rényi entropy index; MAPA=3.852, RA=3.775) indicated that the datasets are comparable, subsequent biodiversity permutation tests with 8 diversity metrics (i.e., Shannon’s H, Evenness H/S, Simpson’s, Menhinick, Margalef, Equitability J, Fisher’s Alpha, and Berger-Parker) revealed that the two datasets were significantly different (permutation  $p_{\text{equal}} = \text{Simpson’s}=0.0001 - \text{Berger-Parker}=0.0369$ ) and that they should be analyzed separately. The datasets differ in composition because a greater variety of ecosystems were sampled in the MAPA program versus the more focused RA reclamation monitoring sampling. Despite these differences, the datasets were combined to create a comprehensive species list. The composite dataset contains a total of 335 species (7 trees, 38 shrubs, 160 forbs, 42 grasses, 13 sedges, 2 rushes, 2 fern-allies, 1 cattail, 30 mosses, 3 liverworts, and 37 lichens).

yarrow (*Achillea millefolium*), bearberry (*Arctostaphylos uva ursi*), pinegrass (*Calamagrostis rubescens*), wild strawberry (*Fragaria virginiana*), common juniper (*Juniperus communis*), lodgepole pine (*Pinus contorta*), and Douglas-fir (*Pseudotsuga menziesii*) had the highest frequencies of occurrence in the non-mining “treatment” whereas common yarrow, crested wheatgrass (*Agropyron cristatum*), alfalfa (*Medicago sativa*), and mullein (*Verbascum thapsus*) had the highest frequencies in the reclaimed mining “treatment”. In the RA dataset, common yarrow, bearberry, pinegrass, wild strawberry, lodgepole pine, low northern sedge (*Carex concinnia*), fireweed (*Epilobium angustifolium*), prickly rose (*Rosa acicularis*), soapberry (*Shepherdia canadensis*), birch-leaved spirea (*Spirea betulifolia*), and common nodding pohlia (*Pohlia nutans*) had the highest frequencies of occurrence in the non-mining “treatment” whereas common yarrow, crested wheatgrass, alfalfa, common nodding pohlia, smooth brome grass (*Bromus inermis*), creeping red fescue (*Festuca rubra*), hard fescue (*Festuca trachyphylla*), and Canada bluegrass (*Poa compressa*) had the highest frequencies in the reclaimed mining “treatment”.

Species richness (S) in the MAPA dataset was greatest in the moist forest (FG), grassland / brushland (GB) and rock outcrop (RO) ecosystems, and lowest in the mine (MI) reclaimed waste rock dump (RY) and reclaimed mine tailings (TZ) ecosystems (Figure 1). In the RA dataset, the moist forest (FG) had the greatest number of species with reclaimed mine tailings (TZ) having the lowest. Dispersion of the data was high for some of the MAPA ecosystems but relatively constant for the ecosystems in the RA dataset.

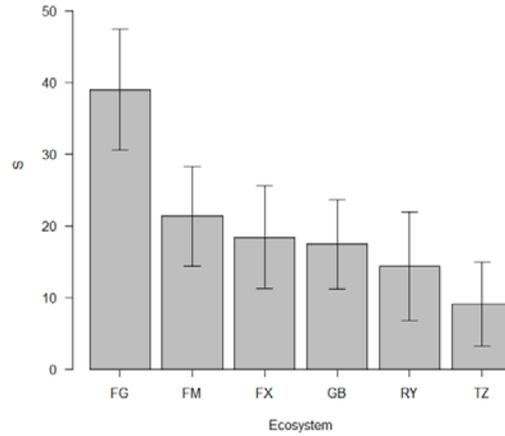
Simpson’s diversity index (D’) was calculated for each ecosystem (Magurran 2004). Diversity was comparable between both datasets with the highest species-based diversity reported for the forested ecosystems (FD, FG, FM, and FX), rock outcrop (RO), talus (RT), and wetland marsh (WM) ecosystems and lowest for the wetland swamp (WS) and the mining disturbances (MI, RY, and TZ) ecosystems (Figure 2). Diversity was most variable within the grassland (GB) and mining disturbed ecosystems. Increased sampling in several of the ecosystems at HVC will improve the understanding of alpha (within-ecosystem) and beta (between-ecosystem) species-based diversity.

MAPA



Key: FD – hydryc forest, FG – hydryc forest, FM – mesic forest, FX – xeric-subxeric, GB – grassland/brush land, MI – mine, RO – rock outcrop, RT – talus, RY – reclaimed mine, TZ – tailings, WM – wetland/marsh, and WS – wetland/swamp. Mean ± SD.

