Vegetation Index of Biotic Integrity (VIBI) for Headwater Wetlands in the Southern Rocky Mountains

Version 2.0: Calibration of Selected VIBI Models

March 16, 2009

Colorado Natural Heritage Program
Colorado State University
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Version 2.0: Calibration of Selected VIBI Models

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EXECUTIVE SUMMARY

The primary objective of the Clean Water Act is to "maintain and restore the chemical, physical, and biological integrity of the Nation's waters," which include wetlands (US EPA 2002a). Although Colorado has an ongoing water quality monitoring program for rivers, streams, lakes and reservoirs, data documenting the integrity of Colorado's wetlands are limited. In order to make informed management decisions, credible data on wetland condition are needed. To this end, the Colorado Natural Heritage Program (CNHP) has developed a vegetation index of biotic integrity (VIBI) for selected headwater wetland types within the Southern Rocky Mountains of Colorado (Rocchio 2006b, Rocchio 2007b). Colorado’s VIBI is a valuable tool that can be used to evaluate wetland restoration and protection projects, monitor the success of on-going management practices, and assess overall wetland condition within a given landscape.

Initial VIBI development took place in two phases (Phases 1 & 2) over three field season (2004–2006) within three central Colorado watersheds. This report documents the third phase of the Colorado wetland VIBI project. Goals of Phase 3 were to: (1) validate or calibrate Version 1.0 VIBI models with additional independent data from the original study watersheds; (2) test the geographic range of Version 1.0 VIBI models with data collected in new watersheds; (3) construct Version 2.0 VIBI models based on the calibration results; and (4) quantify scoring thresholds for condition classes and identify quantitative and descriptive differences between these condition classes.

In Phase 3 of the VIBI project, a total of 38 plots were sampled during the summer of 2007. Most data collection occurred in the Upper Blue River and South Platte River Headwaters in central Colorado to test Version 1.0 models with additional data from similar wetlands. To validate the VIBI’s applicability to the entire Southern Rocky Mountain Ecoregion, nine plots were sampled in the San Juan Mountains. During Phases 1 & 2, VIBI models were developed for five separate wetland types: 1) riparian shrublands, 2) fens, 3) extremely rich fens, 4) slope wet meadows, and 5) riverine wet meadows. Due to limited time and resources, only three of the five previously developed VIBI models were targeted during Phase 3. The three targeted models include the riparian shrubland, fen, and slope wet meadow VIBI models.

Based on Version 1.0 VIBI metrics and models, Phase 3 plots showed weaker correlation coefficients to the human disturbance gradient than Phase 1 & 2 plots for all three models tested. This indicated that the models should be calibrated with the additional data. Models were calibrated by screening 133 separate vegetation metrics and retaining, modifying, or adding metrics. For each wetland type, the strongest combination of original, revised, or additional metrics was selected as the Version 2.0 model. Model calibration produced three robust VIBI models with strong correlations to the human disturbance gradient (R_s ranging from -0.78 to -0.87). Twenty metrics in total were selected for inclusion in the three Version 2.0 models. Version 1.0 VIBI models included five to nine metrics per model, but this was increased to nine metrics per model during calibration. Final Version 2.0 metrics varied according to ecological system type and no metric was included in all three of models.

Once Version 2.0 models were calibrated, analysis of variance (ANOVA) and classification and regression tree (CART) models were used to translate VIBI scores into discrete biotic integrity condition classes such as high, moderate, or low integrity. Ranges for individual metrics and overall VIBI scores were calculated for each condition class and indicator species analysis was used to identify species strongly associated with each condition class. The riparian shrubland and fen models could both reliably distinguish between three condition classes, while the slope wet meadow model could only distinguish two classes. The range of metric and overall VIBI scores calculated provide a quantitative description of differences between wetlands in each condition class. Paired with the indicator species, this information can be used to recognize wetland sites that are degraded and in need of management attention.

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1.0 INTRODUCTION

The primary objective of the Clean Water Act is to "maintain and restore the chemical, physical, and biological integrity of the Nation's waters," which include wetlands (US EPA 2002a). Although Colorado has an ongoing water quality monitoring program for rivers, streams, lakes and reservoirs,[1] data documenting the integrity of Colorado's wetlands are limited. Simply calculating the wetland acreage lost or gained does not provide scientific information about the integrity of wetlands destroyed, impacted, restored, or protected. In order to make informed management decisions aimed at minimizing loss or protecting wetland acreage and function, credible data on the quality of wetlands are needed. It is not practical to measure every human impact to wetlands, since these disturbances are numerous and complex. However, measuring the integrity of the biological community provides a means to evaluate the cumulative effect of all the stressors associated with human disturbance (US EPA 2002a). To this end, the Colorado Natural Heritage Program (CNHP) has developed a vegetation index of biotic integrity (VIBI) for selected headwater wetland types within the Southern Rocky Mountains of Colorado (Rocchio 2006b, Rocchio 2007b).

An index of biotic integrity (IBI) is a cost-effective and direct way to evaluate the biotic integrity[2] of a wetland by measuring attributes of the biological community known to respond to human disturbance (Karr & Chu 1999, US EPA 2002a). CNHP developed a vegetation-based IBI because vegetation is known to be a sensitive measure of human impacts to wetlands. The scientific basis for using vegetation in lieu of other taxa is derived from the following: (1) wetland vegetation structure and composition provides habitat for other taxonomic groups such as waterbirds, migratory songbirds, macroinvertebrates, fish, large and small mammals, etc.; (2) strong correlations exist between wetland vegetation and water chemistry; (3) wetland vegetation influences most wetland functions; (4) wetland vegetation supports the food chain and is the primary vector of energy flow through an ecosystem; (5) plants are found in all wetlands and are the most conspicuous biological feature of wetland ecosystems; (6) many wetland classifications (including CNHP's Colorado Wetland Classification) use vegetation as their basis; and (7) ecological tolerances for many plant species are known and could be used to identify specific disturbances or stressors that may be responsible for a change in wetland biotic integrity (US EPA 2002b).

Colorado's VIBI is a valuable tool that can be used by land managers to monitor and evaluate (1) the performance of wetland restoration, enhancement, and creation projects; (2) the success of preserving ecological integrity via wetland protection projects; and (3) the effectiveness of on-going management practices. The VIBI can also be used to assess

[1] For more information on water quality monitoring in Colorado, see the Colorado Department of Public Health and Environment, Water Quality Control Division website: www.cdphe.state.co.us/wq/.

[2] Biological integrity is defined by Karr and Dudley (1981; as cited in U.S. EPA 2002a) as the ability of a wetland to "support and maintain a balanced adaptive community of organisms having a species composition, diversity, and functional organization comparable to that of natural habitats within a region."

overall wetland quality on a basinwide or statewide basis, indirectly evaluate water quality within a watershed, and prioritize funds for wetland restoration and protection projects. Recently, the Colorado Division of Wildlife (CDOW)'s Wetlands Program initiated development of a statewide strategy to monitor wetland restoration and protection projects funded through the Program and to prioritize future funding decisions. Incorporating the Colorado VIBI into this monitoring strategy will greatly augment CDOW's ability to measure the biological integrity of the Program's projects. Regulatory agencies, such as the Colorado Department of Public Health and Environment (CDPHE) and the Army Corps of Engineers (ACOE), could also use the VIBI to monitor the success of wetland mitigation projects, and the VIBI could assist other federal, state, and local agencies in evaluating their wetland resource. Lastly, the VIBI will aid CNHP in identifying more accurate ranking specifications for wetland occurrences of biodiversity significance tracked in CNHP's Biotics database.

Initial VIBI development took place in two phases ***(Phases 1 & 2)*** over three field season (2004–2006: Rocchio 2006b, Rocchio 2007b). Headwater wetlands and riparian areas were selected for sampling from within the montane and subalpine zones of the Colorado River Headwaters, the Upper Blue River, and the South Platte River Headwaters watersheds. These watersheds were chosen because they are under increasing threat from development and contain most of the major wetland types known within the Southern Rocky Mountain (SRM) Ecoregion (Omernik 1987). In addition, extensive prior work on wetland mapping and assessment had been completed in these watersheds and greatly aided VIBI development by providing potential samples sites as well as site history and other pertinent ecological information (CNHP 1995a, CNHP 1995b, White Horse Associates 1996, CNHP 1997, CNHP 2000, SAIC 2000, Johnson 2001, Johnson 2002, Johnson & Gerhardt 2002). The VIBI models developed within these watersheds showed strong correlations to human disturbance and serve as representative models upon which to expand to the entire SRM Ecoregion.

This report documents the third phase of the Colorado wetland VIBI project. Goals of ***Phase 3*** are to: (1) validate or calibrate Version 1.0 VIBI models with additional independent data from the original study watersheds; (2) test the geographic range of Version 1.0 VIBI models with data collected in new watersheds within the SRM Ecoregion; (3) construct Version 2.0 VIBI models based on the calibration results; and (4) quantify condition classes and scoring thresholds based on the VIBI models and identify quantitative and descriptive difference between condition classes. Condition classes translate the continuous VIBI score into meaningful categories (such high, moderate, or low integrity) that can be easily interpreted by land managers and decision makers.

2.0 STUDY AREAS

To minimize potential geographic variation, sampling for initial VIBI development (Phases 1 & 2) focused on three Hydrologic Unit Code (HUC) Level 8 watersheds within central Colorado (Figure 1): Colorado River Headwaters (HUC 8: 14010001), Upper Blue River (HUC 8: 14010002), and South Platte River Headwaters (HUC 8: 10190001). During the calibration phase (Phase 3), sampling occurred within two of the original study watersheds to test Version 1.0 models with additional data from similar wetlands (Upper Blue River and South Platte River Headwaters: collectively referred to "Summit/Park Counties"). To validate the VIBI's applicability to the entire SRM Ecoregion, additional sampling took place within several HUC 8 watersheds in the San Juan Mountains in southwestern Colorado (Figure 1). General descriptions of the study areas included in Phase 3 are provided below.

2.1 Upper Blue River Watershed

The Upper Blue River watershed (HUC 8: 14010002) generally corresponds with the political boundaries of Summit County, which straddles the west flank of the Continental Divide and is approximately 176,922 hectares (437,183 acres). Elevations range from 4,280 m (14,265 ft) on Quandary Peak to 2,274 m (7,580 ft) where the Blue River leaves Summit County. More than 85% of the county is above 9,000 ft. The watershed is bordered by the Gore Range on the northwest, the Williams Fork Mountains on the northeast, and the Tenmile Range on the west. Hoosier Pass and Loveland Pass lie on the continental divide, which forms the watershed boundary to the south and east. Major tributaries to the Upper Blue River include the Swan River, Snake River, and Tenmile Creek. Three major reservoirs (Blue Lakes, Dillon Lake, and Green Mountain) influence the Blue River and its associated wetlands.

The climate is generally characterized by long, cold, moist winters, and short, cool, dry summers. The Town of Dillon, where climate data are recorded, receives approximately 41 cm (16 in) of precipitation each year and the average total snowfall is 323 cm (127 in). Average annual minimum and maximum temperatures are -8^{o} and 11^{o} C (18^{o} and 52^{o} F), respectively. Average minimum monthly temperature during the coldest month (January) is -18^{o} C (-1^{o} F), while average maximum monthly temperature for the warmest month (July) is 23^{o} C (74^{o} F) (Western Regional Climate Center 2008). These data reflect mid-elevation regions of the watershed along the I-70 corridor; higher elevations experience colder temperatures and greater snowfall, while the lower elevations are warmer and drier.

The geology of Summit County is complex. The Williams Fork Mountains, Gore Range, and the Tenmile Range consist of Precambrian granitic rock with several faults (Tweto 1979). The lower Blue River Valley at the base of the Williams Fork Mountains consists of Pierre Shale. There are outcrops of Dakota sandstone near the Dillon Dam. High elevation outcrops of Leadville limestone are found in the southern portion of the county.

The Blue River Valley has glacial origins as evidenced by the numerous boulder-strewn moraines (Chronic 1980).

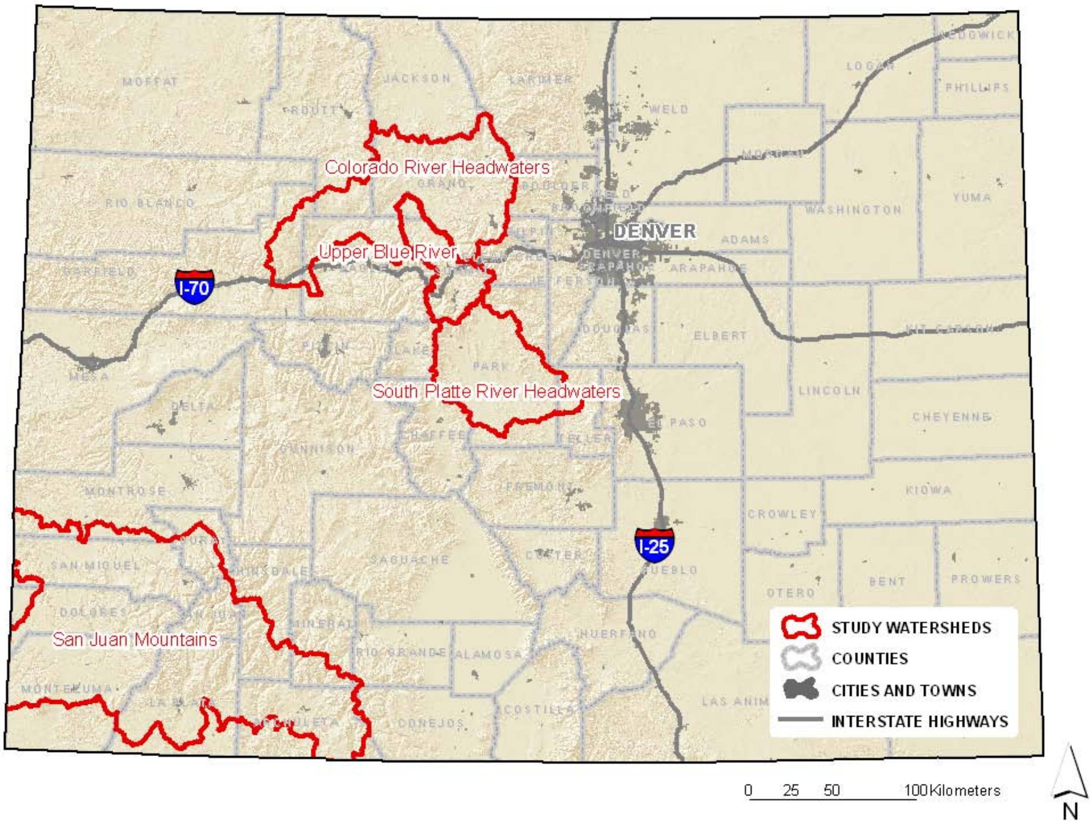

Figure 1. State of Colorado showing study areas. The Colorado River Headwaters is located primarily in Grand County, the Upper Blue River is in Summit County, and the South Platte River Headwaters is in Park County. The San Juan Mountains study area spans several watersheds and several counties, including portions of San Miguel, Dolores, Montezuma, Ouray, San Juan, La Plata, Hinsdale, Mineral, and Archuleta Counties.

Typical Southern Rocky Mountain flora is prevalent in Summit County. Elevations between approximately 2,200–2,400 m (7,500–8,000 ft) are dominated by *Amelanchier alnifolia* (service berry), *Artemisia tridentata* ssp. *vaseyana* (mountain sagebrush) and *Symphoricarpos rotundifolius* (snowberry). At these elevations, riparian wetlands are dominated by *Salix* spp. (willows), *Populus angustifolia* (narrowleaf cottonwood), *Picea pungens* (Colorado blue spruce) and *Alnus incana* (thinleaf alder). Other wetlands within this elevation range include seeps, springs, wet meadows, and fens supported by groundwater discharge. These wetland types are often dominated by graminoid species, mostly of the *Cyperaceae* (sedge) family. Above 2,400 m (8,000 ft), *Populus tremuloides* (quaking aspen), *Pinus contorta* (lodgepole pine), *Pseudotsuga menziesii* (Douglas-fir), and *Picea engelmannii* (Engelmann spruce) dominate uplands and can occasionally be found in confined riparian areas. The most conspicuous wetland types at this elevation are riparian shrublands or willow carrs dominated by various species of willow *(Salix planifolia, S. wolfii, S. brachycarpa,* etc.) and sedges *(Carex utriculata, C. aquatilis,* etc.). Groundwater supported wetlands are common at these elevations as well. In the elevation zone between 3,000 m to 4,300 m (10,000 to 14,000 ft), *Picea engelmannii* (Engelmann spruce), *Abies lasiocarpa* (subalpine fir), *Salix brachycarpa* (short-fruit willow), and *Salix planifolia* (planeleaf willow) occur along riparian zones. Various *Salix* spp. (willow), *Carex* spp. (sedges), and herbaceous species are also found in groundwater discharge sites and snow melt areas.

Historical hard rock and placer mining and timbering operations have dramatically affected lands throughout the county. Many of the larger rivers have large tailings piled throughout the floodplain and some areas remain effected by acid mine drainage. Currently, ski areas and associated residential and commercial developments are widespread in the county. Additionally, gravel mining, grazing, and agricultural activities are found in isolated pockets. Three large reservoirs, Blue Lakes, Dillon Lake and Green Mountain, are also significant components of the human influences in the county. These various land uses introduce problems associated with habitat fragmentation, hydrological alterations, topographic alterations, non-native species invasions, and alternation of natural fire regimes.

2.2 South Platte River Headwaters Watershed

The South Platte River Headwaters watershed (HUC 8: 10190001) encompasses much of Park County and is approximately 415,244 hectares (1,026,097 acres). Elevations range from over 4,267 meters (14,000 ft) to approximately 2,225 meters (7,300 ft). Much of the watershed occurs in a prominent physiographic feature in Park County called South Park, a grass-dominated basin, 80 km (50 miles) long and 56 km (35 miles) wide. South Park is the largest intermountain basin in Colorado and is surrounded on all sides by mountains. It is bordered to the west by the Buffalo Peaks and the Mosquito Range, to the north by Mt. Evans and Mt. Bierstadt, to the east by the Kenosha Mountains, Tarryall Mountains, and Puma Hills, and to the south by the Black and Thirtynine Mile mountains.

The climate is characterized by long, cold, moist winters, and short, cool, dry summers. Climatic data from near Antero Reservoir, in the middle of South Park, indicate that basin receives approximately 26 cm (10 inches) of precipitation each year and the average total snowfall is 119 cm (47 in). Average annual minimum and maximum temperatures at Antero Reservoir are -8^{o} and 12^{o} C (18^{o} and 53^{o} F), respectively. Average minimum monthly temperature during the coldest month (January) is -20^{o} C (-4^{o} F), while average maximum monthly temperature for the warmest month (July) is 24^{o} C (76^{o} F) (Western Regional Climate Center 2008). While these data represent the basin, precipitation and snowfall would be much higher and average temperatures lower for the higher elevations.

In subalpine basins of the South Platte River Headwaters, streams flow over glacial till from the Pinedale and Bull lake glaciations. Elsewhere, streams and tributaries to the South Platte flow over Quaternary alluvial deposits of varying depth (except where bedrock is exposed in narrow canyon reaches). Upper glaciated reaches are in wide U-shaped valleys; below the elevation of glacial terminal moraines, river canyons become narrow and the rivers are steeper, forming narrow, cool canyons with limited floodplain development. Hydrology of the South Platte River is primarily driven by spring and early summer snowmelt runoff from the mountains.

The vegetation on the valley floor of South Park is generally short and sparse as a result of the dry, windy climate, historic and current grazing, fires, and, to a much lesser extent, prairie dog activity. The wetlands of South Park are distinctive. The geologic and hydrologic setting found in South Park combines to create wetlands known as "extremely rich fens," so named because of their high concentrations of minerals. These fens provide habitat for a suite of rare plant species and plant communities. Approximately 20% of the fen communities in the study area have been drained or mined for peat (Sanderson & March 1995). Other wetland types include playa lakes, springs, wet meadows, and riparian wetlands. At higher elevations the vegetation is dominated by *Salix* spp. (willows), *Picea engelmannii* (Engelmann spruce), *Abies lasiocarpa* (subalpine fir), *Pinus ponderosa* (ponderosa pine), *Pinus contorta* (lodgepole pine), *Pinus aristata* (bristlecone pine), *Populus tremuloides* (quaking aspen) and alpine communities.

There are a high percentage of private lands in the watershed, particularly in South Park and on the immediate adjacent slopes. Currently, residential, agricultural (mostly livestock grazing), and commercial developments are widespread. Most of the streams in South Park are used to support some level of irrigation for pasture and/or hay operations. There are three large reservoirs that provide water for Front Range cities. Historical mining and timbering operations have dramatically affected some lands throughout the higher elevations of the county.

2.3 San Juan Mountains

The San Juan Mountains are located in the southwest corner of Colorado and contain the headwaters of numerous major Colorado rivers, such as the San Juan, the Rio Grande, the Gunnison, and the Dolores. The Continental Divide cuts across the San Juan Mountains, separating the Rio Grande from westward draining rivers. For the purpose of this project, only watersheds on the western side of the Divide were included in the study area, specifically portions of the following ten HUC 8 watersheds: Uncompahgre River (14020006), Upper Dolores River (14030002), San Miguel River (14030003), Upper San Juan River (14080101), Piedra River (14080102), Animas River (14080104), Middle San Juan River (14080105), Mancos River (14080107), McElmo Creek (14080202), and Montezuma River (14080203). Elevations in the San Juan Mountains reach over 4,300 m (14,200 ft), and from all sides of the mountains, rivers drain into lower elevation plateaus and valleys that generally lie between 1,500–2,100 m (5,000–7,000 ft). Small mountain towns, such as Telluride, Silverton, and Ouray, are nestled within protected valleys high in the San Juans, while larger, more populous towns, such as Montrose, Cortez, Durango, and Pagosa Springs, are located along the edge of the mountains. The study area includes part or all of nine counties: Archuleta, Dolores, Hinsdale, La Plata, Mineral, Montezuma, Ouray, San Juan, and San Miguel.

The local climate of the San Juan Mountain region depends largely on elevation. Higher elevations are characterized by long, cold winters where precipitation falls predominantly as snow. Mid-elevation regions receive a mix of snow and rainfall, while the low elevations are dominated by rainfall. Average annual minimum and maximum temperatures in Silverton, in the heart of the San Juans, are -8° and 11° C (18° and 52° F), respectively. Average minimum monthly temperature during the coldest month (January) is -19° C (-2° F), while average maximum monthly temperature for the warmest month (July) is 23° C (73° F). Silverton receives approximately 64 cm (25 inches) of precipitation each year and the average total snowfall is 396 cm (156 in). In contrast, average annual minimum and maximum temperatures in Durango, at the base of the mountains, are -1° and 17° C (30° and 63° F), respectively. Average minimum monthly temperature during the coldest month (January) is -12° C (10° F), while average maximum monthly temperature for the warmest month (July) is 29° C (85° F). Durango receives approximately 48 cm (19 inches) of precipitation each year and the average total snowfall is 175 cm (69 in), or less than half of the snowfall in Silverton (Western Regional Climate Center 2008).

The San Juan Mountains are geologically complex and marked by uplift and erosion, volcanism, regional metamorphism, and Quaternary glaciation. The oldest geologic formations in the San Juans are Precambrian basement rocks that date back to ~1.8 billion years before present. Sedimentary rocks found to the south and the west were deposited ~550 million years before present as the ancestral and modern Rocky Mountains were successively uplifted and eroded. Massive volcanism erupted in the region between 20–40 million years before present, leaving several large calderas in the heart of the mountains, including the Silverton caldera, Creede caldera, and San Luis caldera complex. In more recent time, Quaternary glaciation has left behind large U-shaped valleys separated by steep mountains and rugged ridgelines (Tweto 1979, Winters et al. 2006). Historic volcanism is largely responsible for the high concentration of mineralized rock found throughout the mountain range. These mineral veins have led to a long history of mining in the San Juans, and the mountains are riddled with old mine shafts and tailing piles.

Vegetation in the San Juans is similar to other areas of the Southern Rocky Mountains. Lower elevation foothills are dominated by *Pinus edulis* (piñon pine), *Sabina osteosperma* (Utah juniper), *Artemisia tridentata* ssp. *vaseyana* (mountain sagebrush), and *Quercus gambelii* (scrub oak). Low elevation wetlands are generally dominated by *Salix* spp. (willows), *Populus angustifolia* (narrowleaf cottonwood), *Picea pungens* (Colorado blue spruce) and *Alnus incana* (thinleaf alder). Other wetlands within this elevation range include graminoid-dominated seeps, springs, wet meadows, and fens supported by groundwater discharge. Above 2,400 m (8,000 ft), *Populus tremuloides* (quaking aspen), *Pseudotsuga menziesii* (Douglas-fir), and *Picea engelmannii* (Engelmann spruce) dominate forested upland slopes. The most conspicuous wetland types at this elevation are groundwater-fed fens and riparian shrublands dominated by various species of willow *(Salix planifolia, S. wolfii, S. brachycarpa,* etc.) and sedges *(Carex utriculata, C. aquatilis,* etc.). The highest elevations contain extensive alpine tundra and snowmelt fed wetlands that often contain numerous alpine wildflowers.

3.0 METHODS

3.1 Survey Design and Site Selection

Sites sampled during Phases 1 & 2 were subjectively chosen to represent a gradient of human disturbance and to include an equal number of fens, wet meadows, and riparian shrublands (US EPA 2002c, Rocchio 2006b, Rocchio 2007b). For Phase 3, sampling across the human disturbance gradient with equal representation by ecological system remained the goal. However, to add objectivity and a random spatial distribution to the sample site selection, potential sites for Phase 3 were selected using a Generalized Random Tessellation Stratified (GRTS) survey design. The GRTS design includes reverse hierarchical ordering of selected sites and creates a spatially balanced random sample of points (Stevens 1997, Stevens & Olsen 1999). Specific details on the survey design elements for this study are included in Appendix A.

The target population was defined as all fens, wet meadows, and riparian shrublands within the two study areas (Summit/Park Counties and San Juan Mountains). To build the sample frame for the GTRS survey design, a composite GIS shapefile of potential wetlands within the two study areas was created from multiple independent data sources because comprehensive digital coverage of National Wetlands Inventory (NWI) mapping was not available for either study area. A list of data layers used in each study area is presented in Appendix B. Once the data layers were compiled, polygons were attributed to ecological system (fen, wet meadow, or riparian shrubland) and disturbance class (reference, impacted, and highly impacted) where possible. Because of ambiguity in crosswalking the original data layers to the ecological system classification, two additional wetland categories were added (fen/wet meadow and unknown). The Landscape Integrity Model (Rocchio 2007b) was used to assign disturbance class for sites in Summit/Park Counties. For the San Juan Mountains, disturbance class was assigned where information was available, otherwise sites were assigned to an “unknown” disturbance class.

To address access issues, polygons located > 2 km from paved or dirt roads were eliminated from the sample frame, as were polygons that represented wetlands previously sampled during Phases 1 & 2. In addition, polygons that did not meet minimum size criteria were also removed. The minimum size criteria were defined as follows:

- Fens: < 0.5 acre or 0.2 hectare
- Wet Meadows: < 1 acre or 0.4 hectare
- Riparian Shrublands: < 1.25 acre or 0.5 hectare
- Any other combination: < 0.5 acre or 0.2 hectare

Polygons were then converted to centroid points and the GRTS survey design was carried out using the centroid points.

In the field, sites were sampled according to the ordered list generated from the GRTS survey design. If a site could not be sampled or did not fit the category to which it had been assigned, the field teams would move on to the first site in the oversample list. Originally, one field team was stationed in each of the two study areas. However, sampling in the San Juan Mountains proved to be logistically complicated. The San Juan Mountains are particularly rugged, with few paved roads, and access to sample points was difficult. In addition, the lack of *a priori* disturbance information limited the number of sample points within known disturbance categories and many of the randomly selected sites turned out to be reference condition fens. This complicated carrying out the study design, which sought to identify and sample an even number of sites within each disturbance category. After the first month of sampling, both field teams moved to the Summit/Park Counties study area where sampling was more efficient. As a result, far fewer wetland sites were sampled in the San Juan Mountains, and most of those that were sampled were reference condition fens. Towards the end of the sampling period, additional sites outside the GTRS survey design were subjectively chosen to balance the distribution of sites among ecological systems and disturbance classes.

3.2 Wetland Classification

One objective of the VIBI project has been to determine which classification system best explains the natural variation in reference wetland sites and is best suited for VIBI model development. Because VIBI models seek to discriminate useful vegetation "signals" that indicate ecological degradation from the natural variation or "noise" that is ubiquitous in ecological data, classification helps to constrain or minimize natural variation by categorizing wetlands into units that share similar biotic and abiotic characteristics. Classification units that are too large may have too much internal variability to provide useful signals, while units that are too small may pose practical difficulties in application. As noted by Karr (1998): "The challenge is to create a classification system with only as many classes as are needed to represent the range of relevant biological variation in a region and the level appropriate for detecting and defining the biological consequences of human activity."

During Phases 1 & 2 of this project, four different classification systems were compared using multivariate ordination and multi-response permutation procedure (Rocchio 2006b, Rocchio 2007b). The four classification systems included 1) ecological systems (Comer et al. 2003); 2) hydrogeomorphology (HGM: Brinson 1993, Johnson 2005); 3) physiognomy (herbaceous vs. shrub); and 4) soil type (mineral vs. organic). Results confirmed that the *a priori* ecological system classification, which incorporates both biotic and abiotic criteria, best explained variation in the reference dataset and was used for VIBI model development. The headwater wetlands in this study fall into three ecological systems, as defined by Rondeau (2001):

- Rocky Mountain Subalpine-Montane Riparian Shrublands
- Rocky Mountain Subalpine-Montane Fens
- Rocky Mountain Alpine-Montane Wet Meadows

Based on results presented in the Phase 2 report (Rocchio 2007b), two of the three ecological systems were divided into finer-scale wetland types. Extremely rich fens were separated from other fens, and wet meadows within riparian corridors (riverine wet meadows) were separated from sloping wet meadows. This modified ecological systems classification was used to create five separate VIBI models for 1) riparian shrublands, 2) fens, 3) extremely rich fens, 4) slope wet meadows, and 5) riverine wet meadow. Due to limited time and resources, only three of the five previously developed VIBI models will be targeted during Phase 3. The three targeted models include the riparian shrubland, fen, and slope wet meadow VIBI models.

3.3 Wetland Assessment Area

At each sample site, a wetland assessment area (AA) was defined. The AA is the boundary of the wetland (or a portion of the wetland) targeted for sampling and analysis and was defined by the following the steps.

1. Estimate Wetland Boundaries

The first step in identifying the wetland assessment area was to estimate the approximate boundaries of the wetland. Readily observable ecological criteria such as vegetation, soil, and hydrological characteristics were used to define wetland boundaries, regardless of whether they met jurisdictional criteria for wetlands regulated under the Clean Water Act.

2. Delineate Ecological System Boundaries

The second step was to delineate the targeted ecological system type present within the wetland boundary. Ecological system descriptions (Appendix C) were used to define system boundaries in the field. One confounding factor is that ecological systems often co-occur in the landscape. For example, fens may occur along the margins of a valley and adjacent to riparian shrublands on the valley floor. Similarly, wet meadows with mineral soil are often interspersed with organic soil fens, depending on groundwater flow patterns. For such scenarios, it was necessary to delineate the boundaries of the separate ecological systems based on the minimum size criteria associated with each system. If an ecological system patch was less than its minimum size, it would be considered to be an inclusion within the ecological system type in which it is embedded. In a few cases, wet meadows and fens smaller than their minimum size criteria were chosen as sample AAs because they were limited in size only by their hydrogeomorphic position (i.e. small areas of groundwater discharge surrounded by uplands).

3. Size and Land Use Related Boundaries

Once the ecological system boundaries were delineated, size and land use were used to further refine AA boundaries. For example, depending on the size or variation of the wetland area, the AA may consist of the entire site or only a portion of the wetland/riparian area. For small wetlands or those with clearly defined boundaries (e.g., isolated fens or wet meadows), the AA was almost always the entire wetland. In very large wetlands or extensive and contiguous riparian types, a sub-sample of the area was defined as the AA for this project. A few sampled sites contained multiple AAs due to abrupt changes in land use or human-induced disturbances. Specific size and land use criteria by wetland type can be found in (Rocchio 2007b).

3.4 Plot Establishment and Vegetation Sampling

3.4.1 Plot Location

One vegetation plot (20 m x 50 m) was subjectively placed within the AA to maximize abiotic/biotic heterogeneity. Capturing heterogeneity within the plot ensures adequate representation of local, micro-variations produced by such things as hummocks, water tracks, side-channels, pools, wetland edge, micro-topography, etc. in the floristic data.

The following guidelines were used to determine plot locations within the AA[3]:

- The plot was located in a representative area of the AA which incorporated as much microtopographic variation as possible.
- If a small patch of another wetland type was present in the AA (but not large enough to be delineated as a separate ecological system type), the plot was placed so that at least a portion of the patch was in the plot.
- When site characteristics dictated a modification of plot structure, an alternative array of modules was selected to best represent the AA (e.g. 20 m x 20 m for small circular sites or 10 m x 50 m for narrow linear areas)
- Uplands were excluded from plots; however, mesic microtopographic features such as hummocks, if present, were included in the plots.
- Localized, small areas of human-induced disturbance were included in the plot according to their relative representation of the AA (large areas of human-induced disturbance dictated that the area be delineated as a separate AA).

3.4.2 Reléve Method

A 20 m x 50 m reléve plot developed by Robert Peet was used to collect vegetation data. The method has been in use by the North Carolina Vegetation Survey for over 10 years (Peet et al. 1998) and has also been used to successfully develop a VIBI in Ohio (Mack 2004a, Mack 2004b). In Phase 1 of this project, the reléve method was evaluated against a transect plot method and resulted in greater species per plot, a broader range of calculated metric values, and greater sensitivity to human disturbance than the transect method (Rocchio 2006b), making it more suitable for collecting VIBI data.

The structure of the plot consists of ten 100 m^2 modules typically arranged in a 2 x 5 array (Figure 2). Floristic measurements included presence/absence and abundance (e.g. cover) and were made within at least four of the 100 m^2 modules, referred to as "intensive" modules. In addition, nested quadrats within each module were established in at least two corners to provide data from multiple scales. The remaining six modules are considered "residuals" and are searched for any species not documented in the intensive modules.

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[3] Many of the guidelines are based on (Mack 2004a, Mack 2004b).

If the wetland had an irregular shape and the plot did not "fit" within the AA, the 2 x 5 array of modules was restructured accommodate the shape of the wetland or AA. For example, a 1 x 5 array of 100 m^2 modules was used for narrow, linear areas. A 2 x 2 array of 100 m^2 modules was used for small, circular sites (Peet et al. 1998, Mack 2004b). Regardless of the structure, a minimum of four intensive modules was always sampled.

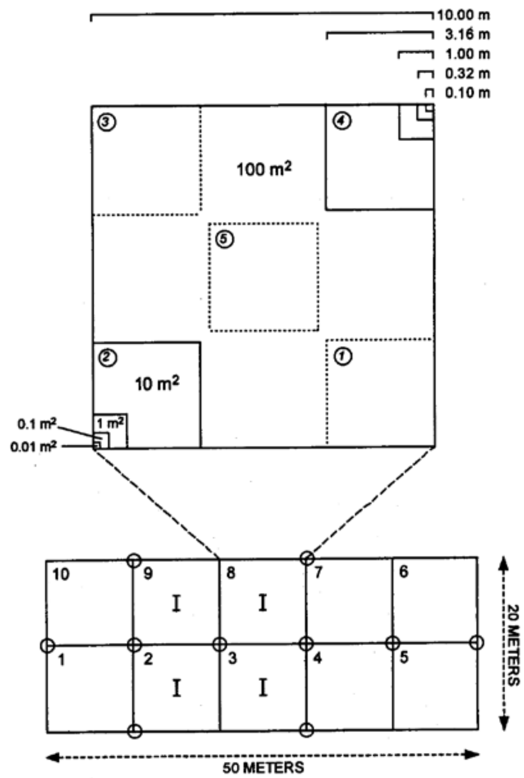

Figure 2. Relève Plot Method (from Peet et al. 1998). I = intensive modules. Nested subquadrats are shown in the inset diagram at the top.

Within intensive modules, a series of nested subquadrats were established to obtain estimates of species composition at multiple spatial scales (e.g. 1.0, 10, 100 m^2; Figure 2). The subquadrats were established in one or more corners in each intensive module. For this project, only two corners in each of the four intensive modules were sampled. The number of subquadrats in a nest is referred to as depth, where a depth of 3 indicates species presence was recorded in the 1.0 m^2 subquadrat, depth of 2 indicates 10 m^2, and depth of 1 indicates 100 m^2. Sampling began at the smallest subquadrat and each species received a number corresponding to the depth at which it was initially encountered. In the original methodology (Peet et al. 1998), five depths (subquadrats) were sampled; however, only 3 subquadrats (1.0, 10, and 100 m^2) were sampled for this project. Presence recorded for a particular depth implies presence at all lower-numbered depths, thus both corners were sampled before documenting which species occur at depth 1 (100 m^2).

Cover was visually estimated at the level of the 100 m^2 module (depth 1) using the following cover classes (Peet et al. 1998):

1 = trace (one individual)
2 = 0–1%
3 = >1–2%
4 = >2–5%
5 = >5–10%
6 = >10–25%
7 = >25–50%
8 = >50–75%
9 = >75–95%
10 = >95%

After sampling each of the intensive modules, the remaining (i.e. residual) modules were walked through to document presence of any species not recorded in the intensive modules. Percent cover of these species is estimated over the entire 1000 m^2 plot. Cover was the only abundance measurement for all species. Further details on plot layout can be found in (Rocchio 2007b). See Appendix D for the VIBI field form.

3.5 Human Disturbance Index

Information related to human disturbance was collected using the Human Disturbance Index (HDI), a semi-quantitative index that provides an independent measure of wetland condition. The HDI is an estimate of the degree to which each site has deviated from the reference condition, as defined by the minimum disturbed condition. This method assumes that the absence of historic and/or contemporary human disturbance indicates that the wetland possesses biotic and ecological integrity and that increasing human disturbance results in a predictable deviation from the ecological reference condition. The HDI was developed using rapidly employed metrics extracted from the related Ecological Integrity Assessment (Faber-Langendoen et al. 2005, Rocchio 2006a) as well as metrics employed in other rapid wetland condition assessment methods (Mack 2001, Montana Department of Environmental Quality 2005). See Appendix E for the HDI field form.

The HDI utilizes a series of metrics related to three major categories of human-induced stressors associated with wetlands and riparian areas in Colorado. The stressor categories and their respective metrics are listed below:

Alterations within Buffers and Landscape Context
- Average Buffer Width
- Land Use in 100 m Buffer
- Percentage of Unfragmented Landscape within 1 km (0.6 miles)
- Riparian Corridor Continuity

Hydrological Alterations
- Hydrological Alterations
- Upstream Surface Water Retention
- Upstream/Onsite Water Diversions/Additions
- Floodplain Interaction

Physical/Chemical Disturbances

- Substrate/Soil Disturbance
- Onsite Land Use
- Bank Stability
- Algal Blooms
- Cattail Dominance
- Sediment/Turbidity
- Toxics/Heavy Metals

Each metric has descriptive criteria indicating the number of points assigned to it. The two highest indicator scores for each metric are summed, then multiplied by a weighting factor (0.33 for Buffer/Landscape Context and Physical/Chemical Disturbances; 0.34 for Hydrology) to arrive at a final score ranging from 0 (reference condition; no/minimal human-induced disturbance) to 100 (highly impacted).

3.6 Data Management

To efficiently analyze and compare data collected from VIBI development (Phases 1 & 2) and VIBI calibration (Phase 3) plots, a Microsoft Access™ database was built based on the original Microsoft Excel™ spreadsheets described in Rocchio (2007b). Vegetation plot data were entered into the database, and relative and mean cover values for each species were averaged across the intensive modules for use in data analysis. For those species only occurring in the residual plots, the cover value for the residual plots was used for analysis. To eliminate spelling errors, a pre-defined species list was used for species entry. For a few vegetation plots, a number in a couplet (depth/cover) was missing. Because one value was recorded, it was assumed that the species was present in the plot and that the second value was simply overlooked. For these situations, a default value of 1 was entered no matter whether the missing value was depth or cover. Unknown or ambiguous species (e.g. *Carex* sp.) were recorded but not included in data analysis. Data entry was reviewed by an independent observer for quality control.

Data from the Colorado Floristic Quality Assessment (FQA: Rocchio 2007a) were used to populate life history traits, wetland indicator status, and C-values in the database for each species in each plot. The FQA table was updated and modified when converted to Microsoft Access™ and species primary nomenclature now follows Weber and Wittmann (2001a, 2001b), though all names are cross-referenced to the nationally accepted names in USDA PLANTS Database (http://plants.usda.gov). Life history traits and cover data were used to calculate metric values using Visual Basic queries programmed in the database. Calculations made by the queries were randomly checked to ensure that the queries were constructed correctly. Environmental data and human disturbance rating scores were also entered into the database so that all relevant data could be stored in one place.

3.7 Data Analysis

3.7.1 Test of Validation vs. Calibration

To determine whether Version 1.0 VIBI models could be validated using an independent dataset, two aspects of the models were evaluated: 1) correlation of VIBI scores to the human disturbance index and 2) effectiveness of the Version 1.0 scoring thresholds. To address the first aspect, VIBI scores were calculated for Phase 3 plots using the Version 1.0 metrics and scoring thresholds. For each of the three models (riparian shrubland, fen, and slope wet meadow), relationships between Phase 3 VIBI scores and the HDI were assessed using scatter plots, Spearman's rank correlation coefficients (R_s), and linear regression. Spearman's rank correlation coefficients were considered the primary measure of correlation, because the HDI contains ordinal data, but linear regression provided additional information on the strength of the relationships. Results of the Phase 3 analyses were compared to similar analyses run using Phase 1 & 2 development plots. If the Phase 3 plots showed the same strength of relationship with the HDI (ΔR_s between Phases 1 & 2 plots and Phase 3 plots < 0.10), the model was considered validated. If the Phase 3 plots did not show the same strength of relationship, they were integrated into the plot database and used for model calibration. Data analysis was conducted using Minitab® Release 14 (Minitab Inc. 2004).

For the fen VIBI model, Phase 3 plots collected in the San Juan Mountains were analyzed separately from those collected in the Summit/Park Counties to provide an initial test of how the model performed within a different region of the Southern Rocky Mountains. However, because sampling in the San Juan Mountains was limited due to time and logistics, plots collected were primarily reference condition fens. Though these plots did not represent the full range of human disturbance, they did provide an opportunity to test the variability of reference fens between the two locations (San Juan Mountains and central Colorado). Simple paired t-tests were run on each metric selected in the Version 1.0 fen VIBI to compare reference fens from central Colorado to reference fens from the San Juan Mountains. To control for inter-annual variability and similar sample size, only fens from Phase 3 were compared. Paired t-tests were carried out in SAS® 9.2 (SAS Institute 2008).

In addition to testing the strength of the relationship between VIBI scores and the HDI, Version 1.0 scoring thresholds were also examined. Version 1.0 scoring thresholds for each metric were originally identified from the Phase 1 & 2 plots using the continuous scoring procedure identified in Blocksom (2003). Observed metric values were divided by the 95th percentile of the metric range to arrive at a metric score (the inverse taken for metrics which increase with disturbance). The 95th and 5th percentile of the data was used in lieu of the maximum value to eliminate strong outliers. See section 3.7.3 (below) for scoring calculations. The continuous scoring method allows comparison of each plot to the natural range of variation represented in the dataset. If the dataset adequately describes the natural range of variation among the sample population, adding new plots should not change the scoring thresholds. However, if additional plots do change the scoring thresholds, the dataset does not adequately describe the natural range of variation. Scoring thresholds set using only Phase 1 & 2 development plots were compared to thresholds set using all plots, including Phase 3, to determine if the additional plots fell within the range already described, or if the new plots extended the range of variability.

3.7.2 Calibration of VIBI Models

Models that could not be validated were then calibrated following the approach described by Mack (2001, 2004). Phase 3 plots were added to the dataset and further metric screening was conducted to improve model performance. For each of the three models calibrated, Version 1.0 metrics that showed a strong correlation to the HDI were maintained, but metrics with a weak correlation were replaced or modified when possible. For the fen and slope wet meadow models, which previously included fewer metrics than the riparian shrubland model, additional metrics were selected to raise the number of metrics to nine. Additional metrics provide more information about each wetland and lead to a more robust model in the face of variability.

Vegetation attributes representing different aspects of the vegetation community, such as functional and compositional guilds, were calculated for each plot. Measures such as richness, relative cover, mean cover, and proportion of species composition of the various functional and composition guilds were calculated for each site and correlated to the human disturbance index. A total of 133 vegetation attributes, listed in Appendix F, were screened for inclusion in the VIBI models. Data analysis was conducted using Minitab® Release 14 (Minitab Inc. 2004).

The following protocol was implemented in the order shown to screen and identify vegetation attributes to improve the VIBI models (Barbour et al. 1996, Blocksom et al. 2002, Blocksom 2003, Jones 2005, Rocchio 2007a).

1. Correlation to Disturbance

The relationship of each attribute to the human disturbance index was assessed using scatterplots and Spearman's rank correlation coefficients (R_s). All original Version 1.0 attributes were retained for further screening, along with attributes with a correlation coefficient $R_s > |0.5|$ and attributes that exhibited a nonlinear pattern. In specific instances, metrics with lower correlations were also considered if they improved overall model performance.

2. Discriminatory Power

Box plots were used to assess the ability of each attribute to discriminate between reference and highly impacted sites (reference: HDI ≥ 66.67; highly impacted: HDI ≤ 33.33). Each attribute was scored according to the following criteria: 3 = no overlap of interquartile range of reference vs. highly impacted sites (middle 50% of observations); 2 = interquartile ranges overlap but medians of both disturbance groups are outside the other's interquartile range; 1 = interquartile ranges overlap and one median occurs inside the other's interquartile range; and 0 = both medians overlap the others interquartile range. Attributes that scored 2 or 3 were retained for further screening.

3. Scope of Detection

The scope of detection is the range from the minimum possible value to the 25th percentile of an attribute's distribution (maximum possible value to the 75th percentile for those metrics that increase with increasing human disturbance). A large interquartile range, relative to the scope of detection, results in decreased ability to detect change from reference conditions. The ratio of the interquartile range to the scope of detection, the "interquartile coefficient" (IC), was used to determine the level of attribute variability (US EPA 1998). Attributes with an IC < 1.0 were considered for further analysis.

4. Redundancy

A correlation matrix was constructed to determine which attributes were highly correlated (using Spearman's correlation coefficient) with each other. Attribute pairs with $R_s > 0.9$ were considered to be redundant. Original Version 1.0 metrics with a strong relationship to the HDI were considered priority metrics to retain. When redundant pairs were identified among potential new metrics, those with the strongest correlation to human disturbance and most effective discriminatory power were retained. If redundant attributes (e.g. % of hydrophytes and % non-native species) provided unique ecological information (change in abundance of wetland dependent species vs. change in abundance of non-native species), they were both retained.

5. Final Selection of Metrics

During final metric screening, a handful of metrics emerged as potential modifications or replacements for weak original metrics. Several potential models constructed from combinations of new and original metrics were evaluated using Spearman's rank correlation coefficients and linear regression. The combination of metrics showing the best performance was selected as the calibrated model.

3.7.3 Metric and VIBI Scoring

Metric Scoring

The following calculations were used to convert each metric value into a score (modified slightly from Rocchio (2007b) to account for metrics that do not range from 0–100):

- Metrics that increase with increasing human disturbance are calculated by the following equation:

  Score = [(Max – observed value)/(Max – 5th percentile of metric range)] X 10

- Metrics which decrease with increasing human disturbance are calculated by the following equation:

  Score = [(Observed value – min)/(95th percentile of metric range – min)] X 10

Metric scores were truncated so that they ranged between 0.0 – 10.0, with 10.0 representing reference conditions.

VIBI Scoring

A total VIBI score was calculated by summing metric scores and dividing by nine, the number of metrics in each VIBI model. This resulted in a VIBI score ranging from 0.0 to 10.0, with 10.0 representing reference conditions.

3.7.4 Identification of Condition Classes, Thresholds, and Indicator Species

In order to translate VIBI scores into discrete biotic integrity condition classes—such as high, moderate, or low integrity—it was necessary to determine the number of statically significant condition classes each VIBI model could distinguish. This was done using one-way analysis of variance (ANOVA). For each model, plots were assigned to k = 2–5 disturbance categories based on the HDI score. The following breaks of the HDI were used to define disturbance categories: 2 categories (50); 3 equal categories (33.33, 66.67); 3 unequal categories (25, 75); 4 categories (25, 50, 75); 5 categories (20, 40, 60, 80). One-way ANOVA with Tukey's multiple comparison method was used to test whether mean VIBI scores of individual disturbance categories were significantly different from one another. Analyses were performed using SAS® 9.2 (SAS Institute 2008). The highest number of significantly different disturbance categories was considered the number of condition classes the model could recognize (Jones 2005).

Once the number of condition classes was identified, predicted VIBI scoring thresholds were calculated for each class using classification tress. Classification and regression tree (CART) models produce a dichotomous key to predefined groups, displayed in a tree-like structure, by recursively partitioning the dataset into increasing homogeneous subsets (Urban 2002). At each node of the tree, a threshold is defined that splits the data points into separate groups. Classification tree analysis was carried out in S-PLUS® 8.0 (TIBCO Software Inc. 2008). In addition, ranges for individual metrics and overall VIBI scores were calculated for each class. Because no one individual metric can determine a wetland's overall condition class, as it is possible for a wetland to score low on one or more metrics but high on several others, thresholds for individual metrics were not calculated. However, the range of typical values in each condition class does provide information about the probable response of a wetland to disturbance. Ranges were based on the interquartile range (25th to 75th percentile) for each condition class in order to exclude outliers.

Lastly, indicator species analysis was used to identify species strongly associated with each condition class (Jones 2005). Indicator species analysis combines information on the frequency of occurrence and average abundance of a species within a particular group. Each species is assigned an indicator value for the group with which it is most strongly associated (Dufrene & Legendre 1997, McCune & Grace 2002). The significance of the indicator value was tested using a Monte Carlo randomization test with 5,000 iterations. Species with P-values $\leq$ 0.05 were considered strong indicators. Indicator species analysis was performed using PC-ORD 5.0 (McCune & Medford 1999).