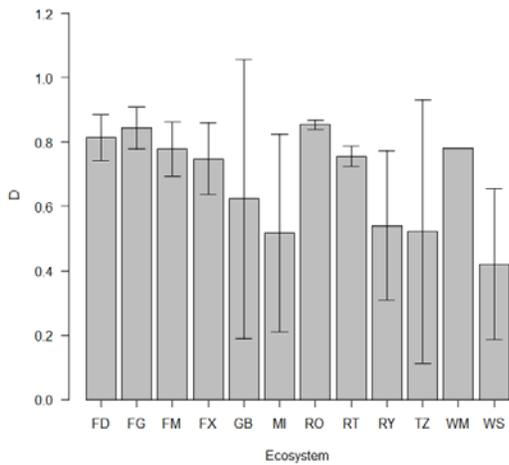
RA



Key: FG – hydryc forest, FM – mesic forest, FX – xeric-subxeric, GB – grassland/brush land, RY – reclaimed mine, and TZ – tailings. Mean ± SD.

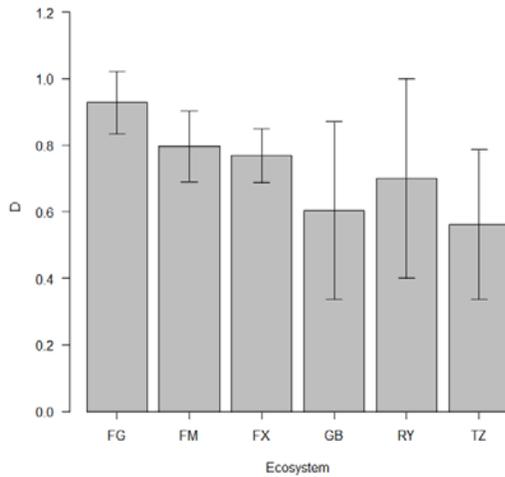
Figure 1. Species Richness (S).

MAPA



Key: FD – hydryc forest, FG – hydryc forest, FM – mesic forest, FX – xeric-subxeric, GB – grassland/brush land, MI – mine, RO – rock outcrop, RT – talus, RY – reclaimed mine, TZ – tailings, WM – wetland/marsh, WS – wetland/swamp. Mean ± SD.

RA



Key: FG – hydryc forest, FM – mesic forest, FX – xeric-subxeric, GB – grassland/brush land, RY – reclaimed mine, TZ – tailings. Mean ± SD.

Figure 2. Simpson's Diversity (D).

### Structural Diversity

Structural stage coding (BCMOFR/BCMOE 2010) was assigned to each of the plots in both datasets. The MAPA dataset contains a broad range of structural stages with the majority of the sample locations classified as herbaceous (HE) (42.6%), mature forest (MF) (20.6%), young forest (YF) (16.2%), and shrub (11.8%) (Figure 3). In contrast, the RA dataset consists primarily of herbaceous (HE) (68.0%) and shrub (SH) (28.0%) structural stages. The results are in part a reflection of the range of ecosystems sampled and also a consequence of the objectives of the respective sampling programs for each dataset. The RA reference plots, as per study design and implementation, are dominated by the low shrub structural stage whereas the MAPA dataset contains a greater variety of structural stages. Structural diversity will increase in the ecosystems represented by both datasets over time.