4.0 RESULTS

4.1 Sample Sites

A total of 38 calibration plots (including 19 reference plots) were sampled in 2007 (Figure 3), bringing the total to 94 plots that represent riparian shrublands, fens, and slope wet meadows in the dataset.[4] In total, the dataset contains 38 riparian shrubland plots (25 development and 13 calibration), 38 fen plots (22 development and 16 calibration), and 18 slope wet meadow plots (9 development and 9 calibration). Throughout the project, wet meadows received less sampling than other wetland types. This is largely due to the decision to split wet meadows into slope wet meadows and riverine wet meadows for VIBI model development (Rocchio 2007b). In this phase of the project, only the slope wet meadow VIBI model and not the riverine wet meadow VIBI model was targeted for calibration. Though there were fewer slope wet meadow plots than riparian shrubland and fen plots, each wetland type had a sufficient number of plots and full representation across the disturbance gradient to see clear trends in the vegetation data corresponding to human disturbance.

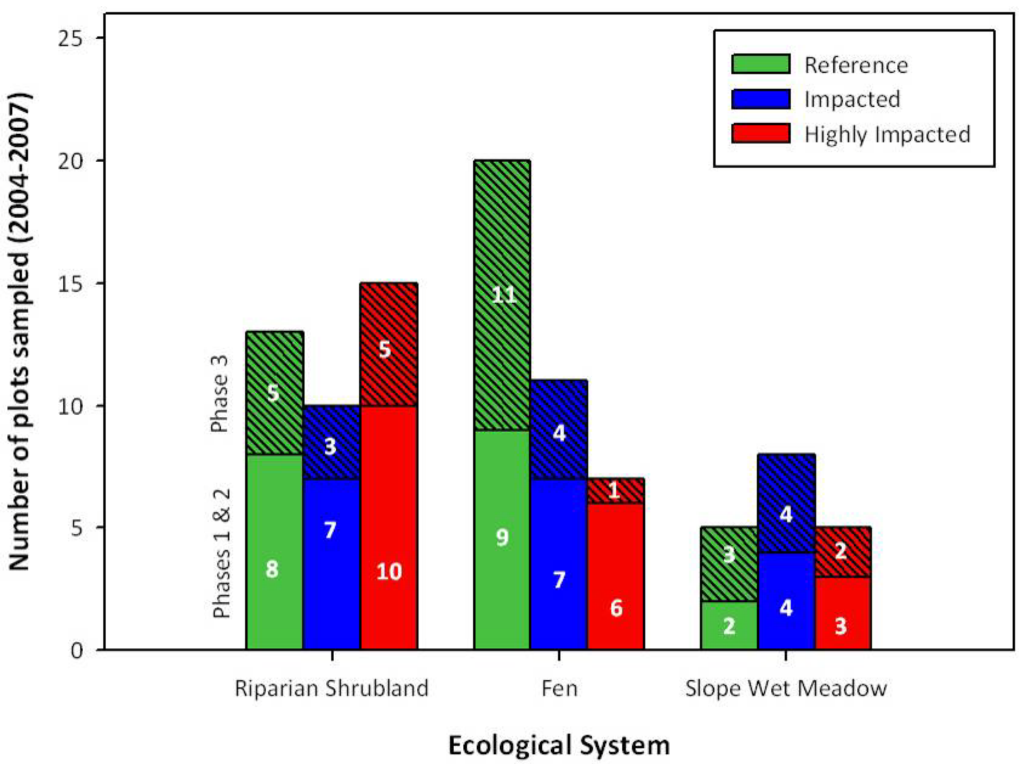

Figure 3. Plot distribution across ecological system types and degree of human disturbance. Solid bars represent Phase 1 & 2 development plots (2004–2006); hatched bars represent Phase 3 calibration plots (2007). White numbers within each bar are the number of plots within each category.

[4] Additional plots were sampled during Phases 1 & 2 in extreme rich fens and riverine wet meadows, but are not included in this report because only the riparian shrubland, fen, and slope wet meadow VIBI models were targeted for calibration.

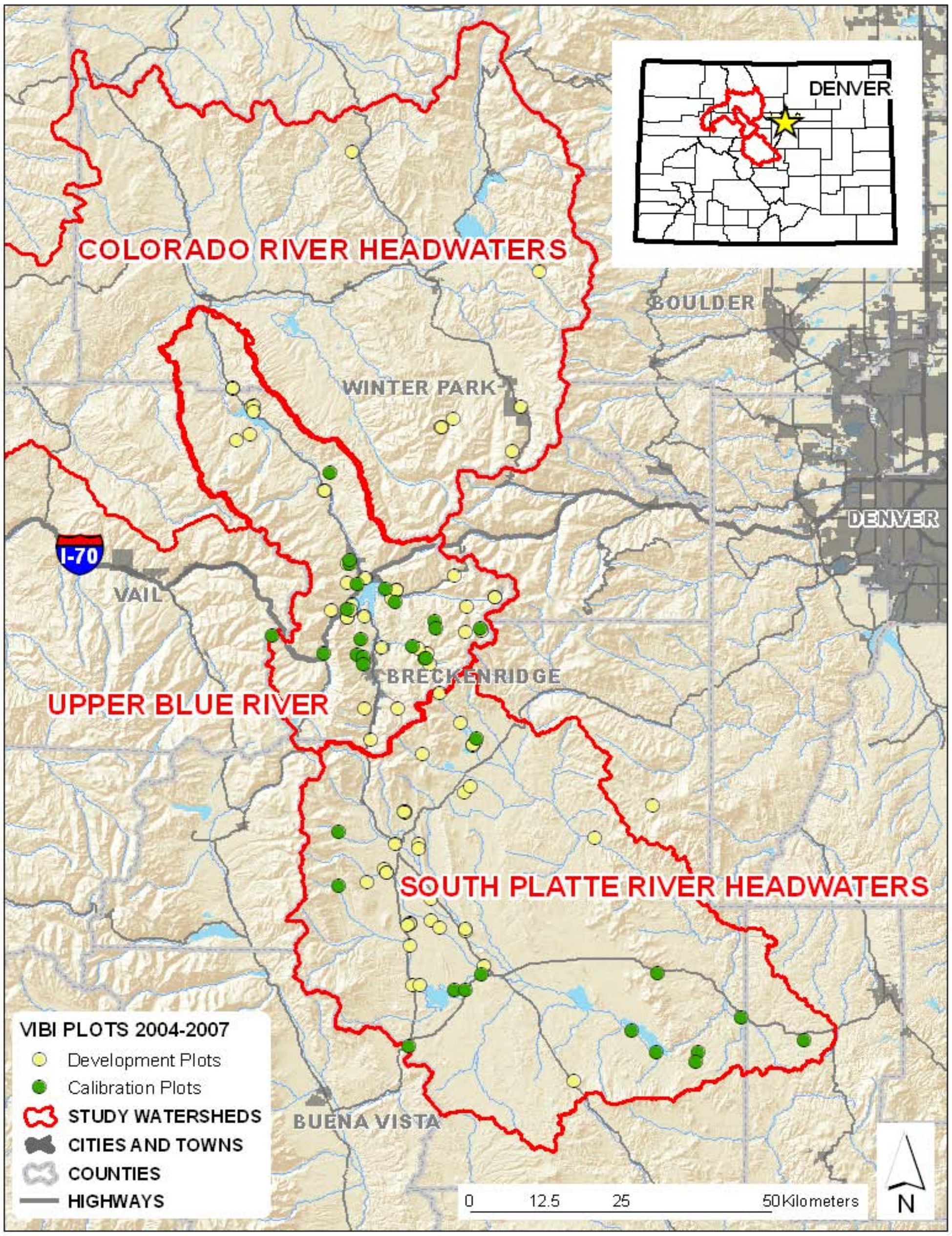

Figure 4. Plot locations within the Colorado River Headwaters, Upper Blue River, and South Platte River Headwaters watersheds. Phase 1 & 2 development plots (2004–2006) are yellow dots and Phase 3 calibration plots (2007) are green dots. Inset map shows the state of Colorado and the study area (red outline) in reference to Denver.

Most data collection occurred in central Colorado (Figure 4), while nine plots were sampled in the San Juan Mountains (Figure 5). Of the nine sites sampled in the San Juan Mountains, six were reference fens, one was an impacted fen, one was an impacted riparian shrubland, and one was a highly impacted riparian shrubland. Site information for the 38 calibration plots can be found in Appendix G. A total of 355 plant species were identified in the 38 calibration plots, with an average of 43 species per plot. A species list is included as Appendix H.

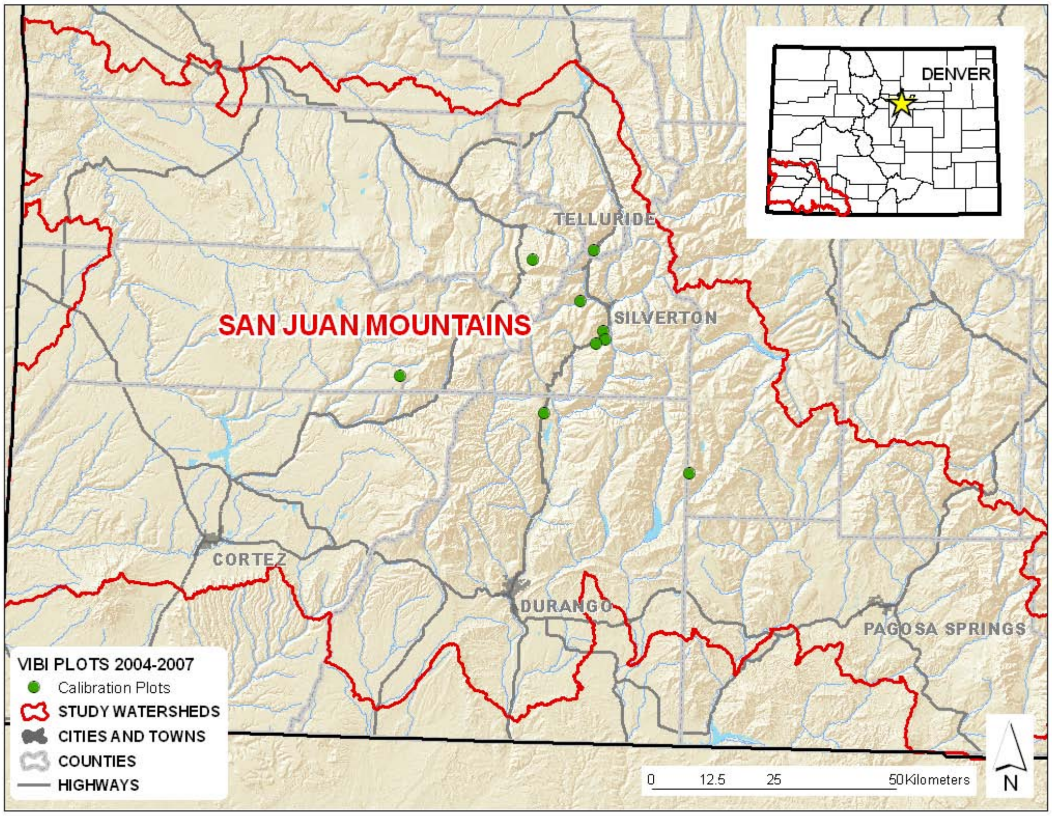

Figure 5. Plot locations in the San Juan Mountains. Only Phase 3 calibration plots (2007) were collected in the San Juan Mountains. Inset map shows the state of Colorado and the study area (red outline) in reference to Denver.

4.2 Calibration of Vegetation Index of Biotic Integrity Models

4.2.1 Rocky Mountain Subalpine-Montane Riparian Shrubland VIBI Model

Based on Version 1.0 metrics and scoring thresholds, Riparian Shrubland VIBI scores for Phase 3 plots showed a statistically significant negative relationship to the human disturbance gradient (RipVIBI = 8.64 – 0.04*HDI, R^2 = 36.9%, P = 0.0028; Figure 6). The relationship, however, was not as strong for Phase 3 plots as for Phase 1 & 2 development plots. Spearman's correlation coefficient for development plots was -0.85, while Phase 3 plots had a coefficient of -0.59. A number of individual metrics also showed weaker correlation to the HDI in the Phase 3 plots (Table 1).

The lower correlation coefficient shown by the Phase 3 plots was in part due to an outlier that had a moderate HDI score (40.85) and one of the lowest VIBI scores (2.8). This site (Plot 3-017) differed somewhat from the other riparian shrublands because the riparian vegetation was narrower and more confined to the channel than many other plots (Figure 7A). However, soils beyond the riparian shrubs showed evidence that the floodplain had historically been wider and that the channel was incised. Based on this evidence, the plot was laid out to include both the riparian shrubs and the surrounding herbaceous vegetation, which included a number of weedy species (Figure 7B). The incised channel and extent of weeds within the site suggests past human disturbance, however the HDI scoring formula resulted in only a moderate score because no obvious hydrologic modification was noted. This site may be a case where the HDI protocol did not adequately capture the degree of human disturbance affecting the site, or it may be that disturbances, such as upstream water diversions, were not obvious in the field and not noted on the HDI form. Removing this site from the dataset resulted in a stronger relationship to the HDI (R_s = -0.71); however, it was more appropriate to include it because it represents a potential expression of riparian vegetation and is not different enough to warrant its removal. This case does suggest possible examination of the HDI protocol in the future.

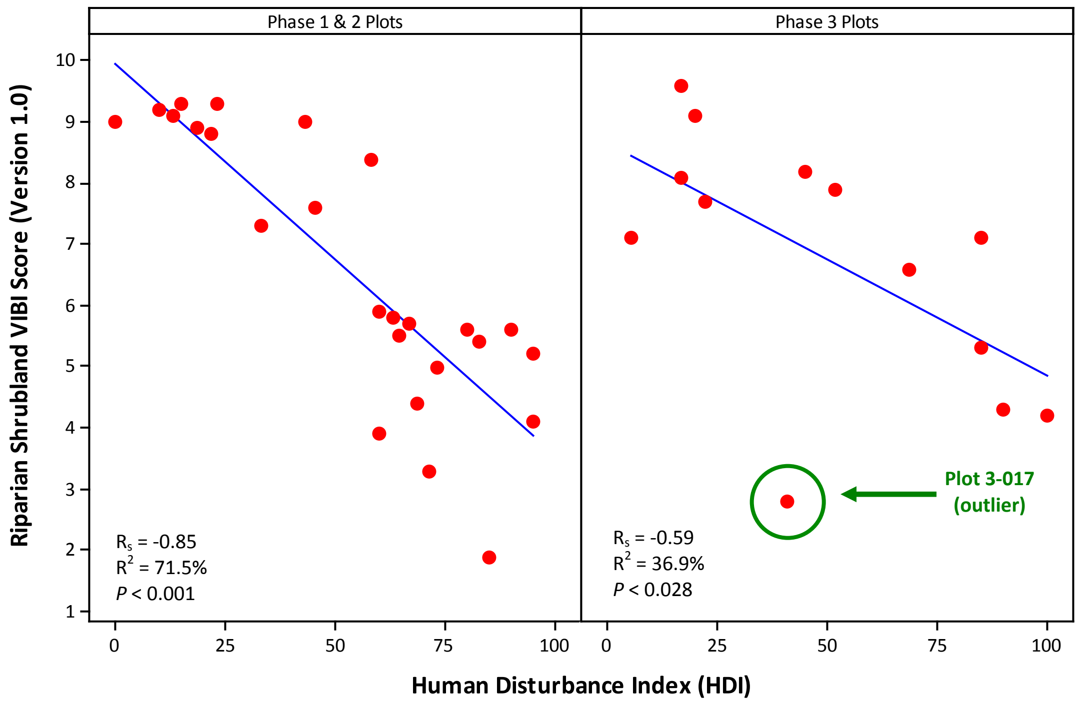

Figure 6. Correlation of Riparian Shrubland VIBI scores to the HDI for Phase 1 & 2 plots and Phase 3 plots. Scores calculated using Version 1.0 metrics and scoring thresholds. Spearman's rank correlation coefficient (R_s) and regression results (R^2 and *P*-value) inset within the graph.

Figure 7. Photos of outlier Plot 3-017. (A) From a distance showing the narrow strip of riparian vegetation and (B) closer in showing the vegetation composition within the channel and beyond.

Phase 3 plots also had an effect on metric scoring thresholds. Eleven out of eighteen values used in scoring calculations were different based on all plots in place of the development plots (data not shown). Different values in the scoring calculations would change metric and overall VIBI scores. This signifies that until the dataset is sufficiently large, these values may need to be periodically adjusted to reflect the full range of variation.

Though Version 1.0 component metrics and overall VIBI scores were correlated to human disturbance for Phase 3 plots, the above analyses indicated that the relationship could be improved with minor adjustments. Phase 3 plots were added to Phase 1 & 2 plots and additional metrics were screened for inclusion. Metric screening identified five potential modification or replacement metrics. Eight potential models were compared with Spearman's rank correlation coefficients and linear regression. The model with the best performance included one replacement metric and one modified metric (Table 2). *Carex* species richness replaced % native forbs and % hydrophytes was modified from relative cover of hydrophytes.

Table 1. Correlation of Riparian Shrubland Version 1.0 metrics and overall score to the HDI for Phase 1 & 2 plots, Phase 3 plots, and all plots combined.

Version 1.0 VIBI Metrics	Correlation to HDI[1]		
	Phase 1&2[2]	Phase 3	All Plots
Mean C (native)	-0.67	-0.49	-0.58
% Intolerant species	-0.72	-0.51	-0.64
% Tolerant species	0.75	0.57	0.70
% Non-native species	0.75	0.71	0.74
Invasive species richness	0.79	0.34	0.64
% Native perennial species	-0.78	-0.23	-0.59
% Native forb species	-0.52	-0.32	-0.47
Relative cover hydrophytes	-0.67	-0.38	-0.54
Mean wetland indicator	0.73	0.28	0.56
Final VIBI Score	**-0.85**	**-0.59**	**-0.76**

[1] Spearman's rank correlation coefficient
[2] Values may be different than those shown in Rocchio (2007a) due to slight changes in the calculations between the original Excel spreadsheet calculators and the new VIBI Access™ database.

Of the nine metrics included in the Version 2.0 Riparian Shrubland VIBI model, three were indicative of community level integrity and the remaining six were indicative of functional groups (Table 2). Eight out of nine metrics were based on richness calculations, while only one was based on dominance. All nine metrics were clearly able to distinguish reference and highly impacted sites (Figure 8) and had a strong linear relationship to the HDI (Figure 9), with each exhibiting a Spearman's correlation coefficient of 0.50 and above (Table 2). Percent non-native species demonstrated the strongest correlation (R_S = 0.74), while mean wetland indicator showed the weakest (R_S =

0.56). Four metrics (% tolerant species, % non-native species, invasive species richness, and mean wetland indicator) had a positive response and five metrics (mean C natives, % intolerant species, % native perennials, *Carex* species richness, and % hydrophytes) had a negative response to increasing human disturbance (Table 2).

The calibrated Version 2.0 riparian shrubland VIBI model showed a strong negative relationship with human disturbance (R_s = -0.78; Figure 11). This relationship was highly statistically significant (RipVIBI = 9.27 – 0.05*HDI, R^2 = 63.1%, $P < 0.001$). Version 2.0 VIBI scores were clearly able to distinguish reference sites from highly impacted sites; but while both reference and highly impacted plots showed little variability, impacted plots were much more variable (Figure 10). The impacted category had the fewest plots (10 impacted plots vs. 13 reference and 15 highly impacted), and included the one outlier discussed above (Plot 3-017). This area of the disturbance gradient was underrepresented during Phases 1 & 2 (Rocchio 2007b), and continues to be represented less than the two ends. Additional sampling could focus on moderately impacted sites to strengthen the model performance.

Table 2. Details on metrics selected for the Rocky Mountain Subalpine-Montane Riparian Shrubland VIBI model, Version 2.0.

Metrics	Metric Category (Basis of Calculation)	Metric Calculation	Increase or Decrease with Disturbance	Correlation to HDI[1]	Min Value	Max Value	95th / 5th Percentile	Change from Version 1.0 Model
Mean C (native)	Community Based (Richness)	Sum of C-values for native species / native species richness	Decrease	-0.58	4.70	6.84	6.69 (95th)	Original metric
% Intolerant species	Community Based (Richness)	Count of intolerant species (C-value ≥ 7) / total species richness	Decrease	-0.64	8%	65%	63% (95th)	Original metric
% Tolerant species	Community Based (Richness)	Count of tolerant species (C-value ≤ 3) / total species richness	Increase	0.70	0%	36%	2% (5th)	Original metric
% Non-native species	Functional Group (Richness)	Count of non-native species / total species richness	Increase	0.74	0%	34%	2% (5th)	Original metric
Invasive species richness	Functional Group (Richness)	Count of invasive species (see Rocchio 2007)	Increase	0.64	0	16	1 (5th)	Original metric
% Native perennial species	Functional Group (Richness)	Count of native perennial species / total species richness	Decrease	-0.59	47%	88%	86% (95th)	Original metric
***Carex* species richness**	Functional Group (Richness)	Count of *Carex* species	Decrease	-0.70	0	10	8 (95th)	Replaced % Native forbs
% Hydrophytes	Functional Group (Richness)	Count of hydrophytes (OBL & FACW) / total species richness	Decrease	-0.61	0%	62%	59% (95th)	Modified from Relative cover hydrophytes
Mean wetland indicator	Functional Group (Dominance)	Sum of wetland indicator values / total species richness (see Rocchio 2007)	Increase	0.56	-2.74	2.80	-2.21 (5th)	Original metric

[1] Spearman's rank correlation coefficient

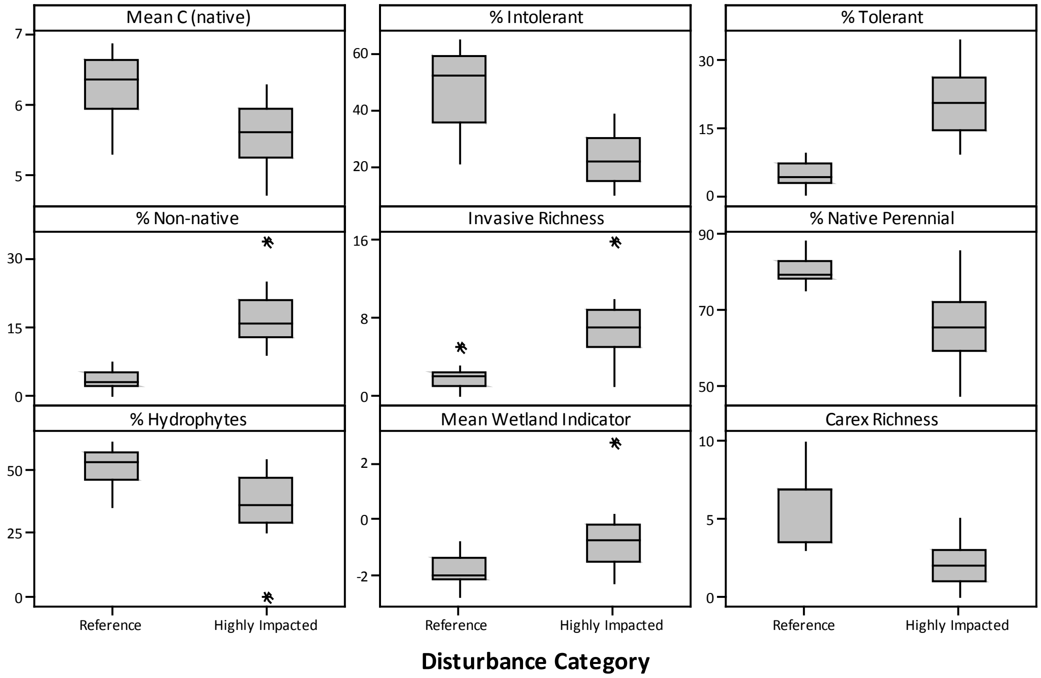

Figure 8. Discriminatory power of individual metrics selected for the Riparian Shrubland VIBI model, Version 2.0. Disturbance categories are equal intervals of the HDI. Reference = HDI of 0.00–33.33; Highly Impacted = HDI of 66.67–100.00. Boxes represent 75th percentile (top) to 25th percentile (bottom). Horizontal lines represent the median. Whiskers extend to the upper and lower limits.

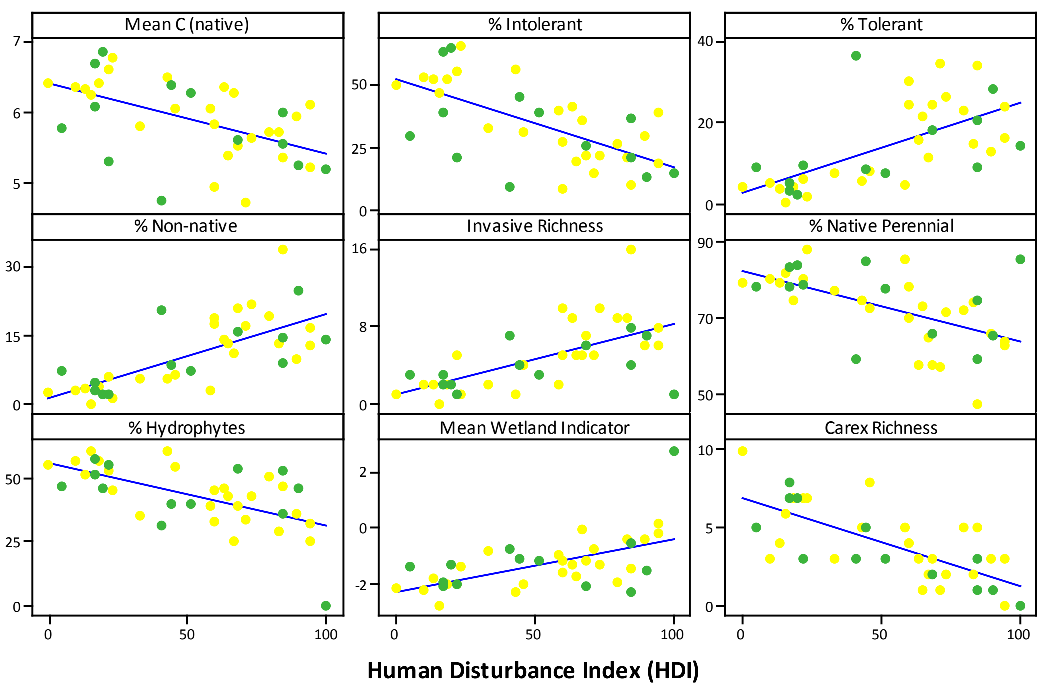

Figure 9. Correlation of individual metrics selected for the Riparian Shrubland VIBI model, Version 2.0, to the HDI. Data points represent development plots (yellow dots •) and calibration plots (green dots •). Spearman's rank correlation coefficients (R_s) for each metric are listed in Table 2.