MAPA

RA

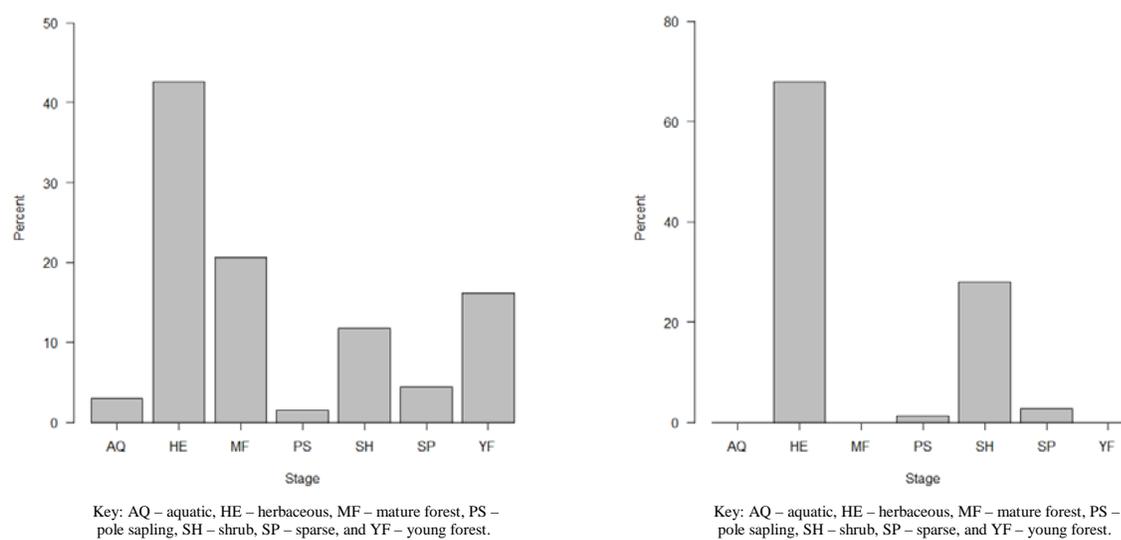


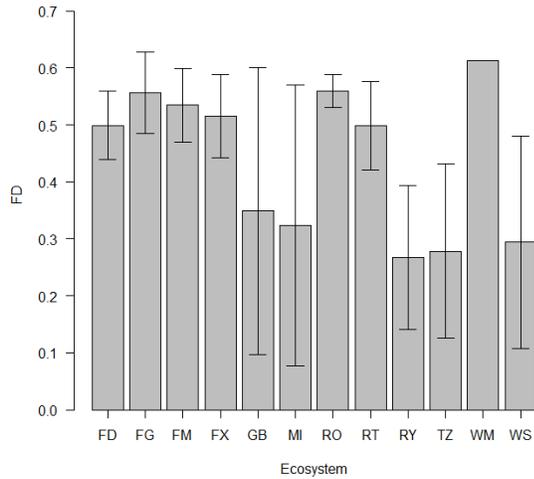
Figure 3. Structural Diversity.

### Functional Diversity

A compound index of functional diversity (FD) was calculated using the plant-trait data. In the MAPA dataset, functional diversity (Figure 4) is greatest for the wetland marsh (WM), moist forest (FG), and rock outcrop (RO) ecosystems and lowest for the reclaimed waste rock (RY), reclaimed mine tailings (TZ), wetland swamp (WS), grassland (GB), and mine pit (MI) ecosystems. For the RA dataset, the forested ecosystems (i.e., FG, FM, and FX) all have a greater functional diversity than the grassland (GB), reclaimed waste-rock (RY), and reclaimed mine tailings (TZ) ecosystems. Within-ecosystem “treatment” variability is most pronounced in the grassland / brushland (GB), mine (MI), reclaimed waste-rock (RY), reclaimed mine tailings (TZ), and wetland swamp (WS) ecosystems. The differences in diversity within these ecosystems may reflect variability in site potential or native species colonization / ingress limitations. As would be expected for species diversity, as new ecosystems develop on the mining disturbances, the difference in species and functional diversity between mined and non-mined sites should decrease provided there are no developmental process barriers. The functional diversity similarity between

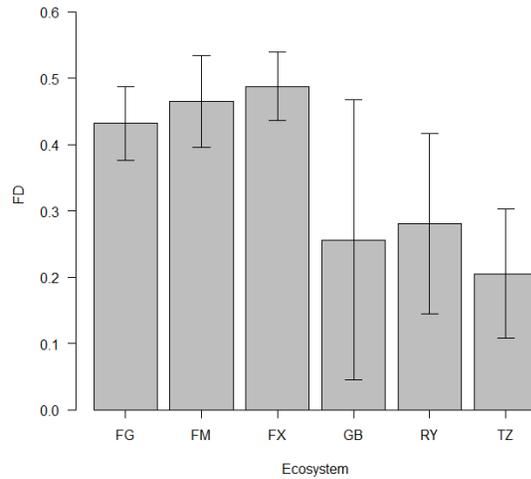
reclaimed mine disturbances and grassland / brushland ecosystems and their dissimilarity with the forested ecosystems is an important consideration in terms of reclamation objectives and monitoring trajectories at HVC.

#### MAPA



Key: FD – hydric forest, FG – hydric forest, FM – mesic forest, FX – xeric-subxeric, GB – grassland/brush land, MI – mine, RO – rock outcrop, RT – talus, RY – reclaimed mine, TZ – tailings, WM – wetland/marsh, WS – wetland/swamp. Mean  $\pm$  SD.

#### RA



Key: FG – hydric forest, FM – mesic forest, FX – xeric-subxeric, GB – grassland/brush land, RY – reclaimed mine, TZ – tailings. Mean  $\pm$  SD.