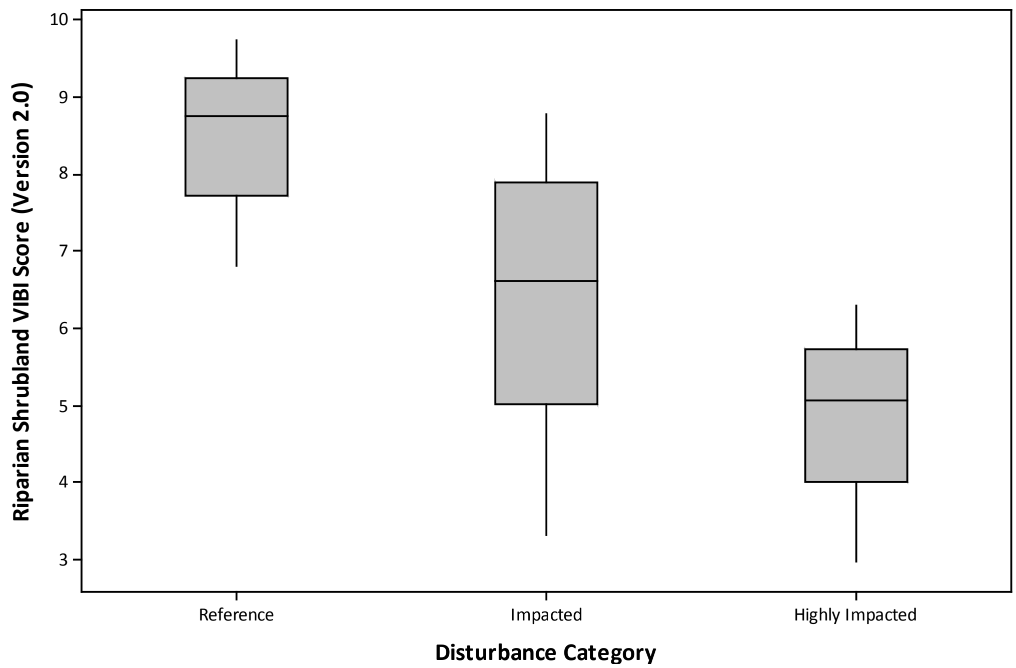

Figure 10. Discriminatory power of the Riparian Shrubland VIBI model, Version 2.0. Disturbance categories are equal intervals of the HDI. Reference = HDI of 0.00–33.33; Impacted = HDI of 33.34–66.66; Highly Impacted = HDI of 66.67–100.00. Boxes represent 75th percentile (top) to 25th percentile (bottom). Horizontal lines represent the median. Whiskers extend to the upper and lower limits.

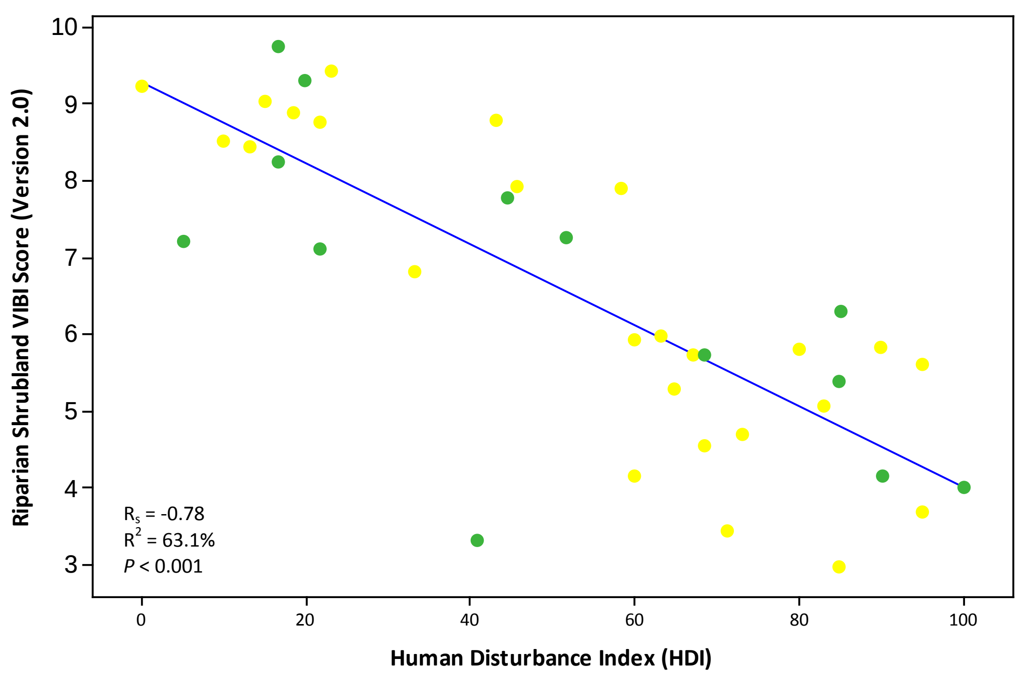

Figure 11. Correlation of Riparian Shrubland VIBI scores, Version 2.0, to the HDI. Data points represent development plots (yellow dots •) and calibration plots (green dots •). Spearman's rank correlation coefficient (R_s) and regression results (R^2 and *P*-value) inset within the graph.

4.2.2 Rocky Mountain Subalpine-Montane Fen VIBI

Version 1.0 metrics and scoring thresholds were used to calculate Fen VIBI scores for Phase 3 plots from both Summit/Park Counties and the San Juan Mountains. Plots in Summit/Park Counties showed a statistically significant negative relationship to the human disturbance gradient (S/P_FenVIBI = 9.44 – 0.04*HDI, R^2 = 83.7%, P = 0.001; Figure 12). Based on Spearman's correlation coefficients, the relationship for Phase 3 plots from Summit/Park Counties (R_s = -0.79) was nearly as strong for as for Phase 1 & 2 development plots (R_s = -0.83; Figure 12, Table 3). The San Juan Mountains plots, however, did not show a significant relationship to the HDI (R^2 = 3.3%, P = 0.697) and the correlation was weak (R_s = -0.28). These results were strongly influenced by the restricted range of the human disturbance gradient sampled in the San Juan Mountains. Six out of seven San Juan Mountain plots were reference fens, and the seventh plot was an impacted fen.

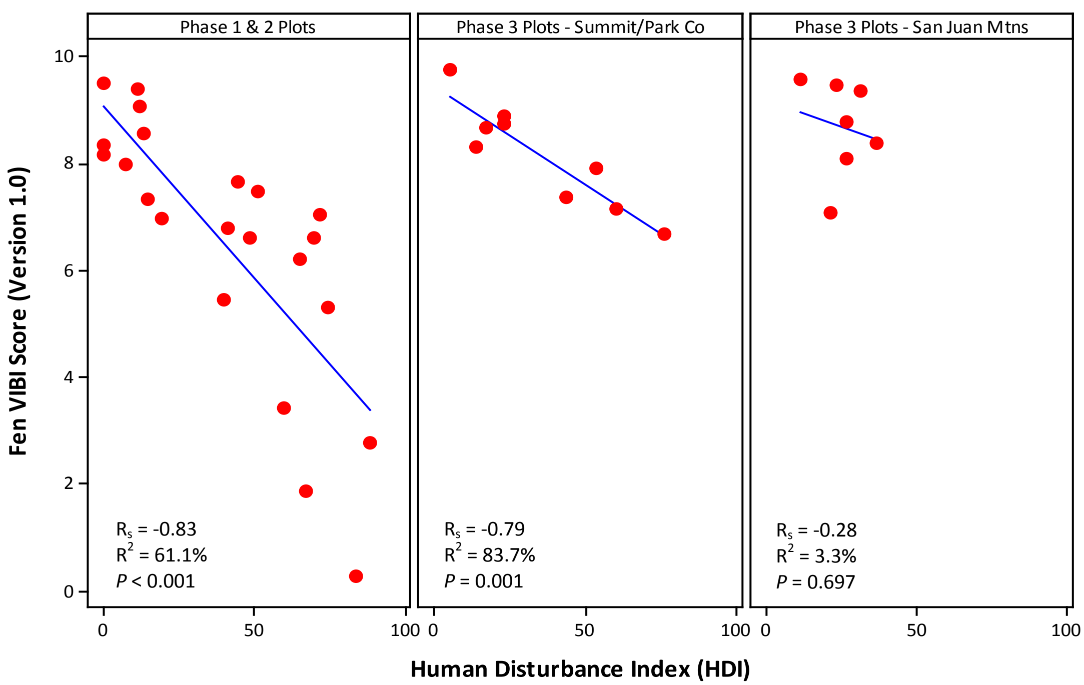

Figure 12. Correlation of Fen VIBI scores to the HDI for Phase 1 & 2 plots, Phase 3 plots from Summit/Park Counties, and Phase 3 plots from the San Juan Mountains. Scores calculated using Version 1.0 metrics and scoring thresholds. Spearman's rank correlation coefficient (R_s) and regression results (R^2 and *P*-value) inset within the graph.

Though the San Juan Mountain plots did not show a similar correlation to the HDI as Summit/Park County plots, reference fens in the San Juan Mountains were not significantly different from reference fens in Summit/Park Counties for any of the six component metrics in the Version 1.0 Fen VIBI. Two tailed paired t-tests of each component metric failed to find any significant differences (Table 4). This indicates that the San Juan Mountain reference fens are within the range of variability represented by the Summit/Park County dataset. Though additional plots from across the disturbance gradient would be necessary to accurately determine the correlation of VIBI scores and the HDI for San Juan Mountain fens, this does indicate that the plots can be integrated into the fen dataset for further analysis and model calibration to extend the model's application to sites beyond Summit/Park Counties. When combined, all Phase 3 plots did have a statistically significant relationship to the HDI (FenVIBI = 9.52 – 0.04*HDI, R^2 = 54.7%, P = 0.001), though it was weaker than for Phase 1 & 2 development plots (R_s = -0.61 vs. R_s = -0.83; Table 3). Absolute cover dominant native species and absolute cover hydrophytes showed particularly weak correlations to the HDI in the Phase 3 plots (Table 3).

Table 3. Correlation of Fen Version 1.0 metrics and overall score to the HDI for Phase 1 & 2 plots, Phase 3 plots from Summit/Park Counties, Phase 3 plots from the San Juan Mountains, and all plots Phase 3 plots combined.

Version 1.0 VIBI Metrics	Correlation to HDI[1]			
	Phase 1&2[2]	Phase 3 Summit/Park	Phase 3 San Juan Mtns	Phase 3 All Combined
Mean C (native)	-0.69	-0.66	-0.14	-0.57
% Non-native species	0.62	0.91	0.47	0.53
Absolute cover dominant native species	-0.44	-0.02	-0.42	-0.10
Absolute cover hydrophytes	-0.57	0.05	-0.42	-0.01
Absolute cover litter	-0.55	-0.57	0.09	-0.40
Absolute cover bare ground	0.63	0.59	0.18	0.39
Final VIBI Score (Version 1.0)	**-0.83**	**-0.79**	**-0.28**	**-0.61**

[1] Spearman's rank correlation coefficient
[2] Values may be different than those shown in Rocchio (2007a) due to slight changes in the calculations between the original Excel spreadsheet calculators and the new VIBI Access™ database.

For the Fen VIBI model, Phase 3 plots also had an effect on metric scoring thresholds, but not as great as seen in the Riparian Shrubland VIBI model. Five out of twelve values used in scoring calculations were different based on all plots (data not shown). This again signifies that until the dataset is sufficiently large, these values may need to be periodically adjusted to reflect the full range of variation.

Version 1.0 component metrics and overall VIBI scores were highly correlated to the HDI for Phase 3 plots from central Colorado, but the above analyses indicated that the model could be adjusted to incorporate data from the San Juan Mountains. One adjustment was to increase the number of component metrics from six to nine, increasing the information imbedded within the model. Phase 3 plots were added to Phase 1 & 2 plots, and additional metrics were screened for inclusion. Metric screening identified seven potential metrics to supplement, modify, or replace the original metrics. Five potential models were compared with Spearman's rank correlation coefficients and linear regression. The model with the best performance included one modified metric and three additional metrics (Table 5). Absolute cover native species was modified from absolute cover of dominant native species, and % intolerant species, % tolerant species, and absolute cover bryophytes were each added to the model.

Table 4. Comparison of mean values for Fen Version 1.0 metrics of Phase 3 reference plots from Summit/Park Counties vs. San Juan Mountains.

Version 1.0 VIBI Metrics	Study Area	Mean +/- Std Err	t value	P-value
Mean C (native)	Summit/Park Co	6.45 +/- 0.64	-0.80	0.444
	San Juan Mtns	6.69 +/- 0.28		
% Non-native species	Summit/Park Co	97.56 +/- 2.38	-0.04	0.971
	San Juan Mtns	97.62 +/- 2.77		
Absolute cover dominant native species	Summit/Park Co	108.90 +/- 29.00	1.24	0.246
	San Juan Mtns	91.82 +/- 16.06		
Absolute cover hydrophytes	Summit/Park Co	122.90 +/- 31.75	1.81	0.103
	San Juan Mtns	96.23 +/- 16.08		
Absolute cover litter	Summit/Park Co	15.58 +/- 6.91	0.87	0.405
	San Juan Mtns	20.03 +/- 8.18		
Absolute cover bare ground	Summit/Park Co	0.28 +/- 0.55	-1.40	0.221[1]
	San Juan Mtns	6.00 +/- 10.02		

[1] All t-test were performed assuming equal variance, except bare ground, which was performed using the Satterthwaite method for unequal variance.

Of the nine metrics included in the Version 2.0 VIBI model, three were indicative of community level integrity and the remaining six were indicative of functional groups (Table 5). Four out of nine metrics were based on richness calculations, while only five were based on dominance. Three metrics (% tolerant species, % non-native species, and absolute cover bare ground) had a positive response and six metrics (mean C natives, % intolerant species, absolute cover native species, absolute cover hydrophytes, absolute cover bryophytes, and absolute cover litter) had a negative response to increasing human disturbance. All nine metrics were able to distinguish reference and highly impacted sites (Figure 13) and most had a Spearman's correlation coefficient of 0.50 and above (Figure 14; Table 5). Percent intolerant species exhibited the strongest correlation (R_s = -0.74) of metrics selected. Interestingly, two of the final metrics exhibited high variability and a relatively weak correlation to human disturbance. Absolute cover native species, which was modified from absolute cover dominant native species, had a slightly higher correlation than the original metric, but its correlation coefficient was only -0.32. Absolute cover hydrophytes, an original metric, had a coefficient of -0.35. Both of these metrics were replaced by others in alternative models, but the best performing model included these metrics. All better performing metrics were redundant with original metrics, and were not chosen for inclusion.

Most metrics showed a linear response to disturbance, but both absolute cover bare ground and absolute cover bryophytes showed a non-linear—though opposite—relationship to the HDI. Absolute cover of bare ground appears to be low for most plots, but rises dramatically for plots with an HDI above 70. The most severely disturbed fen sites were those which had major hydrological or physical alterations (either ditching or peat mining) which, coupled with grazing, resulted in a drastic increase of bare ground. Absolute cover bryophytes is 40% or higher for most reference fens, but drops to 10% or lower from highly impacted fens. The same impacts that lead to higher cover of bare ground in disturbed sites also limit the cover of bryophytes, which depend on soil saturation to thrive.

Cover of bryophytes, though included in the model, is considered a tentative metric because it does not show the same discriminatory power as other metrics selected. There are a handful of reference fens in the dataset with little or no cover of bryophytes recorded. Though high quality fens do occur with little or not bryophyte cover, the number of fens with low cover may, in part, be due to a misunderstanding of data collection protocols. Bryophyte cover should include all bryophytes, whether or not they are beneath vegetation or litter cover. It appears that bryophytes may have been underrepresented in a few reference fens where little or no bryophyte cover was recorded on datasheets, but plot photos clearly show high cover. With clearer instruction on data collection, this metric may be even stronger in the future, but should be regarded as tentative at the present time.

Despite the weak correlations for individual metrics, the overall Version 2.0 Fen VIBI model showed a strong negative relationship with human disturbance (R_s = -0.83; Figure 16). This relationship was highly statistically significant (FenVIBI = 8.29 – 0.06*HDI, R^2 = 65.2%, $P < 0.001$). Version 2.0 VIBI scores were clearly able to distinguish between reference, impacted, and highly impacted sites, though highly impacted plots were more variable than both reference and impacted plots (Figure 15). There were far more reference fens in the data set (20 plots), than either impacted (11 plots) or highly impacted (7 plots) fens. Additional sampling should focus on impacted and highly impacted sites to strengthen the model performance.

Table 5. Details on metrics selected for the Rocky Mountain Subalpine-Montane Fen VIBI model, Version 2.0.

Metric	Metric Category (Basis of Calculation)	Metric Calculation	Increase or Decrease with Disturbance	Correlation to HDI[1]	Min Value	Max Value	95th / 5th Percentile	Change from Version 1.0 Model[2]
Mean C (native)	Community Based (Richness)	Sum of C-values for native species / native species richness	Decrease	-0.71	5.20	7.57	7.18 (95th)	Original metric
% Intolerant species	Community Based (Richness)	Count of intolerant species (C-value ≥ 7) / total species richness	Decrease	-0.74	16%	91%	77% (95th)	Additional metric
% Tolerant species	Community Based (Richness)	Count of tolerant species (C-value ≤ 3) / total species richness	Increase	0.67	0%	37%	0% (5th)	Additional metric
% Non-native species	Functional Group (Richness)	Count of non-native species / total species richness	Increase	0.65	0%	36%	0% (5th)	Original metric
Absolute cover native species	Functional Group (Dominance)	Sum of cover of native species / number of modules sampled	Decrease	-0.32	18%	158%	154% (95th)	Modified from Absolute cover dominant native
Absolute cover hydrophytes	Functional Group (Dominance)	Sum of cover of hydrophytes (OBL & FACW) / number of modules sampled	Decrease	-0.35	3%	155%	150% (95th)	Original metric
Absolute cover bryophytes	Functional Group (Dominance)	Sum of cover of bryophytes / number of modules sampled	Decrease	-0.53	0%	85%	85% (95th)	Additional metric
Absolute cover litter	Functional Group (Dominance)	Sum of cover of litter / number of modules sampled	Decrease	-0.49	1%	85%	85% (95th)	Original metric
Absolute cover bare ground	Functional Group (Dominance)	Sum of cover of bare ground / number of modules sampled	Increase	0.50	0%	85%	0% (5th)	Original metric

[1] Spearman's rank correlation coefficient

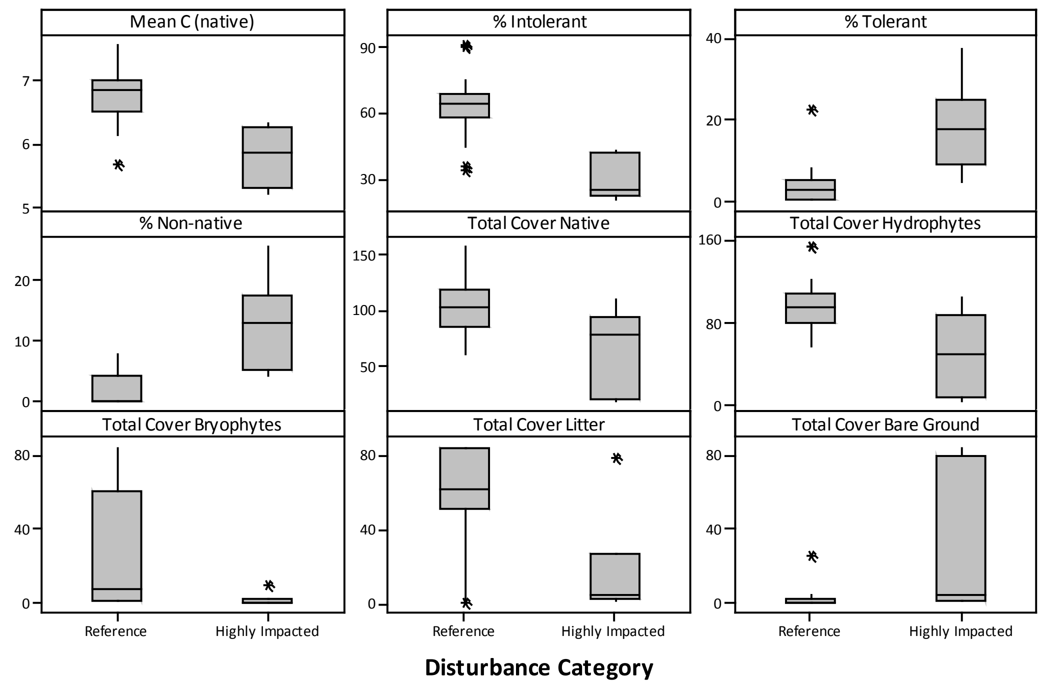

Figure 13. Discriminatory power of individual metrics selected for the Fen VIBI model, Version 2.0. Disturbance categories are equal intervals of the HDI. Reference = HDI of 0.00–33.33; Highly Impacted = HDI of 66.67–100.00. Boxes represent 75th percentile (top) to 25th percentile (bottom). Horizontal lines represent the median. Whiskers extend to the upper and lower limits.

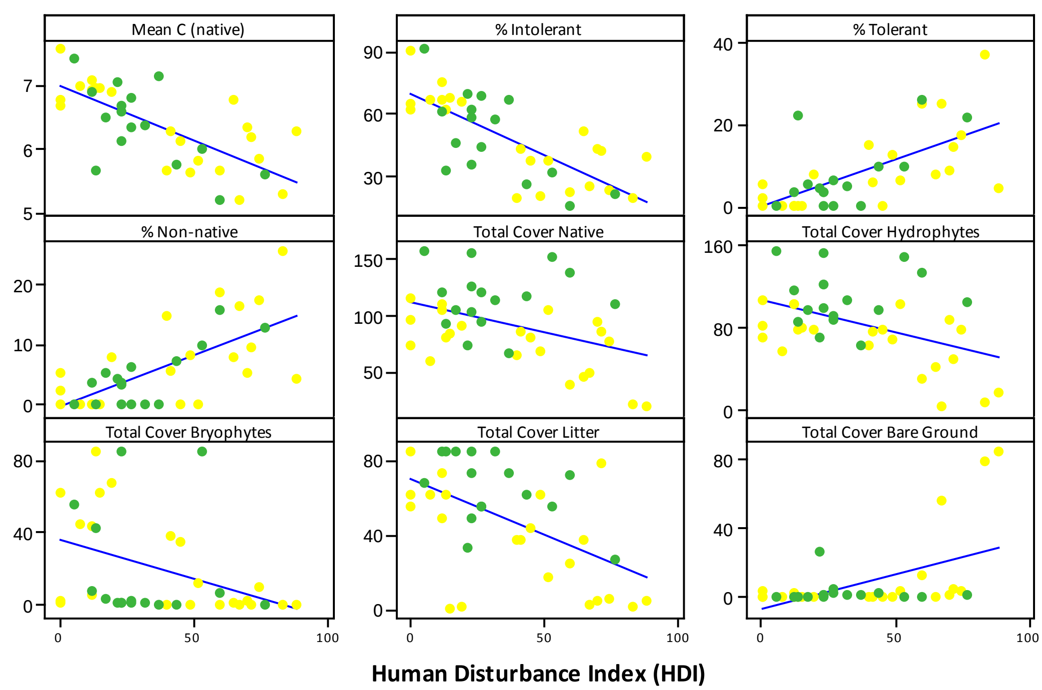

Figure 14. Correlation of individual metrics selected for the Fen VIBI model to the HDI. Data points represent development plots (yellow dots •) and calibration plots (green dots •). Spearman's rank correlation coefficients (R_s) for each metric are listed in Table 5.