Figure 4. Functional Diversity (FD).

#### Plant Traits – Life History

Life-history data when combined with other plant traits data can reveal important population and structural / functional dynamics in developed and developing ecosystems (Gurevitch et al. 2006, Alday et al. 2011). The dominant plant life-histories in both datasets were herbaceous perennials (MAPA=56.5%, RA=58.7%), followed by long-lived non-vascular plants (MAPA=23.3%, RA=17.5%) and woody perennials (MAPA=13.4%, RA=14.6%). The proportion of non-vascular plants (i.e., lichens, liverworts, and mosses) was lower in the RA dataset due to the presence of a greater proportion of reclaimed sites in which this group of plants is slower to reestablish. Annuals (MAPA=2.4%, RA=3.9%) and biennials (MAPA=2.0%, RA=2.9%) constitute a small proportion of the plant groups represented and are typically limited to disturbances such as gravel and paved road verges of non-reclaimed sites or mining disturbances with limited vegetation cover.

#### Plant Traits – Life-Form

The Raunkiaer (1934) life-form classification uses the location of buds on a plant and the way that these resting organs survive periods of stress such as temperature extremes or drought to explain plant-environment interactions (Gurevitch et al. 2006). When combined with other morphological plant traits such as life history and growth habit, life-form assessments can provide a more complete picture of structural diversity.

Hemicryptophytes (herbaceous plants with the buds located at the ground surface) dominate both HVC datasets (MAPA=80.6%, RA=82.5%). The next most prominent life-form class are nanophanerophytes (woody perennials with buds located between 0.5 – 2 m above the ground; MAPA=9.1%, RA=9.2%). Chamaephytes (woody or semi-woody perennials with their perennating bud < 0.5 m from the ground) comprise 2.4% of the MAPA dataset and 3.4% of the RA dataset whereas mesophanerophytes (woody perennials with buds located between 8 – 30 m above the ground) comprise between 2.8% of the MAPA dataset and 2.4% of the RA dataset. Helophytes (perennating bud is below the water surface) constitute a small proportion of the MAPA dataset (aquatic ecosystems were not sampled as part of the RA program). Cryptophytes (buds below the soil or water surface), geophytes (storage organ below soil surface), microphanerophytes (woody perennials with buds located between 2 – 8 m above the ground), and therophytes (annuals) all have proportions of less than 1% within both datasets.

The results of the life-form assessment reflect the young stage of ecosystem development in the RA dataset and the frequency of low- to mid-stature plants in the MAPA dataset. With successional development, the proportions of life-forms in both datasets will change but in divergent directions and for different reasons. For example, hemicryptophytes, chamaephytes, and nanophanerophytes overtime will dominate grassland / brushland and / or drier open forest site-potential habitats whereas taller-stature woody mesophanerophytes will likely dominate areas with more mesic site-potential habitats.

#### Plant Traits – Growth Habit

The shape, appearance, and mode of growth of plants have important implications for vertical and horizontal vegetation structure, ecological functioning, resource acquisition and allocation, and inter- and intra-specific interactions (Gurevitch et al. 2006). Growth form is associated with ecophysiological adaptations to photosynthetic production, protection for climatic conditions, and optimal positioning to avoid or resist herbivory (Pérez-Harguindeguy et al. 2013).

Fourteen growth habit classes were assigned from the standardized functional trait categories of (Pérez-Harguindeguy et al. 2013). The most common growth habits are the extensively-stemmed herbs (MAPA=32.0%, RA=42.2%) and the elongated, leaf-bearing rhizomatous (MAPA=25.7%, RA=20.9%) categories. These growth forms are prominent in both disturbed and undisturbed ecosystems, regardless of ecosystem structural stage. Woody species (<5 m in height) are common, in forest harvesting cut blocks and the understories of young and mature forests. Excurrent (i.e., single stem) trees such as Douglas-fir (*Pseudotsuga menziesii* var. *glauca*) are prominent in young and mature forests with deliquescent (i.e., multiple, semi-equal branching) trees such as trembling aspen (*Populus tremuloides*) less common. The prostrate growth habit of many bryophytes (MAPA=8.3%, RA=2.9%) and the fruticose growth habit of *Cladonia* spp. lichens (MAPA=7.9%, RA=6.8%) are important components of many undisturbed understories but are less prominent in the early seral stages of forest-harvested landscapes and in the reclaimed landscapes of the HVC waste-rock dumps and tailings ponds.

Different growth forms permit species coexistence and therefore increase species richness and overall biodiversity. The differences in above-ground architecture alter the interception of sunlight, precipitation, and particulates which in turn affects the resources available to plants (Gurevitch et al. 2006). The architecture also creates habitats and / or niches to satisfy the life-requisites of different guilds of animals.

### Plant Traits – Leaf Duration

The longevity of assimilated resources by plants reflects specific relative growth rates (RGRs) and the rate of organic-matter inputs to the ecosystem (Gurevitch et al. 2006). From a plant-centric perspective, carbon management is related to differing nutrient conservation strategies and adaptations to stress (Chabot and Hicks 1982).

The majority of the ecosystems sampled are dominated by both herbaceous and woody species that are classified as deciduous (MAPA=65.6%, RA=74.3%) which means, therefore, that there is an important annual influx of decomposing organic matter available for soil development and mineral cycling. Although the biomass of needle-shaped leaves is considerable, the organic-matter inputs to the sampled pole sapling to mature coniferous forested sites are limited. The occurrence of species that retain their dead leaves are variable (MAPA=20.2%, RA=9.2%), with this plant trait more common in non-mining disturbed areas. A special case of non-needle perennial leaves was applied to mosses and lichens; the proportion of these species in the datasets was 10.7% for the MAPA dataset and 12.1% for the RA dataset.

### Plant Traits – Rooting Architecture and Rooting Depth

Diversity in root traits among species has important implications for intra- and inter-specific interactions (Collins and Bras 2007, Pérez-Harguindeguy et al. 2013). Roots are the principal organs for water and nutrient acquisition in vascular plants and must be responsive to resource heterogeneity at different spatial and temporal scales (Jackson et al. 2007).

Rhizomatous (MAPA=28.5%, RA=23.3%) and taproot (MAPA=27.3%, RA=33.5%) systems are the dominant root architectures, followed by fibrous (MAPA=18.6%, RA=21.4%) systems. The fibrous root systems are associated with many of the seeded agronomic species. Non-vascular bryophyte rhizoids (MAPA=12.6%, RA=5.8%) and lichen rhizines (MAPA=10.7%, RA=11.7%) are less common in general. Rhizoid systems more limited in early seral stages because many of the moss species arrive later in the successional sequence.

Plant species in the datasets were classified using the rooting depth categories of Woźniak et al. (2011). The rooting depths of the majority of the species were within the 10 – 50 cm range and reflect the dominance of herbaceous perennials and low-stature woody species or shrubs. Specific rooting depths greater than 50 cm are typically limited to trees and therefore to later seral stage forested sites and older forest harvested sites. Rooting depths less than 10 cm are restricted to non-vascular plants (i.e., mosses, liverworts, and lichens) and some prostrate or procumbent growth habit annuals.

The depth to which roots penetrate determines the soil volume accessible for moisture supplies and, in some cases, reflects when moisture is available during the growing season. The differences in rooting architectures and depth represent important subsurface niche diversification and ultimately species coexistence and richness.

### Plant Traits – Moisture-Use Strategy

Moisture availability is an important driver or limiting factor in individual species establishment, persistence and growth, and in overall ecosystem processes (Gurevitch et al 2006). Classification of plants according to a relative assignment of moisture use is helpful as a qualitative indicator of soil moisture availability. Four categories of moisture-use (hydric, subhygric, mesic, and xeric [Dunster and Dunster 1996]) were applied to the datasets. The majority of the species in both datasets (MAPA=80.2%, RA=90.3%) were categorized as mesophytes (average soil moisture regime [SMR]), 11.1% of the species in the MAPA dataset and 5.3% of the species in the RA dataset were categorized as hygrophytes (moist SMR), 4.3% of the species in the MAPA dataset and 3.9% of the species in the RA dataset were categorized as xerophytes (very dry SMR), and 4.3% of the species in the MAPA dataset and 0.5% of the species in the RA dataset were categorized as hydrophytes (very wet SMR).

The diversity of plants with different moisture-use strategies was relatively low, possibly reflecting relatively broad ecological amplitudes of many of the species in the datasets, facilitating practices such as hydraulic lifting by companion species and / or abiotic compensating factors such as shading (Callaway 2007).

#### Plant Traits – Nutrient-Use Strategy

The efficiency of nutrient assimilation, allocation, and cycling is an important emergent property of ecosystems. The performance of different species in nutrient-limited ecosystems is affected by interspecific differences in nutrient-uptake capacity. Many plants also exploit symbiotic associations with bacteria or fungi to enhance their nutrient-competitive ability (Pérez-Harguindeguy et al. 2013).