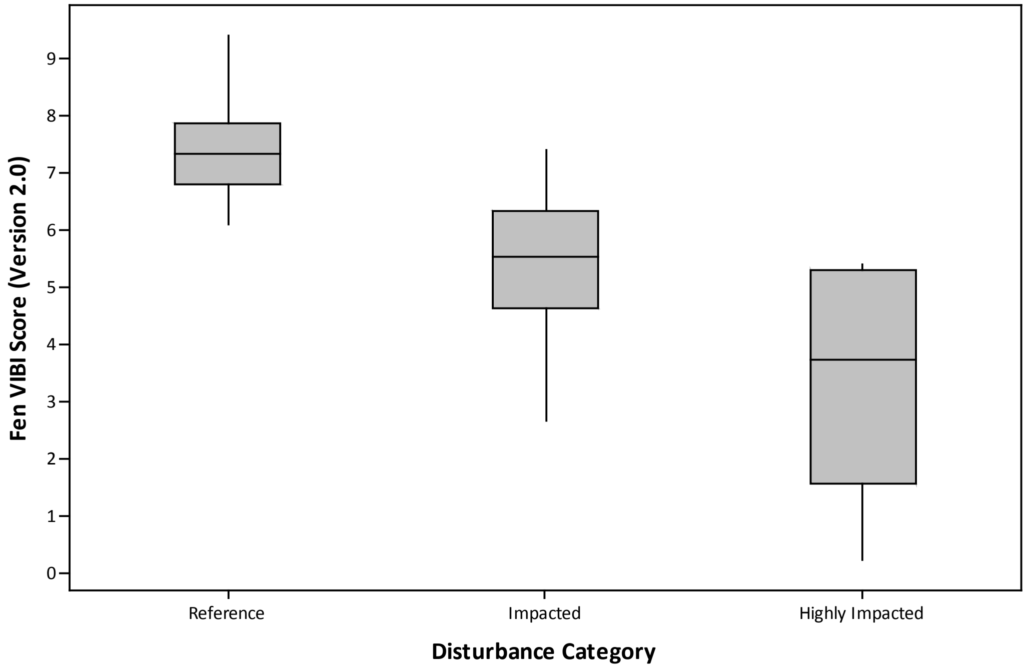

Figure 15. Discriminatory power of the Fen VIBI model, Version 2.0. Disturbance categories are equal intervals of the HDI. Reference = HDI of 0.00–33.33; Impacted = HDI of 33.34–66.66; Highly Impacted = HDI of 66.67–100.00. Boxes represent 75th percentile (top) to 25th percentile (bottom). Horizontal lines represent the median. Whiskers extend to the upper and lower limits.

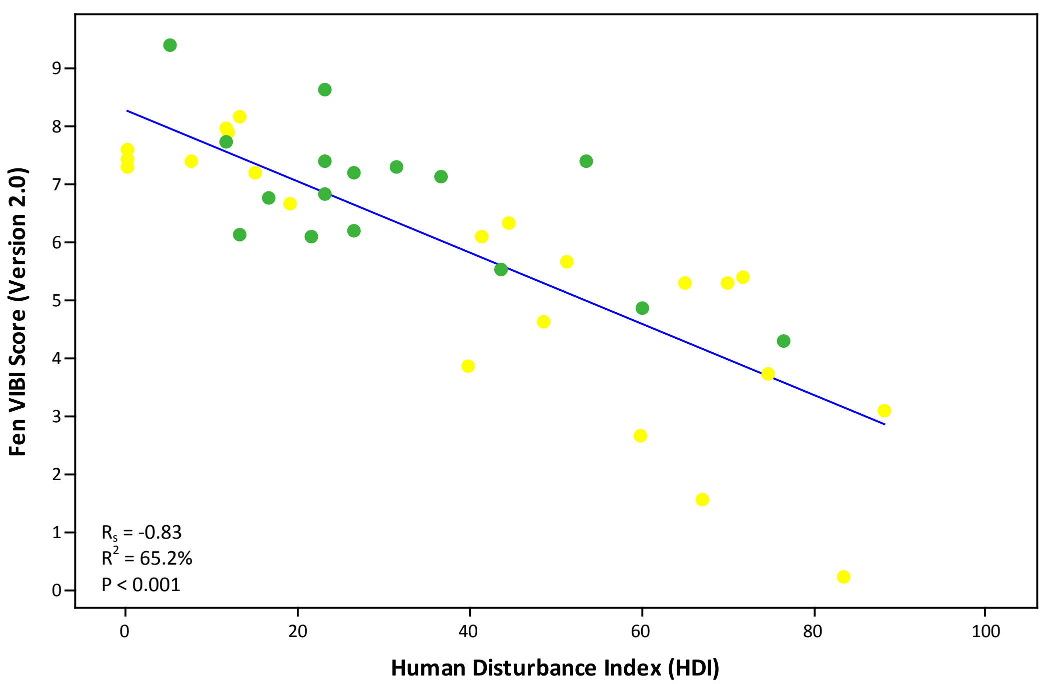

Figure 16. Correlation of Fen VIBI scores, Version 2.0, to the HDI. Data points represent development plots (yellow dots •) and calibration plots (green dots •). Spearman's rank correlation coefficient (R_s) and regression results (R^2 and *P*-value) inset within the graph.

4.2.3 Rocky Mountain Alpine-Montane Wet Meadow VIBI

Using Version 1.0 metrics and scoring thresholds, Slope Wet Meadow VIBI scores were calculated for Phase 3 plots. The resulting relationship between Phase 3 VIBI scores and human disturbance was not statistically significant (MdwVIBI = 7.02 – 0.02*HDI, R^2 = 15.1%, P = 0.300; Figure 17). The relationship was not nearly as strong for Phase 3 plots as for Phase 1 & 2 development plots. Spearman's correlation coefficient for development plots was -0.68, while Phase 3 plots had a coefficient of -0.31. A number of individual metrics also showed much weaker correlation to the HDI in the Phase 3 plots (Table 6).

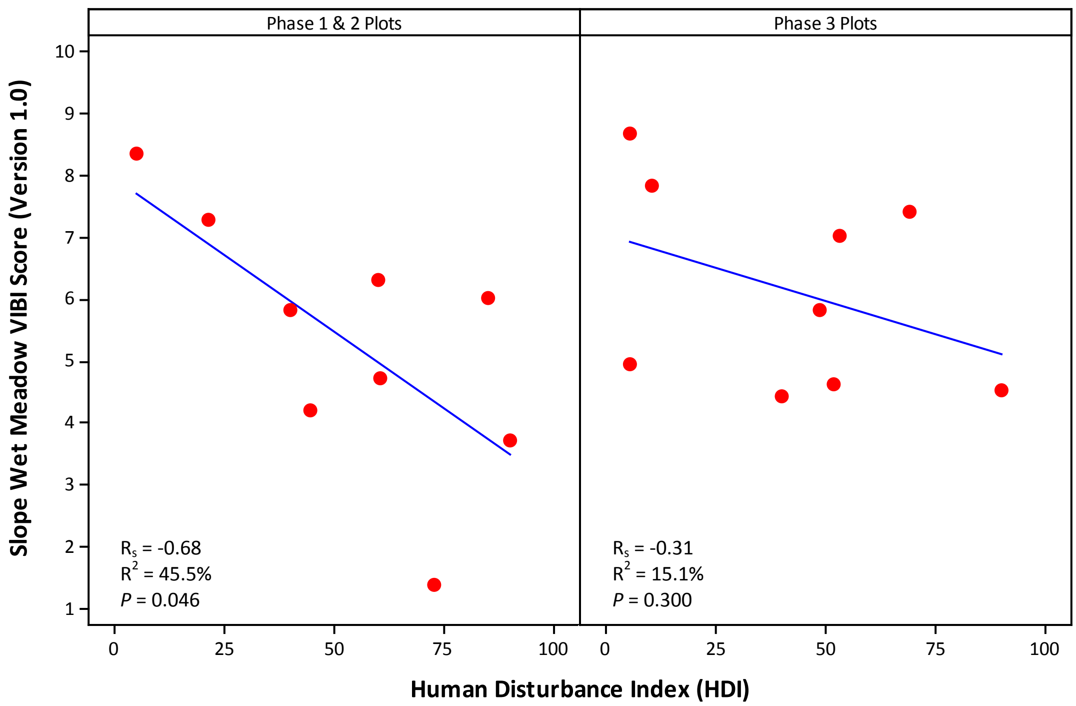

Figure 17. Correlation of Slope Wet Meadow VIBI scores to the HDI for Phase 1 & 2 plots and Phase 3 plots. Scores calculated using Version 1.0 metrics and scoring thresholds. Spearman's rank correlation coefficient (R_s) and regression results (R^2 and *P*-value) inset within the graph.

Phase 3 plots also had an effect on metric scoring thresholds. Nearly all (nine out of ten) values used in scoring calculations were different based on all plots instead of the development plots (data not shown). These different values in the scoring calculations would clearly change metric and overall VIBI scores. This signifies that the dataset does not yet reflect the full range of variation and that these values will need to be periodically adjusted until the dataset is sufficiently large.

The above analyses indicate that the model could be significantly improved by evaluating new metrics and increasing the number of component metrics from five to nine. Phase 3 plots were added to Phase 1 & 2 plots and additional metrics were screened for inclusion. Metric screening identified eight potential metrics to supplement, modify, or replace the original metrics. Three potential models were compared with Spearman's rank correlation coefficients and linear regression. The model with the best performance included two modified metrics, one replacement metric, four additional metrics, and two original metrics (Table 7). Cover weighted FQI (all species) was modified from cover weighted FQI (native) and native perennial species richness was modified from perennial species richness; absolute cover hydrophytes replaces mean cover rhizomatous species; and intolerant species richness, absolute cover native species, % native forb species, and absolute cover bare ground were each added to the model.

Table 6. Correlation of Slope Wet Meadow Version 1.0 metrics and overall score to the HDI for Phase 1 & 2 plots, Phase 3 plots, and all plots combined.

Version 1.0 VIBI Metrics	Correlation to HDI[1]		
	Phase 1&2[2]	Phase 3	All Plots
Cover weighted FQI (native)	-0.57	-0.45	-0.56
Absolute cover perennial species	-0.55	-0.45	-0.51
Perennial species richness	-0.66	-0.21	-0.48
Relative cover *Poaceae* species	0.73	0.20	0.40
Mean cover rhizomatous species	0.27	-0.19	-0.15
Final VIBI Score	**-0.68**	**-0.31**	**-0.60**

[1] Spearman's rank correlation coefficient
[2] Values may be different than those shown in Rocchio (2007a) due to slight changes in the calculations between the original Excel spreadsheet calculators and the new VIBI Access™ database.

Of the nine metrics included in the Version 2.0 Slope Wet Meadow VIBI model, two were indicative of community level integrity and the remaining seven were indicative of functional groups (Table 7). Three out of nine metrics were based on richness calculations, while six were based on dominance. Two metrics (relative cover *Poaceae* and Absolute cover bare ground) had a positive response and seven metrics (cover weighted FQI, intolerant species richness, absolute cover native species, absolute cover perennial species, native perennial species richness, % native forb species, and absolute cover hydrophytes) had a negative response to increasing human disturbance. All nine metrics were able to distinguish reference and highly impacted sites (Figure 18) and most had a Spearman's correlation coefficient of 0.50 and above (Figure 19; Table 7). Absolute cover native species exhibited the strongest correlation ($R_s = -0.75$) of metrics selected. One original metric, relative cover *Poaceae*, had a relatively weak correlation ($R_s = 0.40$), but was still chosen as part of the best performing model. All better performing metrics were redundant with original metrics, and were not chosen for inclusion.

The calibrated Version 2.0 Slope Wet Meadow VIBI model showed a strong negative relationship with human disturbance ($R_s = -0.87$; Figure 21). This relationship was highly statistically significant (MdwVIBI = 8.48 – 0.06*HDI, $R^2 = 74.4\%$, $P < 0.001$). Version 2.0 VIBI scores were clearly able to distinguish reference sites from impacted sites, though highly impacted plots were more variable (Figure 20). Each category had less than ten plots (5 reference, 8 impacted plots, and 5 highly impacted), which limits the strength of conclusions drawn from the data. Additional sampling would greatly improve confidence in the model.

Table 7. Details on metrics selected for the Rocky Mountain Alpine-Montane Slope Wet Meadow Version 2.0 VIBI model.

Metric	Metric Category (Basis of Calculation)	Metric Calculation	Increase or Decrease with Disturbance	Correlation to HDI[1]	Min Value	Max Value	95th / 5th Percentile	Change from Version 1.0 Model
Cover weighted FQI (all species)	Community Based (Dominance)	Cover weighted Mean C * sqrt of total species richness	Decrease	-0.74	5.60	39.53	36.55 (95th)	Modified from cw FQI (native)
Intolerant species richness	Community Based (Richness)	Count of intolerant species (C-value ≥ 7)	Decrease	-0.62	2	36	20 (95th)	Additional metric
Absolute cover native species	Functional Group (Dominance)	Sum of cover of native species / number of modules sampled	Decrease	-0.75	13%	133%	120% (95th)	Additional metric
Absolute cover perennial species	Functional Group (Dominance)	Sum of cover of perennial species / number of modules samples	Decrease	-0.51	35%	133%	118% (95th)	Original metric
Native perennial species richness	Functional Group (Richness)	Count of native perennial species	Decrease	-0.62	2	42	35 (95th)	Modified from perennial species richness
% Native forb species	Functional Group (Richness)	Count of native forb species / total species richness	Decrease	-0.69	0%	66%	60% (95th)	Additional metric
Absolute cover hydrophytes	Functional Group (Dominance)	Sum of cover of hydrophytes / number of modules samples	Decrease	-0.51	2%	125%	100% (95th)	Replaced mean cover rhizomatous species
Relative cover *Poaceae*	Functional Group (Dominance)	Sum of cover of *Poaceae* species / sum of cover of all species	Increase	0.40	5%	88%	7% (5th)	Original metric
Absolute cover bare ground	Functional Group (Dominance)	Sum of cover of bare ground / number of modules samples	Increase	0.50	0.00	22%	0% (95th)	Additional metric

[1] Spearman's Rank Correlation Coefficient

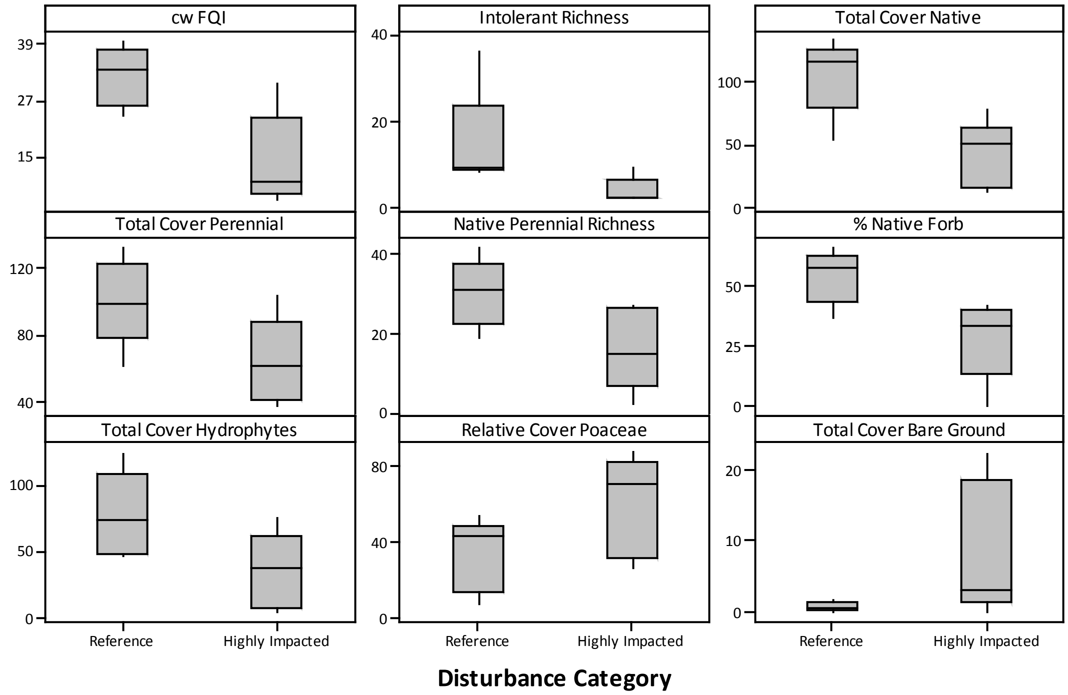

Figure 18. Discriminatory power of individual metrics selected for the Slope Wet Meadow VIBI model, Version 2.0. Disturbance categories are equal intervals of the HDI. Reference = HDI of 0.00–33.33; Highly Impacted = HDI of 66.67–100.00. Boxes represent 75th percentile (top) to 25th percentile (bottom). Horizontal lines represent the median. Whiskers extend to the upper and lower limits.

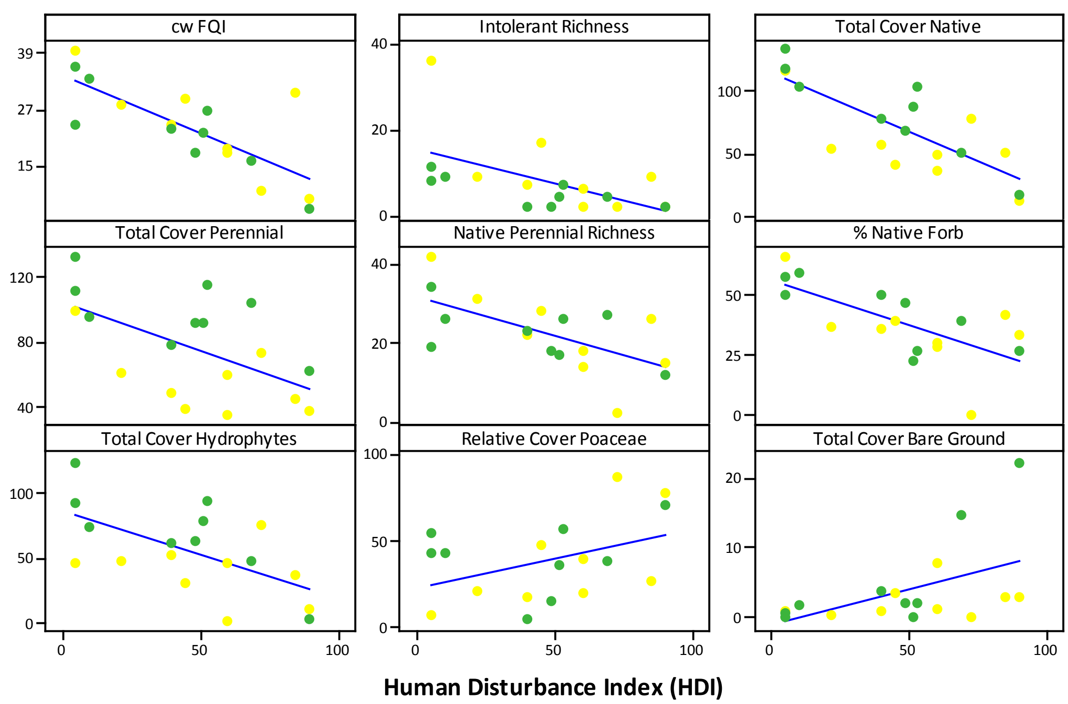

Figure 19. Correlation of individual metrics selected for the Slope Wet Meadow VIBI model to the HDI. Data points represent development plots (yellow dots •) and calibration plots (green dots •). Spearman's rank correlation coefficients (R_s) for each metric are listed in Table 7.

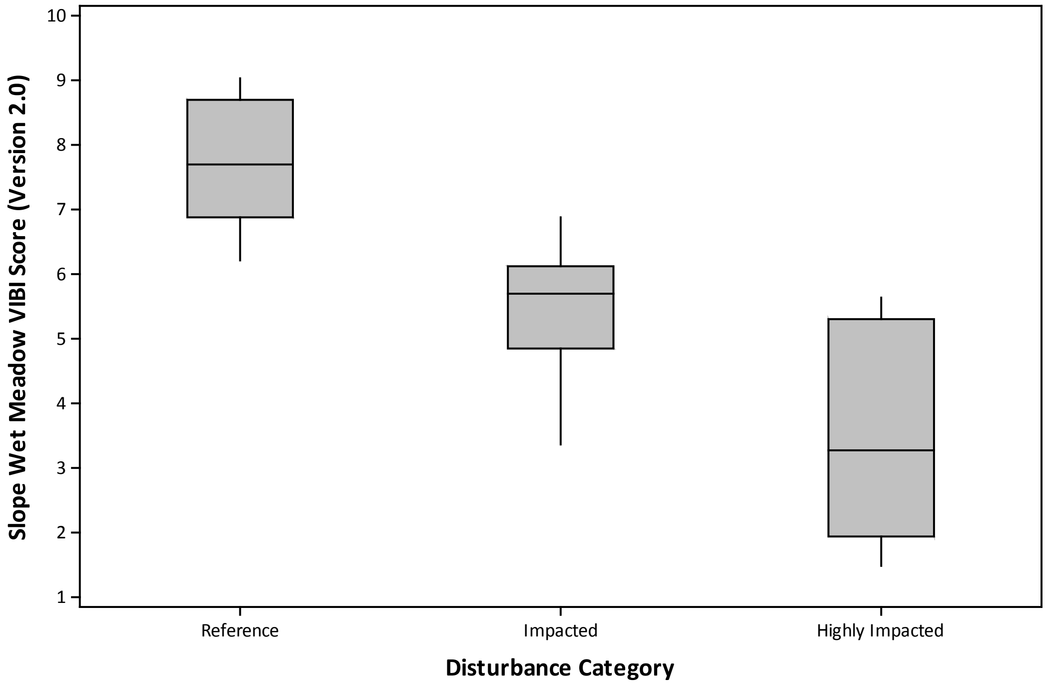

Figure 20. Discriminatory power of the Slope Wet Meadow VIBI Model, Version 2.0. Disturbance categories are equal intervals of the HDI. Reference = HDI of 0.00–33.33; Impacted = HDI of 33.34–66.66; Highly Impacted = HDI of 66.67–100.00. Boxes represent 75th percentile (top) to 25th percentile (bottom). Horizontal lines represent the median. Whiskers extend to the upper and lower limits.

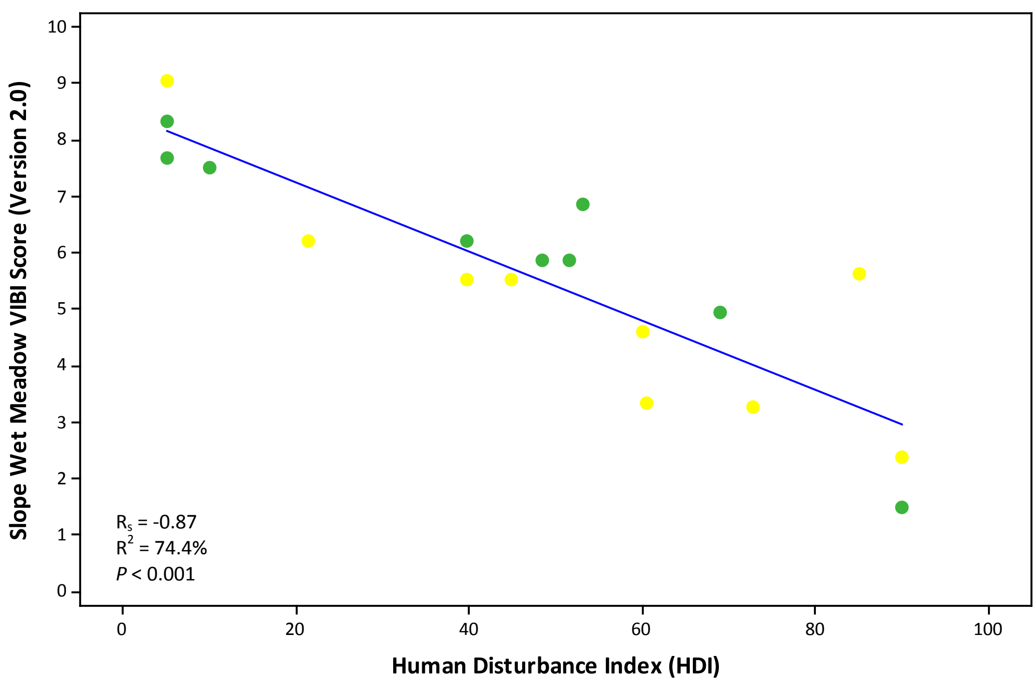

Figure 21. Correlation of Slope Wet Meadow VIBI scores, Version 2.0, to the HDI. Data points represent development plots (yellow dots ●) and calibration plots (green dots ●). Spearman's rank correlation coefficient (R_s) and regression results (R^2 and *P*-value) inset within the graph.

4.3 Final Version 2.0 Vegetation Index of Biotic Integrity Models

Model calibration produced three robust VIBI models, presented in detail in the preceding sections. Twenty metrics in total were selected for inclusion in Version 2.0 models. Version 1.0 VIBI models included five to nine metrics per model, but this was increased to nine metrics per model during calibration. Final Version 2.0 metrics varied according to ecological system type and no metric was included in all three of models (Table 8). Seven metrics were selected for two out of the three models, including mean C (native), % intolerant species, % tolerant species, % non-native species, absolute cover native species, absolute cover hydrophytes, and absolute cover bare ground. In a number of cases, metrics related to the same functional or compositional guild were selected for all models, but with different measures. For example, absolute cover hydrophytes was included in the Slope Wet Meadow and Fen models, while percent hydrophytes was included in the Riparian Shrubland model.

Table 8. Metrics selected for each of the three Version 2.0 VIBI models. See preceding tables for further details on metric calculations.

	Riparian Shrubland VIBI	Fen VIBI	Slope Wet Meadow VIBI
Mean C (native)	X	X	
cw FQI (all species)			X
% Intolerant species	X	X	
Intolerant species richness			X
% Tolerant species	X	X	
% Non-native species	X	X	
Absolute cover native species[1]		X	X
Invasive species richness	X		
Absolute cover perennial species			X
% Native perennial species	X		
Native perennial species richness			X
% Native forb species			X
% Hydrophytes	X		
Absolute cover hydrophytes		X	X
Mean wetland indicator	X		
Carex species richness	X		
Relative cover *Poaceae*			X
Absolute cover bryophytes		X	
Absolute cover litter		X	
Absolute cover bare ground		X	X

[1] Metrics referred to as “mean cover” in Version 1.0 now referred to as “absolute cover.”