Each of the species in the two datasets were classified using fifteen nutrient-use strategies identified from the literature referenced previously. The proportion of species that possessed some form of symbiotic relationship ranged from 79.5% for the MAPA dataset to 81.6% for the RA dataset. The high proportion of symbiotic relationships represents the importance of belowground species interactions. A greater proportion of symbiotic plants are documented for the RA dataset which has a larger number of agronomic species with symbiotic relationships than the MAPA data.

Symbiotic relationships with vesicular arbuscular mycorrhizae (VAM) is the most common strategy in both datasets (MAPA=41.1%, RA=42.2%) and transcend herbaceous and woody species lifeforms. The conifers (Pinaceae) and some willow species (Salicaceae) are ectomycorrhizal. The proportions of species that are ectomycorrhizal, primarily conifers, range from 6.8% for the RA dataset to 7.5% for the MAPA dataset.

The proportion of rhizobia-inoculated plants ranges from 2.4% for the MAPA dataset to 6.3% for the RA dataset while the proportion of actinorhizal symbiotic plants ranges from 0.8% for the MAPA dataset to 1.5% for the RA dataset. The rhizobium nitrogen-fixers in the two datasets are all herbaceous perennials while the actinorhizal species are all woody perennials. The greater proportion of nitrogen-fixers present on reclaimed mine disturbances are due to the purposeful seeding of species such as alfalfa (*Medicago sativa*) as part of operational reclamation practices at HVC. Some of the species such as the legumes (agronomic and native) have both rhizobial and VAM relationships.

The proportions of plants with arbutoid (ARB), dark septate endophytes (DSE), dematiaceous surface fungi (DSF), ectendomycorrhizae (EEM), ericoid (ERM), hyaline septate endophyte (HSE), orchid mycorrhizae (ORM), and pyroloid mycorrhizae (PYM) symbiotic relationships are very small (< 1.0% each). Between 5.8% and 8.7% of the species recorded in both datasets are confirmed as non-mycorrhizal, of which, many are members of the mustard family (Brassicaceae) and the sedge family (Cyperaceae).

The proportion of species that employ absorption through leaves as the primary mechanism for nutrient assimilation (i.e., mosses and liverworts) range from 5.8% for the RA dataset to 12.6% for the MAPA dataset while the proportion of species (primarily lichens) that use an ion exchange/particulate entrapment absorption mechanism to assimilate dry and wet particulates range from 10.7% (MAPA) to 11.7% (RA). Literature describing specific nutrient-use strategies was lacking for 15.0% of the MAPA dataset species and 22.3% of the RA dataset species.

#### Plant Traits – Shade Tolerance

Shade tolerance was classified as tolerant, semi-tolerant, or intolerant (NRCS 2015). The proportions of each category were relatively evenly distributed: tolerant (MAPA=32.4%, RA=27.7%), semi-tolerant (MAPA=30.4%, RA=34.0%), and intolerant (MAPA=37.2%, RA=38.3%). Access to sunlight, or lack thereof, is a potential stressor in ecosystems and is often an important determinant of the sorting of species in an ecological succession time series. Shade tolerance has a direct relationship to Grime's ecological life history traits and to the design and management of recovering ecosystems.

#### Plant Traits – Ecological Life History Strategy

Grime (2002) classified plants based on a CSR ternary construct of competitors (C), stress-tolerators (S), and ruderals (r). Competitors (C) allocate available resources to growth and are very efficient at assimilating resources and excluding resources from accompanying species. Stress-tolerators (S) occupy resource-limited (e.g., low soil moisture, low light, or low nutrient) habitats and allocate assimilated resources to maintenance and defense. Ruderals (r) (weedy species) typically occupy temporary or frequently disturbed habitats and allocate assimilated resources to reproduction.

The species in the HVC datasets were qualitatively assigned individual C-S-R codes or composite codes based on their structural, physiological, reproductive, and ecological attributes. Stress-tolerators (S) represent 93.7% of the RA dataset and 95.3% of the MAPA dataset. Ruderals (r) comprise between 16.2% of the MAPA dataset and 22.3% of the RA dataset while competitors (C) constitute 9.5% of the MAPA dataset and 13.1% of the RA dataset. The competitor (C) species are typically trees, tall shrubs, and, in some cases, herbaceous agronomic species.