4.4 Condition Classes, Thresholds, and Indicator Species

The Riparian Shrubland VIBI model, Version 2.0, could reliably distinguish between three equal disturbance categories ($F_{2,35} = 30.03$, $P < 0.0001$, all pairwise comparisons significant at 0.05 level). At four and five disturbance categories, the overall analyses of variance were significant, but pairwise comparisons showed that mean VIBI scores for each category were not strongly differentiated. Using the three disturbance categories as pre-defined groups, classification tree analysis predicted scoring thresholds for three condition classes (Figure 22). Sites with RipVIBI scores > 8.08 were considered to have high integrity (associated with minimal disturbance or reference conditions). Sites with RipVIBI scores between 6.56–8.08 were considered to have moderate integrity (associated with the impacted disturbance category). Sites with RipVIBI scores < 6.56 were considered to have low integrity (associated with the highly impacted disturbance category). Overall, the predicted scoring thresholds for condition classes agreed with the disturbance categories for 76% of sites (Table 9). Typical ranges for individual metrics and overall VIBI score in each condition classes are shown in Table 12a. Indicator species for each condition class are shown in Table 13.

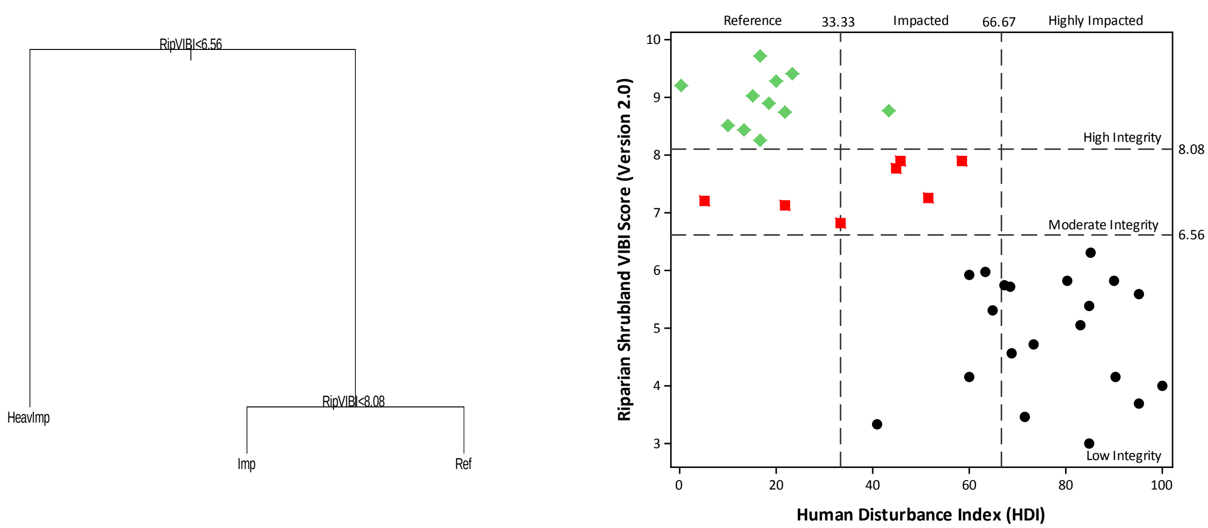

Figure 22. (A) Tree diagram showing Riparian Shrubland VIBI scoring thresholds predicted through classification tree analysis. Ref = Reference, Imp = Impacted, HeavImp = Heavily Impacted. (B) Scatter plot of Riparian Shrubland VIBI scores and human disturbance. Symbols represent predicted condition classes derived from classification tree scoring thresholds: High Integrity (green diamonds ◆), Moderate Integrity (red squares ■), and Low Integrity (black circles ●).

Table 9. Agreement between disturbance categories (derived from HDI scores) and condition classes (derived from VIBI scores) for the Riparian Shurbland VIBI model.

Disturbance Category	Riparian Shrubland VIBI Condition Class: High Integrity	Moderate Integrity	Low Integrity	Category Total
Reference	10	3	0	**13**
Impacted	1	4	5	**10**
Highly Impacted	0	0	15	**15**
Condition Class Total	**11**	**7**	**20**	**38**
Overall agreement	**76%**			

The Fen VIBI model, Version 2.0, could also reliably distinguish between three equal disturbance categories ($F_{2,35}$ = 29.53, P < 0.0001, all pairwise comparisons significant at 0.05 level). As with the Riparian Shrubland model, the overall analyses of variance were significant at four and five disturbance categories, but pairwise comparisons showed that mean VIBI scores for each category were not strongly differentiated. Using the three disturbance categories as pre-defined groups, classification tree analysis predicted scoring thresholds for three condition classes (Figure 23). Sites with FenVIBI scores > 6.06 were considered to have high integrity (associated with minimal disturbance or reference conditions). Sites with FenVIBI scores between 3.90–6.06 were considered to have moderate integrity (associated with the impacted disturbance category). Sites with FenVIBI scores < 3.90 were considered to have low integrity (associated with the highly impacted disturbance category). Overall, the predicted scoring thresholds for condition classes agreed with the disturbance categories for 82% of sites (Table 10). Typical ranges for individual metrics and overall VIBI score in each condition classes are shown in Table 12b. Indicator species for each condition class are shown in Table 14.

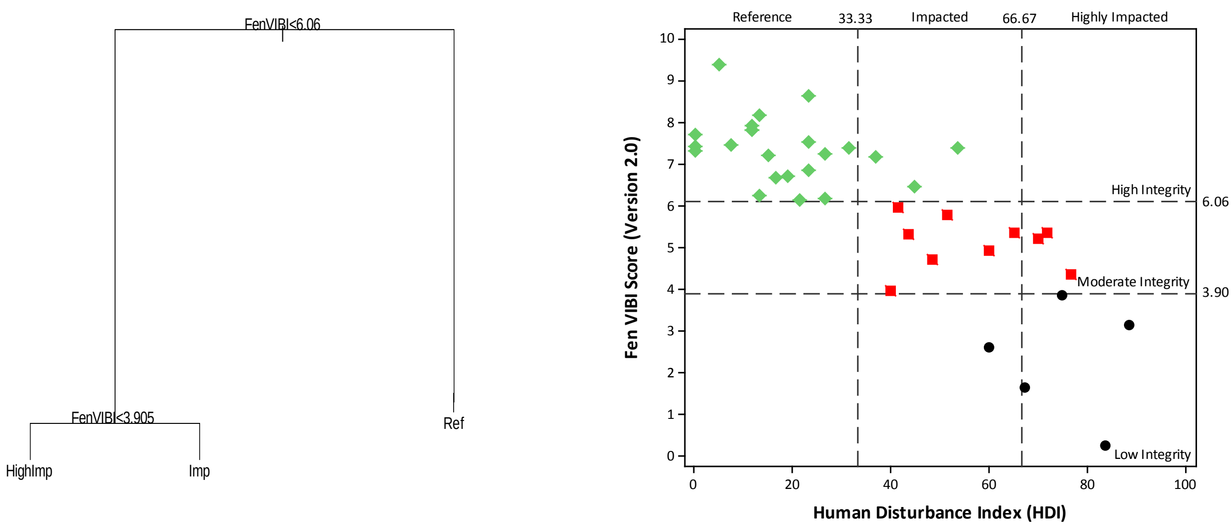

Figure 23. (A) Tree diagram showing Fen VIBI scoring thresholds predicted through classification tree analysis. Ref = Reference, Imp = Impacted, HeavImp = Heavily Impacted. (B) Scatter plot of Fen VIBI scores and human disturbance. Symbols represent predicted condition classes derived from classification tree scoring thresholds: High Integrity (green diamonds ◆), Moderate Integrity (red squares ■), and Low Integrity (black circles ●).

Table 10. Agreement between disturbance categories (derived from HDI scores) and condition classes (derived from VIBI scores) for the Fen VIBI model.

Disturbance Category	Fen VIBI Condition Class			Category Total
	High Integrity	Moderate Integrity	Low Integrity	
Reference	20	0	0	**20**
Impacted	3	7	1	**11**
Highly Impacted	0	3	4	**7**
Condition Class Total	**23**	**10**	**5**	**38**
Overall agreement	**82%**			

The Slope Wet Meadow VIBI model, Version 2.0, could only reliably distinguish between two equal disturbance categories ($F_{2,16} = 12.77$, $P = 0.0025$, all pairwise comparisons significant at 0.05 level). As the model with the fewest data points, the overall analyses of variance were significant at three, four, and five disturbance categories, but pairwise comparisons showed that mean VIBI scores were not strongly differentiated. Using the two disturbance categories as pre-defined groups, classification tree analysis predicted scoring thresholds for two condition classes (Figure 24). Sites with WetMdwVIBI scores > 5.24 were considered to have higher integrity (associated with minimal disturbance or reference conditions). Sites with WetMdwVIBI scores < 5.24 were considered to have lower integrity (associated with the impacted disturbance category). Overall, the predicted scoring thresholds for condition classes agreed with the disturbance categories for 83% of sites (Table 11). Typical ranges for individual metrics and overall VIBI score in each condition classes are shown in Table 1cb. Indicator species for each condition class are shown in Table 15.

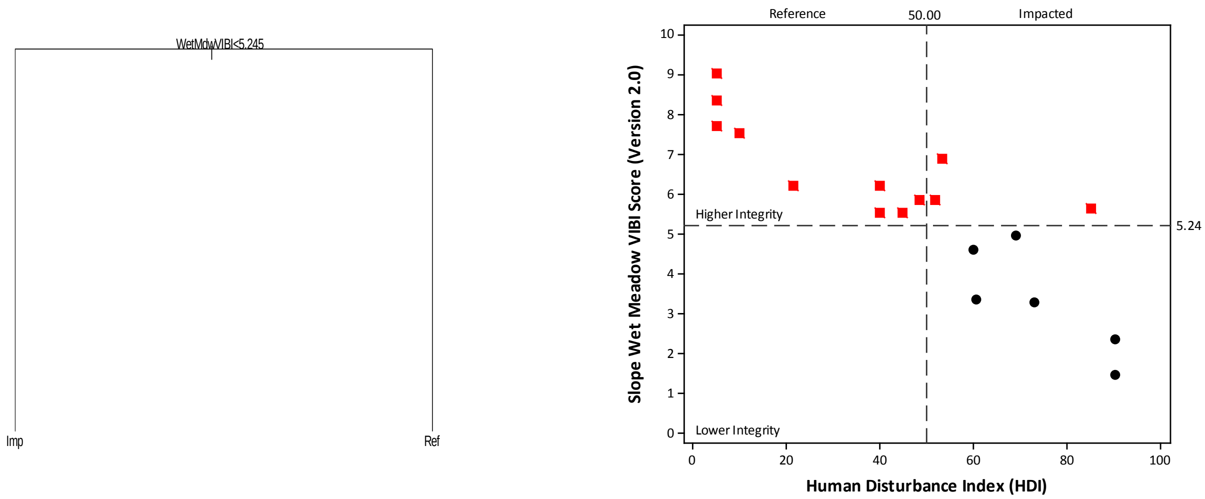

Figure 24. (A) Tree diagram showing Slope Wet Meadow VIBI scoring thresholds predicted through classification tree analysis. Ref = Reference, Imp = Impacted. (B) Scatter plot of Slope Wet Meadow VIBI scores and human disturbance. Symbols represent predicted condition classes derived from classification tree scoring thresholds: Higher Integrity (red squares ■), and Lower Integrity (black circles ●).

Table 11. Agreement between disturbance categories (derived from HDI scores) and condition classes (derived from VIBI scores) for the Slope Wet Meadow VIBI model.

	Slope Wet Meadow VIBI Condition Class		
Disturbance Category	**Higher Integrity**	**Lower Integrity**	**Category Total**
Reference	9	0	**9**
Impacted	3	6	**9**
Condition Class Total	**12**	**6**	**18**
Overall agreement	**83%**		

Table 12. Typical ranges for individual metrics and overall VIBI score in each of the identified condition classes for A) Riparian Shrubland VIBI Model, B) Fen VIBI Model, and C) Slope Wet Meadow VIBI Model.

A) Riparian Shrubland VIBI Condition Class		Mean C (native)	% Intolerant species	% Tolerant species	% Non-native species	Invasive species richness	% Native perennial species	*Carex* species richness	% Hydrophytes	Mean wetland indicator	VIBI Score
High Integrity	Mean	**6.47**	**54%**	**4%**	**3%**	**2**	**81%**	**6**	**55%**	**-1.94**	**8.94**
	Range	6.34–6.64	51–59%	3–5%	2–4%	1–2	79–83%	6–7	52–58%	(-2.15)–(-1.82)	8.64–9.25
Moderate Integrity	Mean	**5.94**	**34%**	**8%**	**6%**	**3**	**79%**	**5**	**45%**	**-1.31**	**7.43**
	Range	5.78–6.16	30–39%	7–9%	4–7%	2–4	78–82%	3–5	40–51%	(-1.64)–(-0.99)	7.16–7.83
Low Integrity	Mean	**5.54**	**22%**	**22%**	**17%**	**7**	**66%**	**2**	**38%**	**-0.84**	**4.88**
	Range	5.24–5.85	14–28%	15–27%	14–20%	5–9	59–72%	1–3	33–47%	(-1.50)–(-0.37)	4.11–5.76

B) Fen VIBI Condition Class		Mean C (native)	% Intolerant species	% Tolerant species	% Non-native species	Absolute cover native species	Absolute cover hydrophytes	Absolute cover bryophytes	Absolute cover litter	Absolute cover bare ground	VIBI Score
High Integrity	Mean	**6.72**	**60%**	**3%**	**2%**	**88%**	**98%**	**31%**	**61%**	**2%**	**7.35**
	Range	6.43–6.98	52–67%	0–5%	0–4%	70–102%	78–108%	2–59%	53–79%	0–2%	6.79–7.75
Moderate Integrity	Mean	**5.92**	**32%**	**13%**	**9%**	**72%**	**83%**	**6%**	**44%**	**2%**	**5.09**
	Range	5.63–6.23	21–43%	8–15%	6–12%	58–87%	65–102%	1–6%	30–63%	0–2%	4.77–5.37
Low Integrity	Mean	**5.65**	**26%**	**22%**	**17%**	**33%**	**27%**	**2%**	**9%**	**48%**	**2.30**
	Range	5.28–5.86	23–25%	18–25%	17–19%	16–44%	8–31%	0–1%	4–7%	13–80%	1.65–3.15

C) Slope Wet Meadow VIBI Condition Class		Cover weighted FQI	Intolerant species richness	Absolute cover native species	Absolute cover perennial species	Native perennial species richness	% Native forb species	Absolute cover hydrophytes	Relative cover *Poaceae*	Absolute cover bare ground	VIBI Score
Higher Integrity	Mean	**27.71**	**10**	**84%**	**84%**	**26**	**44%**	**68%**	**32%**	**2%**	**6.70**
	Range	23.34–31.09	6–10	55–106%	58–102%	21–29	37–52%	49–83%	17–45%	1–2%	5.81–7.57
Lower Integrity	Mean	**12.61**	**3**	**40%**	**62%**	**15**	**26%**	**32%**	**56%**	**8%**	**3.34**
	Range	8.40–17.30	2–4	21–50%	43–70%	13–17	27–33%	6–48%	39–77%	2–13%	2.59–4.31

Table 13. Indicator species for High Integrity, Moderate Integrity , and Low Integrity Riparian Shrublands. Indicator value represents the strength of indication (0 = no indication, 100 = perfect indication). *P*-values were calculated by Monte Carlo permutation test with 5,000 iterations. Species with *P*-values ≤ 0.05 were considered strong indicators and included in this table. C-values and Nativity status are from the Colorado FQA (Rocchio 2007a). Species are ordered by strength of indication within each condition class. Nomenclature follows Weber and Wittmann (2001a, 2001b) with common synonyms in parenthesis.

Scientific Name	Common Name	Indicator Value	*P*-value	C-value	Nativity
High Integrity					
Luzula parviflora	smallflowered woodrush	78.7	0.000	7	Native
Phleum commutatum (P. alpinum)	alpine timothy	67.4	0.001	6	Native
Oxypolis fendleri	Fendler's cowbane	66.9	0.000	7	Native
Clementsia (Rhodiola) rhodantha	redpod stonecrop	65.6	0.000	8	Native
Micranthes (Saxifraga) odontoloma	brook saxifrage	61.0	0.001	8	Native
Calamagrostis canadensis	bluejoint	59.7	0.022	6	Native
Carex aquatilis	water sedge	58.3	0.035	6	Native
Senecio triangularis	arrowleaf ragwort	58.2	0.003	7	Native
Pedicularis groenlandica	elephanthead lousewort	55.3	0.003	8	Native
Carex aurea	golden sedge	54.5	0.000	7	Native
Salix planifolia	diamondleaf willow	52.1	0.033	7	Native
Carex stevenii (*C. norvegica* ssp. *stevenii)*	Steven's sedge	50.8	0.008	8	Native
Galium trifidum ssp. *subbiflorum*	threepetal bedstraw	49.4	0.005	7	Native
Carex canescens	silvery sedge	47.5	0.009	8	Native
Swertia perennis	felwort	45.7	0.017	8	Native
Antennaria corymbosa	flat-top pussytoes	43.9	0.008	5	Native
Veronica nutans (V. wormskjoldii)	American alpine speedwell	43.8	0.009	7	Native
Poa leptocoma	marsh bluegrass	43.1	0.010	8	Native
Picea pungens	blue spruce	41.9	0.014	6	Native
Arnica mollis	hairy arnica	39.7	0.009	7	Native
Crunocallis (Montia) chamissoi	water minerslettuce	38.0	0.025	8	Native
Gentianopsis thermalis	Rocky Mountain fringed gentian	36.4	0.020	8	Native
Juncus mertensianus	Mertens' rush	36.4	0.014	7	Native
Stellaria calycantha	northern starwort	36.4	0.014	8	Native
Sagina saginoides	arctic pearlwort	32.9	0.024	7	Native
Carex nelsonii	Nelson's sedge	27.3	0.025	9	Native
Erigeron elatior	tall fleabane	27.3	0.029	7	Native
Luzula comosa	Pacific woodrush	27.3	0.022	7	Native
Parnassia fimbriata	fringed grass of Parnassus	27.3	0.024	8	Native
Gentianella heterosepala (*G.amarella* ssp. *heterosepala)*	autumn dwarf gentian	25.8	0.033	8	Native

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Table 13. Continued from previous page.

Moderate Integrity					
Thalictrum fendleri	Fendler's meadow-rue	46.7	0.010	6	Native
Bistorta (Polygonum) bistortoides	American bistort	38.4	0.024	7	Native
Delphinium robustum	Wahatoya Creek larkspur	32.6	0.016	6	Native
Draba aurea	golden draba	28.6	0.029	7	Native
Low Integrity					
Poa pratensis	Kentucky bluegrass	78.1	0.006	0	Non-native
Breea (Cirsium) arvensis	Canada thistle	61.4	0.004	0	Non-native
Bromopsis (Bromus) inermis	smooth brome	53.5	0.007	0	Non-native
Phleum pratense	timothy	49.1	0.023	0	Non-native
Cirsium scariosum	meadow thistle	38.8	0.035	6	Native
Thlaspi arvense	field pennycress	35	0.027	0	Non-native

Mean C-Value of Indicator Species for **High Integrity** Riparian Shrublands	7.3	
Mean C-Value of Indicator Species for **Moderate Integrity** Riparian Shrublands	6.5	
Mean C-Value of Indicator Species for **Low Integrity** Riparian Shrublands	1.0	

Table 14. Indicator species for High Integrity, Moderate Integrity , and Low Integrity Fens. Indicator value represents the strength of indication (0 = no indication, 100 = perfect indication). *P*-values were calculated by Monte Carlo permutation test with 5,000 iterations. Species with *P*-values ≤ 0.05 were considered strong indicators and included in this table. C-values and Nativity status are from the Colorado FQA (Rocchio 2007a). Species are ordered by strength of indication within each condition class. Nomenclature follows Weber and Wittmann (2001a, 2001b) with common synonyms in parenthesis.

Scientific Name	Common Name	Indicator Value	*P*-value	C-value	Nativity
High Integrity					
Pedicularis groenlandica	elephanthead lousewort	65.0	0.007	8	Native
Psychrophila (Caltha) leptosepala	white marsh marigold	64.9	0.009	7	Native
Carex aquatilis	water sedge	59.2	0.006	6	Native
Swertia perennis	felwort	52.9	0.024	8	Native
Carex canescens	silvery sedge	39.1	0.050	8	Native
Moderate Integrity					
Juncus arcticus ssp. *ater* *(J. arcticus* ssp. *littoralis, J. balticus)*	mountain rush	70.7	0.004	4	Native
Carex utriculata	Northwest Territory sedge	57.9	0.032	5	Native
Trimorpha (Erigeron) lonchophylla	shortray fleabane	50.0	0.006	5	Native
Taraxacum officinale	common dandelion	49.4	0.036	0	Non-native
Epilobium ciliatum	fringed willowherb	48.6	0.031	4	Native
Lomatogonium rotatum ssp. *tenuifolium*	marsh felwort	40.0	0.010	9	Native
Argentina anserina	silverweed cinquefoil	35.3	0.037	3	Native
Agoseris glauca	pale agoseris	30.0	0.042	5	Native
Antennaria corymbosa	flat-top pussytoes	30.0	0.049	6	Native
Carex praegracilis	clustered field sedge	30.0	0.044	7	Native
Koeleria macrantha	prairie Junegrass	30.0	0.049	5	Native
Pedicularis crenulata	meadow lousewort	30.0	0.049	6	Native
Low Integrity					
Triglochin palustris	marsh arrowgrass	45.7	0.012	7	Native
Muhlenbergia richardsonis	mat muhly	45.1	0.008	8	Native
Lepidium densiflorum	common pepperweed	40.0	0.017	0	Non-native
Phleum pratense	timothy	38.5	0.021	0	Non-native
Calamagrostis stricta	slimstem reedgrass	36.0	0.050	7	Native
Critesion (Hordeum) brachyantherum	meadow barley	32.7	0.040	Not Assigned	Native

Mean C-Value of Indicator Species for **High Integrity** Fens	7.7	
Mean C-Value of Indicator Species for **Moderate Integrity** Fens	4.9	
Mean C-Value of Indicator Species for **Low Integrity** Fens	4.4	

Table 15. Indicator species for Higher Integrity and Lower Integrity Slope Wet Meadows. Indicator value represents the strength of indication (0 = no indication, 100 = perfect indication). *P*-values were calculated by Monte Carlo permutation test with 5,000 iterations. No species showed *P*-values ≤ 0.05 for the Slope Wet Meadow condition classes. Species shown are those with Indicator Values > 25.0. Species with *P*-values ≤ 0.10 are bold and notes with asterisk (*). C-values and Nativity status are from the Colorado FQA (Rocchio 2007a).Species are ordered by strength of indication within each condition class. Nomenclature follows Weber and Wittmann (2001a, 2001b) with common synonyms in parenthesis.

Scientific Name	Common Name	Indicator Value	*P*-value	C-value	Nativity
Higher Integrity					
Juncus arcticus ssp. *ater* (*J. arcticus* ssp. *littoralis, J. balticus*)	mountain rush	58.2	0.315	4	Native
Elymus trachycaulus	slender wheatgrass	48.4	0.165	4	Native
Equisetum arvense	field horsetail	42.9	0.192	4	Native
Epilobium ciliatum	fringed willowherb	40.7	0.317	4	Native
Carex praegracilis	clustered field sedge	40.4	0.180	5	Native
Salix planifolia	diamondleaf willow	39.8	0.235	7	Native
Calamagrostis canadensis	bluejoint	37.5	0.396	6	Native
Pentaphylloides floribunda (Dasiphora fruticosa)	shrubby cinquefoil	35.8	0.382	4	Native
Agrostis scabra	rough bentgrass	33.3	0.229	4	Native
Distegia (Lonicera) involucrata	twinberry honeysuckle	33.3	0.225	7	Native
Salix monticola	park willow	32.9	0.271	6	Native
Calamagrostis stricta	slimstem reedgrass	32.2	0.274	7	Native
Potentilla pulcherrima	beautiful cinquefoil	26.6	0.401	5	Native
Alopecurus pratensis	meadow foxtail	25.0	0.455	0	Non-native
Psychrophila (Caltha) leptosepala	white marsh marigold	25.0	0.443	7	Native
Conioselinum scopulorum	Rocky Mountain hemlockparsley	25.0	0.447	7	Native
Eleocharis quinqueflora	fewflower spikerush	25.0	0.456	8	Native
Fragaria virginiana ssp. *glauca*	Virginia strawberry	25.0	0.371	5	Native
Mertensia ciliata	tall fringed bluebells	25.0	0.447	7	Native
Populus tremuloides	quaking aspen	25.0	0.444	5	Native
Clementsia (Rhodiola) rhodantha	redpod stonecrop	25.0	0.443	8	Native
Senecio triangularis	arrowleaf ragwort	25.0	0.447	7	Native
Veratrum tenuipetalum	Colorado false hellebore	25.0	0.441	4	Native

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Table 15. Continued from previous page.