Several species are classified as having composite CS (MAPA=2.8%, RA=2.9%), SR (MAPA=9.1%, RA=10.7%), and CSR (MAPA=4.0%, RA=7.3%) attributes. The composite ecological-strategy-coded species are typically associated with stressful habitats. The CSR-coded species were almost exclusively agronomic species seeded onto the mining disturbances. Agronomic species are particularly effective in assimilating resources, dominating habitats, and persisting through growth and sexual/asexual reproduction. With successional development and concomitant species turnover, the prominence of C-

strategists and R-strategists is expected to increase (Prach et al. 1997). Changes in the proportions of CSR strategies with time should create greater beta (between-type) diversity.

#### Plant Traits – Sexual and Asexual Reproduction

Reproductive traits are important determinants of species colonization, persistence, and population expansion (Gurevitch et al. 2006, Alday et al. 2011). The traits examined included sexual and asexual (vegetative) reproduction and mode of propagule (sexual and asexual) dispersal.

Species in the datasets were categorized according to their ability to reproduce sexually and asexually. The three-code sexual reproduction and seven-code asexual reproduction systems listed by Pérez-Harguindeguy et al. (2013) were applied.

Sexual reproduction is common to all species in the datasets. Sexual reproduction occurs via seeds in vascular plants or via spores in bryophytes and lichens.

In terms of asexual reproduction, the greatest proportion (MAPA=39.1%, RA=48.1%) of the species in the datasets do not possess an observable vegetative means of reproduction. Vegetative reproduction via rhizomes was recorded for 23.3% of the species in the RA dataset and 28.5% of the species in the MAPA dataset while fragmentation was recorded for 17.5% of the species in the RA dataset and 23.3% of the species in the MAPA dataset. Fragmentation was the most common mode of vegetative reproduction for non-vascular plants. Layering is common in woody species but only represented 5.9% of the species in the MAPA dataset and 6.8% of the species in the RA dataset. Reproduction via stolons and suckering are uncommon in the HVC datasets (< 1.0%). The proportion of tubers as vegetative reproduction organs range from 2.0% in the MAPA dataset to 3.4% in the RA dataset. Overall, sexual reproduction appears to be more important for medium- to long-distance establishment while vegetative reproduction appears to be more important to occupancy of biological space and persistence.

#### Plant Traits – Propagule Dispersal

The arrival and distribution of propagules (sexual and asexual) is highly variable and is an important determinant of ecosystem species composition, ecosystem functioning, and ecosystem development trajectories (Prach et al. 1997, Pywell et al. 2003).

The dispersal of both sexual and asexual propagules was classified for all species in the datasets. Most species possess multiple mechanisms of dispersal with several having primary, secondary, or tertiary mechanisms. The dominant dispersal mechanism is wind (anemochorous) (MAPA=66.4%, RA=60.7%). Between 40.7% of the species in the MAPA dataset and 44.2% of the species in the RA in the dataset do not have a specialized primary dispersal mechanism (autochory) and rely on opportunistic mechanisms such as ombrochory (raindrop splashes) and boleochory (animal-strikes-plant) to disperse propagules.<sup>7</sup> Endozoochory (internal animal transport) as a dispersal mechanism is employed by 9.1% of the species in the MAPA dataset and by 14.6% of the species in the RA dataset while epizoochory (external animal

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<sup>7</sup> Boleochory occurs in 7.1% of the MAPA-dataset species and 7.3% of the RA-dataset species while ombrochory occurs in 4.0% of the MAPA-dataset species and 4.4% of the RA-dataset species.

transport) occurs in 9.5% of the species in the MAPA dataset and 9.7% of the species in the RA dataset. Ballistic (ballistochory) dispersal is limited to lupine and geranium species (MAPA=0.4%, RA=1.5%). Hydrochory (water-mediated transport) only occurs in water-dominated habits and was only recorded (6.3%) in the MAPA dataset. Between 28.9% of the MAPA dataset species and 34.0% of the RA dataset species have multiple dispersal mechanisms.

#### Plant Functional Group Classification

Piekarska-Stachowiak et al. (2014) suggested that analyses using plant functional groups can provide important insights into the development of ecosystems on mine disturbances. The indicator analysis (IA) module in PC-ORD Version 6.0 (McCune and Mefford 2011) was applied to the plant-trait data as categorized by ecosystem unit. All plant-traits described in the preceding text (Section 4.4) except the nutrient-use-strategy (NUS) trait were included in the analyses.<sup>8</sup> As well, 17 plant-trait classes in the MAPA dataset and 32 plant traits in the RA dataset were excluded in the initial stages of the IA because they were determined analytically to be non-discriminating. The results of the IA indicate that currently, the Raunkiaer life form, growth habit, rooting architecture, moisture-use strategy, and clonality plant traits are the most important indicators of ecosystem functioning and structure in the datasets. Using permutation tests, 4 plant trait categories in the RA dataset and 13 in the MAPA dataset were significantly different statistically ( $p=0.05$ ).