Lower Integrity					
Poa pratensis	Kentucky bluegrass	66.7	0.145	0	Non-native
Carex utriculata	Northwest Territory sedge	45.8	0.482	5	Native
Glyceria elata (G. striata)	fowl mannagrass	45.6	0.115	6	Native
Phleum pratense	timothy	36.9	0.443	0	Non-native
Hackelia floribunda	manyflower stickseed	36.3	**0.085***	3	Native
Seriphidium (Artemisia) canum	silver sagebrush	33.3	**0.100***	5	Native
Seriphidium (Artemisia) tridentatum	big sagebrush	33.3	**0.096***	4	Native
Festuca (Schedonnardus) pratensis	meadow fescue	33.3	0.103	0	Non-native
Trifolium repens	white clover	32.0	0.174	0	Non-native
Trimorpha (Erigeron) lonchophylla	shortray fleabane	30.7	**0.096***	5	Native
Muhlenbergia richardsonis	mat muhly	26.7	0.174	8	Native

Mean C-Value of Indicator Species for **Higher Integrity** Slope Wet Meadows	5.4	
Mean C-Value of Indicator Species for **Lower Integrity** Slope Wet Meadows	3.3	

5.0 DISCUSSION

5.1 Vegetation Metrics Selected for Version 2.0 VIBI Models

A distinct set of metrics was selected for each of the three Version 2.0 VIBI models, but important general conclusions can be drawn from the final list of all selected metrics (Table 8). Classification continued to exert a strong influence over individual metrics and categories of metrics chosen for each model. Overall, richness-based metrics were far more important in the riparian shrubland model, while dominance-based measures were more important for the fen and slope wet meadow models. For the riparian shrubland model, eight out of nine metrics were richness-based. In contrast, five out of nine metrics were dominance-based for the fen model, as were six out of nine for the slope wet meadow model. These results continue trends from the Version 1.0 models (Rocchio 2007b). Riparian areas are highly dynamic systems and often have higher species diversity. For all plots within the VIBI database, average species per plot was greater for riparian shrublands (54 species/plot) than either fens (30 species/plot) or slope wet meadows (33 species/plot). Riparian areas experience a higher degree of natural disturbance through annual cycles of flooding, scouring, and near drought. This regular disturbance creates numerous micro-habitats for species colonization, such as stream banks, beaver ponds, oxbows, levees, sand bars, and backwater flood channels, and also serves as a pathway for new species introduction. Fens and wet meadows, conversely, are more stable systems and are typically dominated by a few, often rhizomatous species that provide the bulk of plant cover. These differences in natural processes may explain the importance of richness vs. dominance-based metrics in the models.

For all three models, metrics related to nativity, invasiveness, and coefficients of conservatism (C-values: Rocchio 2007a) consistently showed the highest correlations to disturbance. For the riparian shrubland model, % invasive species showed the strongest correlation to disturbance ($R_s = 0.75$), followed by % non-native species ($R_s = 0.74$). Similarly, absolute cover native species showed the highest correlation ($R_s = -0.75$) for the slope wet meadow model. In fact, six out of the ten best performing metrics for the slope wet meadow model were related to nativity (absolute cover native species, % native forb species, native forb species richness, absolute cover native perennial species, native perennial species richness, and absolute cover dominant native species), though not all of these metrics were selected due to redundancy. For the fen model, nativity metrics were among the highest (% non-native species, $R_s = 0.65$), but metrics based on C-values were even more important. When correlations were calculated for all potential metrics for the fen model, eleven out of eighteen metrics with correlations > $|0.5|$ were derived from C-values.

Five of the twenty metrics selected for the final Version 2.0 models—mean C (native), cover weighted FQI, % intolerant species, intolerant species richness, and % tolerant species—are based on calculations derived from C-values. Although these five metrics were the only C-value metrics selected for the calibrated models, several others showed strong correlations to disturbance during metric screening for each of the three models. Additional C-value based indices were not selected as component metrics for the Version 2.0 models because they were often redundant with metrics already included. However, it is important to note the strength of these metrics, as they can also be used as stand alone measures of ecological integrity. Most notably, mean C (all species) was among the most correlated metrics for the riparian shrubland and fens models, though it was less strong for the slope wet meadow model. Mean C (all species) was not included in any of the final models because of redundancy, but these results demonstrate that mean C (all species) should be considered a highly robust single measure of ecological integrity due to the fact that it incorporates two of the strongest measures of ecological condition: C-values and nativity.

Similar to Version 1.0 models, the metrics selected for Version 2.0 models represent a number of ecological processes, functions, and/or stressors. No one metric showed perfect correlation to disturbance, yet this is not surprising given the range of disturbances that affect wetlands and the range of potential responses. In combination, the metrics selected for Version 2.0 models represent a wide ranging and robust set of responses to the array of common disturbances. For example, each model includes at least one metric related to wetland indicator status, which is indicative of hydrologic integrity or alteration. For the riparian shrubland model, both mean wetland indicator status and % hydrophytes were included. For the fen and slope wet meadow models, absolute cover of hydrophytes was selected. For each model, these metrics signify a shift in species composition from more wetland-dependant species to more upland species in the face of certain human disturbance, such as altered flooding regimes, downcut or incised banks that prevent overbank flow, lowered water tables from altered groundwater flow patterns, etc. Interestingly, while both sets of metrics indicate response to a similar stressor (hydrologic alteration), the specific metrics selected again demonstrates the importance of richness-based metrics for the riparian shrubland model and dominance-based metrics for the fen and slope wet meadow models.

Other examples of metrics closely related to ecological processes include absolute cover litter and absolute cover of bare ground. Both metrics were retained in the fen model and absolute cover of bare ground was added to the slope wet meadow model. A range of disturbances can result in lower litter cover and higher bare ground. Potential causes include grazing, pugging by livestock, lowered water tables, physical removal of vegetation due to peat mining, etc. Both metrics can be associated with primary production and carbon cycling. It is likely that fens and wet meadows with lower litter cover and higher cover bare ground have lower rates of soil organic matter production, as less aboveground biomass is available to be incorporated into the soil and decomposition rates increase due to higher soil temperatures. For fens in particular, bare and disrupted ground can lead to organic matter decomposition and eventual loss of peat soil (Chimner & Cooper 2003).

For both the riparian shrubland and slope wet meadow models, metrics related to the richness and abundance of perennial species were selected. For the riparian shrubland model, % native perennial species was retained as a metric in the calibrated model. For the slope wet meadow model, absolute cover perennial species and native perennial species richness were retained or modified. Perennial species are generally slower to establish after disturbance. A high number or high cover of perennial species, particularly native perennial species, could indicate that the wetland has not experienced excessive recent disturbance. In addition to metrics related to perennial species, both models also include metrics related to the composition of the perennial community. For riparian shrublands, *Carex* species richness was added to the Version 2.0 model. This metric signifies that a healthy, undisturbed riparian shrubland typically contains a high number of sedge species, and that this particular taxonomic group drops in number in the face of disturbance. Indicator Species Analysis selected a handful of sedge species *(Carex aurea, Carex stevenii,* and *Carex nelsonii)* as indicators of high integrity riparian shrublands. These species each have C-values between 7–9, indicating that they are sensitive to disturbance and may be among the first to be lost after disturbance. For the slope wet meadow model, relative cover of *Poaceae* was an original Version 1.0 metrics maintained in the Version 2.0 model. Combined with information from Indicator Species Analysis, which selected several non-native grass species as indicators of lower integrity wet meadows *(Poa pratensis, Phleum pratense,* and *Festuca pratensis),* this metric indicates that native graminoids (sedges, rushes, etc.) loose ground to non-native grass species as disturbance increases.

5.2 Final Version 2.0 VIBI Models

The three VIBI models calibrated in this phase of the project all show strong correlations to the human disturbance gradient (Table 16) and were clearly able to differentiate between reference and highly impacted sites (see previous sections). Each of the three models had a higher Spearman's rank correlation coefficient than any of their component metrics, similar to findings for Version 1.0 models. This reinforces the conclusion that each VIBI model effectively integrates different types of ecological responses to human disturbance. As each of the VIBI's component metrics are reflective of underlying ecological processes, functions, and/or stressors, the VIBI models provide a strong surrogate measure for overall ecological integrity. Because VIBI models integrate multiple quantitative vegetation metrics, they provide a much more thorough and consistent assessment of vegetation response to human disturbance than traditional single measures, such as species diversity or percent native species.

Table 16. Summary of HDI and VIBI Scores for all Version 2.0 Models.

Version 2.0 Model	Number of sites	Correlation to HDI[1]	Range of HDI Scores 0.00 (reference) - 100.00 (highest impact)		Range of VIBI Scores 0.00 (lowest integrity) - 10.00 (highest integrity)	
			Min	Max	Min	Max
Riparian Shrubland VIBI	38	-0.78	0.00	100.00	2.99	9.73
Fen VIBI	38	-0.83	0.00	88.25	0.26	9.39
Slope Wet Meadow VIBI	18	-0.87	4.95	90.10	1.48	9.04

[1]Spearman's rank correlation coefficient.

Riparian shrublands and fens are both well represented in the dataset, with 38 sites each (Table 16). The Version 2.0 models for these ecological systems can be used with confidence in their ability to quantify ecological condition, though continued data collection will refine the models even further. Although slope wet meadows are not as well represented, the slope wet meadow Version 2.0 model does have a strong correlation to disturbance for the sites sampled. This model should be used with more caution than the other ecological systems, but should also provide a reliable measure of ecological condition. For all three ecological systems, the sites sampled represented a wide range of human disturbances. Human disturbance index scores spanned at least 85% of the gradient for each wetland type (Table 16). Interestingly, VIBI scores did not all span the full possible spectrum from 0.0 to 10.0. The slope of the line representing change in VIBI due to human disturbance was different for each ecological system. This is important to note because the VIBI score for a riparian shrubland cannot be compared to the VIBI score for a fen, which is one reason for determining condition class thresholds for each model.

5.3 Condition Classes Derived from Version 2.0 VIBI Models

Actual VIBI scores and component metrics contain the most accurate information about a wetland's ecological condition. But it is often important to place this number into context for the variety of users interested in wetland assessment, including land managers, regulators, and the general public alike. Condition classes provide an intuitive way to communicate wetland condition and also provide a way to compare between wetland types, as VIBI scores are not comparable. For these reasons, condition classes were identified for each of the three Version 2.0 VIBI models. Both the riparian shrubland and fen models were able to distinguish between three different disturbance categories, but the slope wet meadow model was only able to distinguish two. Threshold values calculated through CART models based on the disturbance categories resulted in fairly robust condition classes. For each model, the overall agreement between condition classes and disturbance categories ranged between 76–83%, meaning that over three-quarters of all plots fell within the excepted condition class for its assigned disturbance category. Reference sites fell within the high integrity condition class, impacted sites fell within the moderate integrity class, and highly impacted sites fell within the low integrity class.

This was considered an assessment of agreement and not an accuracy assessment for two primary reasons. First, VIBI scores and resulting condition classes have been developed and calibrated based on HDI scores and associated disturbance categories. Though the HDI used in this project is highly correlated to other measures of disturbance used by other states (Rocchio 2006b), these disturbance indices are constructed based on best professional judgment and have not been validated again a truly independent measure of disturbance, simply because such a measure does not exist. As it is difficult to validate the HDI's accuracy, it is also difficult to say with certainty that non-agreement between the HDI and the VIBI is caused by inaccuracy within the VIBI. Secondly, and perhaps more importantly, there can be a time lag between disturbance and a measurable biologic response (Findlay & Bourdages 2000). In some instances, recent disturbances measured through the HDI may take time to change the vegetative community within a wetland. In these cases, the HDI may predict a lower VIBI score than is actually measured. In other instances, historic disturbances can be hard to see in the landscape and may be overlooked through the HDI, but their impact on the biologic community may persist for decades. This scenario would produce a lower VIBI score than the HDI would predict.

For these and other reasons, additional data would help clarify the best breaks in the data and add confidence to the assignment of VIBI scores into condition classes. This is particularly true for the slope wet meadow model, which could only reliably distinguish two disturbance categories. From the slope wet meadow graph, it appears that there could be more effective splits in the data, especially on the upper end of the VIBI, but these were not detected using the methods employed in this report. Other studies have used power analysis to determine the number of reliable condition classes (Fore et al. 1994), but this technique requires repeated sampling over multiple years to determine inter-annual variability. Until further data is collected, these condition classes should be considered somewhat tentative.

Though tentative, the condition classes still provide pertinent and useful information about the measurable effects of disturbance on the wetland types included in this study. Typical ranges for individual metrics and indicator species calculated for each condition class together outline quantitative and descriptive difference between wetlands of varying integrity. Even without conducting a full VIBI survey, these values could provide stand-alone warning signs about ecological condition. For example, if a fen has >5% non-native species or >10% bare ground, it could be cause to investigate potential disturbances. Likewise, if a riparian shrubland contains 3 or more invasive species and 5 or less *Carex* species, the system may need management attention. These ranges could also inform benchmarks to evaluate the success of wetland mitigation or restoration projects. If the target outcome of a mitigation project was a high integrity riparian shrubland, for instance, that site might need to meet the mean value of seven out of nine metrics in the high integrity condition class.

The indicator species lists could also be used as a quick field-based check, as the presence or absence of these species could point to a wetland's condition. Overall, the indicator species do reflect the disturbance and condition gradients. For each ecological system, the mean C-value for indicator species is highest for higher integrity wetlands and lowest for lower integrity wetlands (Tables 13–15). As the C-value represents a species' tolerance or intolerance of disturbance, this result confirms that high integrity wetlands are more likely to contain high C-value species. Though useful in their current form, refining and validating these indicator species with further data collection would strengthen the reliability of the lists. Some species on the current lists are likely a result of the specific wetlands sampled through this project. For instance, fewer low integrity fens were sampled compared to high integrity fens and a few of the indicator species for low integrity fens do not make intuitive ecological sense, especially in light of their C-values. *Triglochin palustris, Muhlenbergia richardsonis,* and *Calamagrostis stricta* are all species selected as indicators of low integrity fens, though they have C-values of 7 or 8. It is likely that these species were present in the handful of sites surveyed in this project, but that they would not be found in other highly disturbed fens across the Southern Rocky Mountains. Alternatively, the C-values for these species could be inaccurate and in need of review. Figures 25–27 illustrate wetlands in each condition class. See Rocchio (2007b) for additional field photos and associated scores.

Plot 2-18: VIBI = 8.43, HDI = 13.20 **—High Integrity Sites—** Plot 2-31: VIBI = 9.22, HDI = 0.00

Within National Forest, dirt road nearby. No alteration in watershed or wetland.

Plot 2-11: VIBI = 7.91, HDI = 45.53 **—Moderate Integrity Sites—** Plot 3-375: VIBI = 7.77, HDI = 44.55

Adjacent to residential development and golf course. Dirt roads and intensive recreation in area.

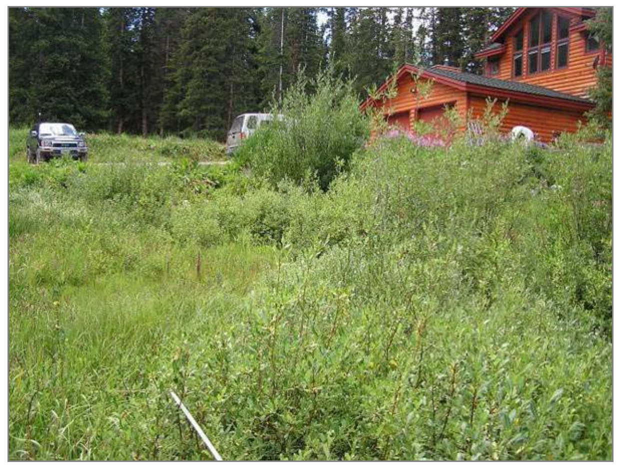
Plot 2-68: VIBI = 3.45, HDI = 71.25 **—Low Integrity Sites—** Plot 3-154: VIBI = 4.15, HDI = 90.10

Intensive grazing has damaged soil and vegetation. Residential development and hydrologic modification.

Figure 25. Examples of Rocky Mountain Subalpine-Montane Riparian Shrublands by condition class.

Plot 2-32: VIBI = 7.30, HDI = 0.00 **—High Integrity Sites—** Plot 3-011: VIBI = 8.63, HDI = 23.10

No alteration in watershed or wetland. Grazing in watershed, but not within fen.



Plot 2-17: VIBI = 6.10, HDI = 41.35 **—Moderate Integrity Sites—** Plot 2-61: VIBI = 5.31, HDI = 64.95

Powerlines in background and minor pugging. Residential development on edge of fen.

Plot 2-21: VIBI = 3.45, HDI = 71.25 **—Low Integrity Sites—** Plot 2-75: VIBI = 4.15, HDI = 90.10

Intensive grazing within fen has damaged soil and vegetation. Large areas of bare soil caused by peat mining.

Figure 26. Examples of Rocky Mountain Subalpine-Montane Fens by condition class.

Plot 3-157: VIBI = 7.70, HDI = 4.95 **—Higher Integrity Sites—** Plot 2-64: VIBI = 5.53, HDI = 45.75
Only minor alteration in watershed. Moderate grazing in meadow.

Plot 2-22: VIBI = 2.37, HDI = 90.10 **—Lower Integrity Sites—** Plot 3-016: VIBI = 4.96, HDI = 69.80
Intensive grazing within meadow has removed vegetation. Moderate grazing and adjacent roads.

Figure 27. Examples of Rocky Mountain Alpine-Montane Slope Wet Meadows by condition class.

5.4 Conclusion and Next Steps

Calibration and validation is a necessary step in any modeling process. Model development based on initial data must be evaluated against independent data in order to fine-tune the model's ability to accurately depict ecological conditions. Though vegetation-based IBI models have been successfully developed across the United States in areas such as Florida (Reiss 2006, Lane 2003), Massachusetts (Carlisle et al. 1999), Michigan (Simon et al. 2001, Kost 2001), Minnesota (Gernes & Helgen 2002), Montana (Jones 2004, Jones 2005), North Dakota (DeKeyser et al. 2003), Ohio (Mack 2004a), Pennsylvania (Miller et al. 2006), and Wisconsin (Lillie et al. 2002), not all of them have been calibrated with additional data. This report offers a first run at calibration of Colorado's VIBI models for three headwater wetland types: riparian shrublands, fens, and wet meadows.

In Phase 3 of the VIBI project, 38 additional wetlands were sampled from within the original study watersheds and from additional watersheds in a separate area of the state. These sites were first used to test whether the original Version 1.0 VIBI models could be validated with independent data. For each of the three models, analysis indicated that the models were not able to be validated, but should instead be calibrated with the additional data. Calibration included screening over 130 metrics to determine which original metrics should be retained in the models, which could be modified, and which should be replaced by new metrics. The Version 2.0 calibrated models showed strong correlation to human disturbance and could clearly distinguish between reference and highly impacted sites. Based on the Version 2.0 models, condition classes were identified and typical values for each metric in each condition class, as well as indicator species for each condition class, were calculated. This information can be used by a variety of interested parties across the state, including regulators, land managers, conservation groups, and researchers.

In the future, additional data collection and analysis would continue to improve these models. The most advanced VIBI models in the country have undergone several rounds of calibration before they were considered final (Mack 2007). Data from new wetlands, particularly from slope wet meadows, would continue to strengthen and refine the current models. One objective of this project was to test the geographic range of the models, but logistical considerations made this goal difficult to achieve. Future testing of the models in various locations across the state would accomplish this goal. In 2008, the Colorado Natural Heritage Program and the Colorado Division of Wildlife launched a basinwide wetland condition assessment of the Rio Grande Headwaters river basin in south central Colorado. The VIBI models developed and calibrated in this project are being used to assess wetland condition in the Rio Grande, and the data collected will feed into model testing and calibration. In future year, this work will be continued in both the North and South Platte River basins, further expanding the scope and application of the models.

In addition to further calibration of the existing models, additional VIBI models could be developed for the remaining wetlands ecological systems in Colorado. Wetland ecological systems that occur at lower elevations along Colorado’s Front Range are of particular importance. This area is experiencing rapid population growth, which places considerable strain on aquatic resources. Lower elevation wetlands, such as marshes, wet meadows, riparian woodlands and shrublands, have been impacted by urban and suburban development, road construction, water development and re-allocation, and increased nutrient and sediment inputs. VIBI models could be developed for these wetland systems to help guide management decisions, mitigation action, and prioritize conservation efforts. A fuller suite of wetland VIBI models will provide a comprehensive set of tools for wetland condition assessment throughout the state of Colorado.

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APPENDIX A: VIBI Calibration Survey Design

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Description of Sample Design

Target Population: The target population consists of all fens, wet meadows, and riparian shrublands within two geographic regions: 1) Upper Blue River and South Platte River Headwaters and 2) San Juan Mountains.

Sample Frame: Colorado Natural Heritage Program provided the shapefile, Wetland_pts_potentialVIBIsample, for the sample frame. Prior to calculating polygon centroids, polygons greater than 2 km from roads were eliminated, which may explain some of the clustered distribution and empty spaces in the distribution of potential points. Original GIS data contained many contiguous polygons within a complex of wetlands that were delineated separately because of characteristics interpreted from aerial photos (e.g., vegetation composition, vegetation structure, landscape form). Although these may have been cross-walked to the same wetland type the separate polygons and associated centroids were retained. This may also account for some clustering of points.

Fields of interest are:

- **WetEco_Sys –** Wetland type classification. In addition to the three types (fen, wet meadow, and riparian shrubland) there are two uncertain types (fen/wet meadow, unknown). Ambiguous types were included as separate categories because there were many of them.
- **Disturb_cl –** Disturbance class indicator. There are 3 disturbance classes (Highly Impacted, Impacted, Reference) and one category where disturbance was not known (Unknown). As above, the “Unknown” class was retained as a separate category rather than guessing the type because there were many of them.
- **GIS_source –** Link to the original data source.
- **Region** – Specifies the study region (Upper Blue River/South Platte River Headwaters or San Juan Mountains). The target is ~ 40 sites in each region.
- **X_point** and **Y_point –** Coordinates of the points (in most cases, polygon centroids forced to inside polygons). The coordinates are in Albers Equal Area projection.

- **Area_m2 –** Calculated area in square meters of the polygon represented by the centroid. Area was calculated after polygon shape files were converted into Albers Equal Area. Area was used to eliminate polygons smaller than the defined critical area (Wet Meadows: < 1 acre or 0.4 hectare; Fens: < 0.5 acre or 0.2 hectare; Riparian Shrublands: < 1.25 acre or 0.5 hectare; any other combination: < 0.5 acre or 0.2 hectare). Area will not be used for stratification or unequal probability weighting by size class. There are 47 points that were not derived from polygon data and therefore have no associated area (i.e., Area_m2 = 0).
- The other fields are unique record identifiers associated with the source file and are retained in the file to assist in quickly looking up sample point information.

A new attribute, WET_DISTURB was created that combined information on wetland type and disturbance class. The combinations created are:

- FenWet_HI="fen/wet meadow_Highly Impacted"
- FenWet_I=c("fen/wet meadow_Impacted", "fen/wet meadow_Unknown")
- FenWet_R="fen/wet meadow_Reference"
- Fen_HI="fen_Highly Impacted"
- Fen_I=c("fen_Impacted", "fen_Unknown")
- Fen_R= "fen_Reference"
- Rip_HI="riparian shrubland_Highly Impacted"
- Rip_I=c("riparian shrubland_Impacted", "riparian shrubland_Unknown")
- Rip_R="riparian shrubland_Reference"
- Wet_HI="wet meadow_Highly Impacted"
- Wet_I=c("wet meadow_Impacted", "wet meadow_Unknown")
- Wet_R="wet meadow_Reference"
- Unk_Unk= "unknown_Unknown"

The reason for the collapsing is due to lack of information on disturbance classes for many wetlands. For lack of other information, the “Unknown” disturbance class was combined with the “Impacted” class.

Survey Design: A Generalized Random Tessellation Stratified (GRTS) survey design for a finite/point resource was used. The GRTS design includes reverse hierarchical ordering of the selected sites.

Stratification: The two geographic regions: Upper Blue River/South Platte River Headwaters and San Juan Mountains.

Multi-Density Categories: The WET_DISTURB attribute was used to define unequal probability categories

Panels: Base and Over sample

Sample Size: Each region has 40 sites. Within each region, the final study will result in 13, 13, and 14 wetlands respectively for fen, wet meadow, and riparian shrubland. Within each wetland class, the goal is to have approximately an equal number of sites for the three disturbance classes. Given the information available in the sample frame, the survey design can not directly allocate sites to meet this requirement. The following procedure was followed: (1) wetlands classified as fens or wet meadow or riparian shrubland were each allocated 6 sites (2 within each disturbance class) within each region (if possible). (2) The remaining sites for fens and wetlands were allocated to the fen/wet meadow class (equal number for each disturbance class). (3) If a disturbance class was not present, then no sites were allocated to it. (4) Unknown wetland types were allocated 25% of the sample based on percent of wetlands that were unknown to total number of wetlands.

Oversample: Over sample size of 360 sites for each region.

Site Use: These sites are identified by panel name in the variable "Panel". If it is necessary for a site in any panel to be replaced, then the lowest ordered SiteID that is part of the over sample of sites (identified by "OverSamp" in variable "Panel" must be used. Subsequent replacement sites continue to be used in the same way.

Given the uncertainty in classification of wetland types and disturbance classes, implementing the design will require that sites be evaluated in a more complex manner than normal. Recommend do following:

For Upper Blue River/South Platte River Headwaters:

- Sites explicitly classified as Fen_HI, Fen_R, Wet_HI, Wet_R, Rip_HI, and Rip_R be evaluated to determine what class they are and assign them to that class. Once that is completed, then we will know how many sites have the correct wetland type and disturbance class within each region.
- Then evaluate the FenWet_HI, FenWet_I, and FenWet_R, classifying them correctly, until have 4,4,5 total sites that are correctly classified in fen and wet meadow for each disturbance class respectively. Do this by evaluating an equal number of sites within these three WET_DISTURB categories. This will ensure that all wetlands have a chance of being selected.
- Then evaluate the Rip_HI, Rip_I, and Rip_R classes, classifying them correctly, until have 4,4,5 total sites that are correctly classified in fen and wet meadow for each disturbance class respectively. Do this by evaluating an equal number of sites within these three WET_DISTURB categories. This will ensure that all wetlands have a chance of being selected.