While some of the plant traits identified as indicators are correlated (i.e., clonality with rooting architecture or growth habit with Raunkiaer life form), examining differences in these traits provides insight into processes that affect/mediate species interactions (i.e., moisture use, light capture, and nutrient availability) and cause niche partitioning. Niche partitioning increases species diversity potential. Over time, it is expected that the relative importance of different traits will change in response to differential plant establishment and growth as constrained by abiotic habitat filters.

#### **SUMMARY**

The results presented in this paper are based primarily on floristic (plant species) data collected typically as part of baseline or monitoring studies at mines and secondarily on plant-trait data derived from a plant-traits database. Analyses where species-based data collected at the mines (conventional practice) are combined with trait-based data (non-conventional practice) provide useful information for environmental managers and reclamation practitioners tasked with managing existing ecosystems within or adjacent to mine leases and for designing and monitoring reclaimed landscapes. By combining these two types of analyses, it is possible to design species mixes and planting prescriptions that incorporate more directly mechanisms / drivers of vegetation dynamics such as facilitation and competition. Complementary analyses will also improve our understanding of ecosystem processes and biodiversity recovery on reclaimed mine sites. The analyses do not require the collection of additional field data although the availability of a plants-traits database is required. The results of the HVC analyses are summarized briefly.

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<sup>8</sup> The NUS plant trait was not used because categorical data was lacking for between 15.0 and 22.3% of species in the respective datasets.

- Currently, species richness and diversity is lower on reclaimed mine disturbances compared with non-mined disturbed or “undisturbed” forest cut block ecosystems in the surrounding landscapes. The differences in species richness and diversity reflect the relatively early stage of vegetation recovery at HVC as well as current revegetation practices. The new planting prescriptions proposed for HVC will decrease the difference in floristic composition between off-site and on-site in the early seral stages of reclaimed mine disturbances.
- Forbs and secondarily shrubs are the most common growth forms comprising the species diversity within HVC and the vicinity of mine operations. The area surrounding the mine has a number of non-mining related cut blocks which influences strongly the growth form assessment results.
- Structural and functional diversity are lower in the reclaimed mine disturbances as compared to non-mined areas. Structural diversity and functional diversity indices calculated for both datasets reflect the early seral stage status or youthfulness of the ecosystems in the area in part as well as revegetation practices. As mentioned previously, changes in plant prescriptions at HVC will alter this result for future reclamation efforts.
- Depending on site conditions, seeded agronomic species on the mine have composite competitive (C), stress-tolerator (S), ruderal (r), strategies that enable them to establish, persist, and dominate. The composite C-S-R behavior of these species has implications for ecosystem development that should be considered in the design and management of the reclaimed mine disturbances. For example, as succession progresses, composite C-S-R strategies are likely to diminish in importance with, depending on site conditions, a greater proportion of either C-dominated or S-dominated species to be more prominent. Consideration of C-S-R strategies is also important in the design of planting prescriptions where non-competitive or stress-tolerant native species are to be established.
- Currently, Raunkiaer life-form, growth habit, rooting architecture, moisture-use strategy, and clonality plant-traits are the most important indicators of ecosystem functioning and structure in the datasets. These traits should be considered in the design of plant prescriptions and factored into the interpretation of monitoring results.
- Propagule dispersal was not found to be a plant trait indicator, unlike other studies (e.g., Alday et al. 2011). The sampling programs focused on sites for secondary succession with residual propagules or where revegetation practices have introduced short distance dispersal agronomic species. Broadening the RA sampling to include ecosystems with spontaneous colonization (no deliberate revegetation) such as non-reclaimed mine waste will likely reveal plant functional groups that possess long-distance dispersal mechanisms as a trait.
- Species-based and functional diversity analyses are complementary with functional traits analysis in understanding the structure and function of historic and developing ecosystems. Plant-traits assessments and functional diversity analyses are useful for assessing plant-habitat relationships

because the underlying pattern in the data can be more easily understood when the data are organized *a priori* according to traits before analyses.

- Plant-traits change with ecosystem development (Prach et al. 1997, Piekarska-Stachowiak et al. 2014), so monitoring plant-traits along with species turnover can reveal trends in ecosystem processes. Plant functional traits data grouped into plant functional groups (PFGs) provides additional insights into ecosystem development / biodiversity recovery and the possible need for management interventions.

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