For the San Juans, follow the same process as above, except limiting number of wetlands to 3-4. Then for remainder of required San Juan sites, evaluate the Unk_Unk class as a final step.

Operationally, this may be difficult to do and may require a large number of wetlands to be evaluated. Do as much of the evaluation of the wetlands selected in the office before going to the field. You may need to do two separate field operations within each region. In the first field operation, you may find that you have not correctly classified the wetlands in the office. Once you have results from the field, then you will know the number of sites correctly classified. Then you can evaluate more sites to fill in classes requiring more.

Sample Frame Summary

Upper Blue River/S. Platte River Watershed

	Highly Impacted	Impacted	Reference	Unknown	Sum
fen	1	5	4	0	10
fen/wet meadow	267	1746	1607	5	3625
riparian shrubland	218	875	754	0	1847
unknown	0	0	0	0	0
wet meadow	32	84	19	0	135
Sum	518	2710	2384	5	5617

San Juans

	Highly Impacted	Impacted	Reference	Unknown	Sum
fen	24	89	22	94	229
fen/wet meadow	0	2	0	1119	1121
riparian shrubland	1	0	0	592	593
unknown	0	0	0	473	473
wet meadow	1	0	0	57	58
Sum	26	91	22	2335	2474

Total

	Highly Impacted	Impacted	Reference	Unknown	Sum
fen	25	94	26	94	239
fen/wet meadow	267	1748	1607	1124	4746
riparian shrubland	219	875	754	592	2440
unknown	0	0	0	473	473
wet meadow	33	84	19	57	193
Sum	544	2801	2406	2340	8091

WET_DISTURB	Upper Blue River/S. Platte River Watershed	San Juans	Sum
FenWet_HI	267	0	267
FenWet_I	1751	1121	2872
FenWet_R	1607	0	1607
Fen_HI	1	24	25
Fen_I	5	183	188
Fen_R	4	22	26
Rip_HI	218	1	219
Rip_I	875	592	1467
Rip_R	754	0	754
Wet_HI	32	1	33
Wet_I	84	57	141
Wet_R	19	0	19
Unk_Unk	0	473	473
Sum	5617	2474	8091

Site Selection Summary

Upper Blue River/S. Platte River Watershed

	panel		
mdcaty	Base	OverSamp	Sum
FenWet_HI	0	44	44
FenWet_I	8	52	60
FenWet_R	8	46	54
Fen_HI	0	1	1
Fen_I	1	4	5
Fen_R	0	4	4
Rip_HI	7	35	42

```
  Rip_I        7       41  48
  Rip_R        3       35  38
  Wet_HI       2       18  20
  Wet_I        2       21  23
  Wet_R        2       17  19
  Unk_Unk      0        0   0
  Sum         40      318 358

San Juans
           panel
mdcaty      Base OverSamp Sum
  FenWet_HI    0        0   0
  FenWet_I    11       99 110
  FenWet_R     0        0   0
  Fen_HI       3       16  19
  Fen_I        2       19  21
  Fen_R        4       17  21
  Rip_HI       0        1   1
  Rip_I        6       76  82
  Rip_R        0        0   0
  Wet_HI       0        1   1
  Wet_I        1       21  22
  Wet_R        0        0   0
  Unk_Unk     13       92 105
  Sum         40      342 382

Total
           panel
mdcaty      Base OverSamp Sum
  FenWet_HI    0       44  44
  FenWet_I    19      151 170
  FenWet_R     8       46  54
  Fen_HI       3       17  20
  Fen_I        3       23  26
  Fen_R        4       21  25
  Rip_HI       7       36  43
  Rip_I       13      117 130
  Rip_R        3       35  38
  Wet_HI       2       19  21
```

```
Base
              Upper Blue River/S. Platte River Watershed San Juans  Sum
  fen                                                  1         9  10
  fen/wet meadow                                      16        11  27
  riparian shrubland                                  17         6  23
  unknown                                              0        13  13
  wet meadow                                           6         1   7
  Sum                                                 40        40  80

OverSamp
              Upper Blue River/S. Platte River Watershed San Juans  Sum
  fen                                                  9        52  61
  fen/wet meadow                                     142        99 241
  riparian shrubland                                 111        77 188
  unknown                                              0        92  92
  wet meadow                                          56        22  78
  Sum                                                318       342 660

Total
              Upper Blue River/S. Platte River Watershed San Juans  Sum
  fen                                                 10        61  71
  fen/wet meadow                                     158       110 268
  riparian shrubland                                 128        83 211
```

```
unknown                                                    0        105 105
wet meadow                                                62         23  85
Sum                                                      358        382 740
```

Description of Sample Design Output:

To achieve an expected sample size of sites in the target population, an appropriate sample size was selected for the study area. A Base set of sites and an Oversample of sites are included in the output. The oversample sites should be added, as needed, in numerical SiteID order. Oversample sites are identified in the “panel” data column as Oversamp. Note that sites may be used in order beginning at the first SiteID number and continuing until desired sample size is reached.

The dbf file that is one of the files associated with the shapefile for sites selected has the following variable definitions:

Variable Name	Description
SiteID	Unique site identification (character)
x	x-coordinate
y	y-coordinate
mdcaty	Multi-density categories used for unequal probability selection (WET_DISTURB)
weight	Weight (number of wetlands), inverse of inclusion probability, to be used in statistical analyses
stratum	Strata used in the survey design
panel	Identifies base sample by panel name and Oversample by OverSamp
auxiliary variables	Remaining columns are from the sample frame provided

Projection information

PROJCS["NAD_1983_Albers",
GEOGCS["GCS_North_American_1983",
DATUM["D_North_American_1983",
SPHEROID["GRS_1980",6378137.0,298.257222101],
PRIMEM["Greenwich",0.0],
UNIT["Degree",0.0174532925199433],
PROJECTION["Albers"],
PARAMETER["False_Easting",0.0],
PARAMETER["False_Northing",0.0],
PARAMETER["Central_Meridian",-96.0],
PARAMETER["Standard_Parallel_1",29.5],
PARAMETER["Standard_Parallel_2",45.5],
PARAMETER["Latitude_Of_Origin",37.5],
UNIT["Meter",1.0]

Evaluation Process

The survey design weights that are given in the design file assume that the survey design is implemented as designed. Typically, users prefer to replace sites that can not be sampled with other sites to achieve the sample size planned. The site replacement process is described above. When sites are replaced, the survey design weights are no longer correct and must be adjusted. The weight adjustment requires knowing what happened to each site in the base design and the over sample sites. EvalStatus is initially set to "NotEval" to indicate that the site has yet to be evaluated for sampling. When a site is evaluated for sampling, then the EvalStatus for the site must be changed. Recommended codes are:

EvalStatus Code	Name	Meaning
TS	Target Sampled	site is a member of the target population and was sampled
LD	Landowner Denial	landowner denied access to the site
PB	Physical Barrier	physical barrier prevented access to the site
NT	Non-Target	site is not a member of the target population
NN	Not Needed	site is a member of the over sample and was not evaluated for sampling
Other codes		Many times useful to have other codes. For example, rather than use NT, may use specific codes indicating why the site was non-target.

References

Diaz-Ramos, S., D. L. Stevens, Jr, and A. R. Olsen. 1996. EMAP Statistical Methods Manual. EPA/620/R-96/002, U.S. Environmental Protection Agency, Office of Research and Development, NHEERL-Western Ecology Division, Corvallis, Oregon.

Stevens, D.L., Jr. 1997. Variable density grid-based sampling designs for continuous spatial populations. Environmetrics, **8:**167-95.

Stevens, D.L., Jr. and Olsen, A.R. 1999. Spatially restricted surveys over time for aquatic resources. Journal of Agricultural, Biological, and Environmental Statistics, **4:**415-428

Stevens, D. L., Jr., and A. R. Olsen. 2003. Variance estimation for spatially balanced samples of environmental resources. Environmetrics, **14:**593-610.

Stevens, D. L., Jr., and A. R. Olsen. 2004. Spatially-balanced sampling of natural resources in the presence of frame imperfections. Journal of American Statistical Association, **99:**262-278.

APPENDIX B: Data Layers Used in the Survey Design

The following data layers were used to create the sample frame for the VIBI Phase 3 survey design. Data layers are broken down by study area into Park/Summit Counties and San Juan Mountains. The lists are ordered by priority for inclusion and classification, in cases where data layers contained conflicting information. Layers listed first were considered the most accurate.

Summit / Park Counties

1. Wetland polygons classified by HGM class for Summit County. Data derived from multiple sources and merged into one shapefile, which was provided to CNHP by Brad Johnson. More information on the primary data sources can be found on page 9 of Johnson (2005). The primary data layers included 1) White River National Forest aerial photography survey, 2) Summit County private land aerial photography survey, and 3) Town of Silverthorne aerial photography survey.

2. Riparian and Wetland Mapping created by the Colorado Division of Wildlife (CDOT). This mapping was conducted on a quad by quad basis, but is not complete for the study area. More information about methodology and extent can be found on CDOT's Riparian and Wetland Mapping homepage: http://ndis1.nrel.colostate.edu/riparian/riparian.htm.

San Juan Mountains

1. Fen polygons delineated in target watershed as part of an investigation of fen characteristics, distribution, and restoration need across the San Juan Mountains (Chimner et al. 2008). More information on the study and access to the data layer can be found on the Mountain Studies Institute webpage: http://www.mountainstudies.org/Research/fenProject.htm.

2. Fen polygons delineated throughout the San Juan National Forest as part of a forest-wide inventory of fens. Unpublished data obtained through the San Juan National Forest.

3. Riparian and wetland vegetation types pulled from the Existing Vegetation data layer for the San Juan National Forest. Data layer used was current as of March 27, 2006. Most current version of the data layer can be found on the San Juan National Forest GIS webpage: http://www.fs.fed.us/r2/sanjuan/projects/gis/index.shtml.

References

Chimner, R.A. et al. (2008) Final report: regional assessment of fen distribution, condition, and restoration needs, San Juan Mountains. Unpublished report prepared for US EPA Region 8. Michigan Technical University, Houghton, Michigan; Colorado State University, Fort Collins, Colorado; and Mountain Studies Institute, Silverton, Colorado.

Johnson, J.B. (2005) Hydrogeomorphic wetland profiling: an approach to landscape and cumulative impacts analysis. *EPA/620/R-05/001.* US Environmental Protection Agency, Washington DC.

APPENDIX C: Ecological System Descriptions

Rocky Mountain Alpine-Montane Wet Meadow

Wet meadows are dominated by herbaceous species and range in elevation from montane to alpine (3,280 to 11,800 ft.). These types occur as large meadows in montane or subalpine valleys, as narrow strips bordering ponds, lakes, and streams, and near seeps and springs. They are typically found on flat areas or gentle slopes, but may also occur on sub-irrigated sites with slopes up to 10%. In alpine regions, sites typically are small depressions located below late-melting snow patches or on snowbeds. Soils of this system are mineral but may have large amounts of organic matter. Soils show typical hydric soil characteristics, including high organic content and/or low chroma and redoximorphic features. This system often occurs as a mosaic of several plant associations, often dominated by graminoids. Often riparian shrublands, especially those dominated by willows (*Salix* spp.), are immediately adjacent to wet meadows. Wet meadows in the alpine are tightly associated with snowmelt and typically not subjected to high disturbance events such as flooding, however montane wet meadows may be seasonally flooded. Wet meadows also occur near the fringes of lakes and ponds as well as near ephemeral groundwater discharge sites where the water table is high enough to support hydrophytic vegetation but fluctuates or is deep enough to restrict the development of organic soils. The size of wet meadows can vary greatly depending on their topographic location, underlying soil texture, and driving hydrological processes. Some are very small (< 1 acre) while others can be very large (> 75 acres). In order for a patch of wet meadow to be considered a distinct ecological system, it must meet a minimum size of 1 acre.

Rocky Mountain Subalpine-Montane Fen

Fens are confined to specific environments defined by ground water discharge, soil chemistry, and peat accumulation of at least 40 cm. Fens remain saturated primarily as a result of discharging groundwater, seasonal and/or perennial surface water input, or due to their location on the fringes of lakes and ponds. Fens form at low points in the landscape or on slopes where ground water intercepts the soil surface. Ground water inflows maintain a fairly constant water level year-round, with water at or near the surface most of the time. Constant high water levels lead to accumulation of organic material. In addition to peat accumulation and perennially saturated soils, the extremely rich fens have distinct soil and water chemistry, with high levels of one or more minerals such as calcium and magnesium. Fens usually occur as a mosaic of several plant associations. Shrubs may be dominant. Mosses are an integral floristic as well as functional component to fens. Mosses provide a critical role in the accumulation of peat, formation of hummocks, and nutrient cycling. Most fens in the Southern Rocky Mountains are dominated by brown mosses such as *Drepanocladus aduncus*, *Tomenthypnum nitens,* and *Aulacomnium palustre*. *Sphagnum* species are not as common as brown mosses in intermediate and rich fens however *Sphagnum* is an important and conspicuous component of poor and iron fens. A distinguishing characteristic between wet meadows and fens is the depth of the water table. In fens, ground water maintains a fairly constant water level year-round, with water at or near the surface most of the time whereas water tables in wet meadows are more variable and tend to fluctuate or decline throughout the growing season. The size of fens can vary greatly depending on their topographic location, underlying soil texture, and driving hydrological processes. Some are very small (< 0.5 acre) while others can be very large (> 2.5 acres). In order for a patch of fen to be considered a distinct ecological system, it must meet a minimum size of 0.5 acre.

Rocky Mountain Subalpine-Montane Riparian Shrubland

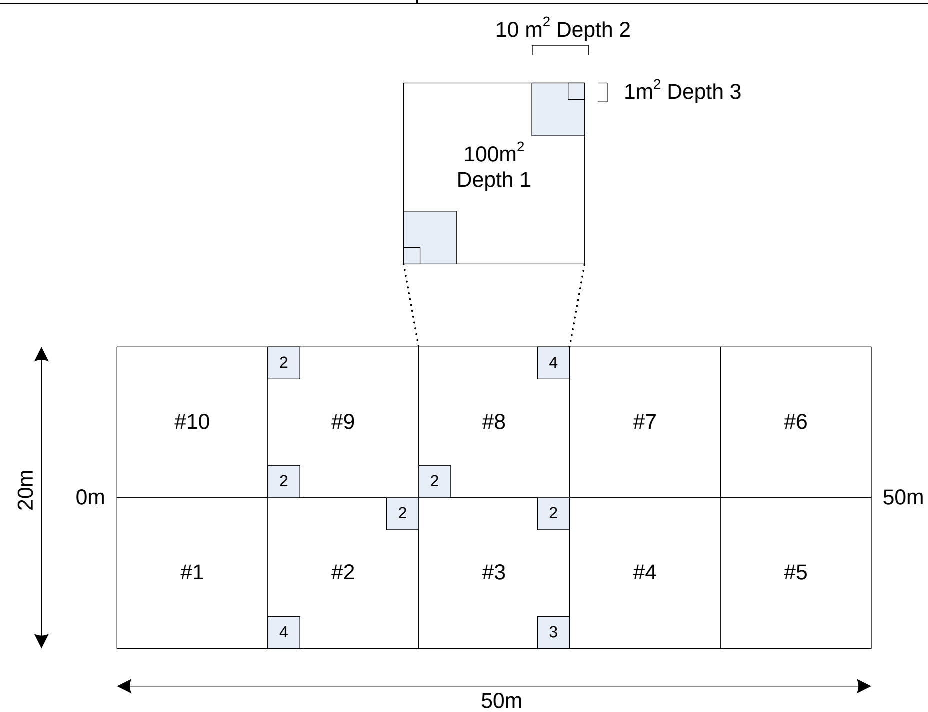
This system is located in the montane to subalpine and occurs as narrow to wide bands of shrubs lining stream banks and alluvial terraces in narrow to wide, low gradient valley bottoms and flood plains with sinuous stream channels. In general, most riparian shrublands in the Southern Rocky Mountains are dominated by various assemblages of willow (*Salix* spp.). Valley geomorphology and substrate dictate the types of riparian shrublands which typically develop. For example, thinleaf alder (*Alnus incana*), Drummonds willow (*Salix drummondiana*), and red-osier dogwood (*Cornus sericea*) are often dominant shrublands on steep and/or gravelly streams whereas a variety of willows (*Salix* sp.) occupy more gently sloped streams with finer sediment or peat substrates. However, riparian shrublands in the Southern Rocky Mountains are most commonly found in wide glaciated valleys or open parks where they often occupy a substantial portion of the valley floor. It has been reported that most riparian shrublands below 9000 ft. have mineral soils, while those above this elevation generally have peat or organic soils (Cooper 1986). For the purpose of VIBI development and application, the latter types may be separated as a distinct variation of riparian shrublands or included within the fen Ecological System type. Additional data collection and future classification analysis is needed to confirm whether this separation is needed.

The size of riparian shrublands can vary greatly depending on their topographic location, underlying soil texture, and driving hydrological processes. Some are very large (> 1.5 linear miles) while others can be very small (< 0.5 linear miles). In order for a patch of riparian shrubland to be considered a distinct ecological System, it must meet a minimum size of 0.5 miles long by 30 feet wide.

APPENDIX D: VIBI Plot Field Form

Plot and Vegetation Form

General Information	Location		Site Characteristics
Plot #:	General:		Ecological System:
Team:	County:		
Date:	USGS quad:		Elevation (m/ft):
Weather Conditions:	**GPS Location**		Slope (deg):
	0m	**50m**	Compass (looking from 0 to 50m mark):
	UTM Zone:		
Ownership:	UTM-E:		
	UTM-N:		
	Accuracy:		
Photos			
Photographer:	Township/Range/Section		
Frame(s):	T: R: S:		



Plot Notes (structure used (i.e. 2x5/1x5/2x2), additional modules sampled, etc.)**:**

Land use in watershed

Types:	Relative %:

Land use w/in 100m of wetland

Types:	Relative %:

Land Use in Wetland

Types:	Relative %:

Community Classification	
CNHP Plant Association:	
HGM Class:	
HGM Subclass:	

Broad Disturbance Category		√ one
	Reference	
	Minimal Impact	
	Moderate Impact	
	High Impact	

<u>Site Description:</u>

Site Drawing

Soil Pit 1 ***Module:***

Horizon	Range (depth cm)	Texture	Soil & Mottle Color	Depth to water table (cm)	Depth to Saturated Soils (cm)	Depth of Peat (cm)	Structure	% Coarse (Est.% per horizon by type- gravel, cobble, boulder)	Comments (90% root depth, charcoal, etc.) Mottle Abundance(few <2%, common 2-20%, many >20%), Size (fine <5 mm dia., medium 5-15 mm, large >15 mm) and Contrast (faint-similar to matrix, distinct-contrast slightly, prominent-mottles vary by several units of hue, value or chroma)

Soil Pit 2 ***Module:***

Horizon	Range (depth cm)	Texture	Soil & Mottle Color	Depth to water table (cm)	Depth to Saturated Soils (cm)	Depth of Peat (cm)	Structure	% Coarse (Est.% per horizon by type- gravel, cobble, boulder)	Comments (90% root depth, charcoal, etc.) Mottle Abundance(few <2%, common 2-20%, many >20%), Size (fine <5 mm dia., medium 5-15 mm, large >15 mm) and Contrast (faint-similar to matrix, distinct-contrast slightly, prominent-mottles vary by several units of hue, value or chroma)

Module / Corner		M	C	M	C	M	C	M	C	M	C	M	C	M	C	M	C	M	C	R	R
Depth / Cover		D	C	D	C	D	C	D	C	D	C	D	C	D	C	D	C	D	C		
Cover Classes: **1**=trace **2**=0-1% **3**=1-2% **4**=2-5% **5**=5-10% **6**=10-25% **7**=25-50% **8**=50-75% **9**=75-95% **10**=>95%																					
Species	**Collection # /Notes**																				
Water																					
Bare Ground																					
Litter																					
Bryophytes																					

Module / Corner		M	C	M	C	M	C	M	C	M	C	M	C	M	C	M	C	R	R
Depth / Cover		D	C	D	C	D	C	D	C	D	C	D	C	D	C	D	C		
Cover Classes: **1**=trace **2**=0-1% **3**=1-2% **4**=2-5% **5**=5-10% **6**=10-25% **7**=25-50% **8**=50-75% **9**=75-95% **10**=>95%																			
Species	**Collection # /Notes**																		

Module / Corner		M	C	M	C	M	C	M	C	M	C	M	C	M	C	M	C	R	R
Depth / Cover		D	C	D	C	D	C	D	C	D	C	D	C	D	C	D	C		
Cover Classes: **1**=trace **2**=0-1% **3**=1-2% **4**=2-5% **5**=5-10% **6**=10-25% **7**=25-50% **8**=50-75% **9**=75-95% **10**=>95%																			
Species	**Collection # /Notes**																		

APPENDIX E: HDI Field Form

HUMAN DISTURBANCE INDEX FORM

Plot #: **Date:** **Observers:** **County:**

Alterations within Buffers and Landscape Context	**Score**
1a. Average Buffer Width. (ALL) This metric is measured by estimating the width of the buffer surrounding the assessment area. Buffers are natural vegetated areas with no or minimal human-use. Buffer boundaries extend from the assessment area edge to intensive human land uses which result in non-natural areas. Some land uses such as light grazing and recreation may occur in the buffer, but other more intense land uses should be considered the buffer boundary. Irrigated meadows may be considered a buffer if the area appears to function as a buffer between the assessment area and nearby, more intensive land uses such as agricultural row cropping, fenced or unfenced pastures, paved areas, housing developments, golf courses, mowed or highly managed parkland, mining or construction sites, etc.	
0pts EXCELLENT Wide > 100 m	
3pts GOOD Medium. 50 m to <100 m	
7pt FAIR Narrow. 25 m to 50 m	
10pts POOR Very Narrow. < 25m	
1b. Adjacent Land Use. (ALL) This metric is measured by documenting surrounding land use(s) within 100 m of the outer buffer boundary. To calculate a Total Land Use Score estimate the % of the adjacent area within 100 m of the buffer boundary under each Land Use type and then plug the corresponding coefficient (Table 1) with some manipulation to account for regional application) into the following equation: *Sub-land use score* = ∑ LU x PC/100 where**:** LU = Land Use Score for Land Use Type; PC = % of adjacent area in Land Use Type. Do this for each land use within 100 m of the buffer edge, then sum the Sub-Land Use Score(s) to arrive at a Total Land Score. For example, if 30% of the adjacent area was under moderate grazing (0.3 * 0.6 = 0.18), 10% composed of unpaved roads (0.1 * 0.1 = 0.01), and 40% was a natural area (e.g. no human land use) (1.0 * 0.4 = 0.4), the Total Land Use Score would = 0.59 (0.18 + 0.01 + 0.40).	
0pts EXCELLENT Average Land Use Score = 1.0-0.95	
3pts GOOD Average Land Use Score = 0.80-0.94	
7pt FAIR Average Land Use Score = 0.4-0.79	
10pts POOR Average Land Use Score = < 0.4	
1c. Percentage of Unfragmented Landscape Within One Kilometer (ALL) This metric is measured by estimating the area of the largest block of unfragmented area in a one km buffer surrounding the assessment area and dividing that by the total area. This can be completed in the office using aerial photographs or GIS.	
0pts EXCELLENT Embedded in 90-100% unfragmented, roadless natural landscape;	
3pts GOOD Embedded in 60-90% unfragmented, roadless natural landscape;	
7pt FAIR Embedded in 20-60% unfragmented, roadless natural landscape;	
10pts POOR Embedded in < 20% unfragmented, roadless natural landscape;	
1d. Riparian Corridor Continuity (RIPARIAN ONLY) This metric is measured as the percent of anthropogenic patches within the riparian corridor. Anthropogenic patches are defined as areas which have been converted or are dominated by human activities such as heavily grazed pastures, roads, bridges, urban/industrial development, agriculture fields, and utility right-of-ways. The riparian corridor itself is defined at the width of the geomorphic floodplain. Using GIS, field observations, and/or aerial photographs the area occupied by anthropogenic patches is compare to the area occupied by natural vegetation with the riparian corridor.	
0pts EXCELLENT < 5% of riparian reach with gaps / breaks due to cultural alteration	
3pts GOOD > 5 - 20% of riparian reach with gaps / breaks due to cultural alteration	
7pt FAIR >20 - 50% of riparian reach with gaps / breaks due to cultural alteration	
10pts POOR > 50% of riparian reach with gaps / breaks due to cultural alteration	

Calculation	**Subtotal Score**
(Sum of two highest scores/20) * 100	

Hydrological Alterations	Score
2a. Hydrological Alterations (NON-RIPARIAN ONLY) Measured by evaluating land use and human activity within or near the assessment area which appear to be altering hydrology of the site. (see Table 2)	
0pts EXCELLENT No alterations. No dikes, diversions, ditches, flow additions, pugging, or fill present in assessment area that restricts or redirects flow	
8pts GOOD Low intensity alteration such as roads at/near grade, pugging, small diversion or ditches (< 1 ft. deep) or small amount of flow additions	
16pts FAIR Moderate intensity alteration such as 2-lane road, low dikes, pugging, roads w/culverts adequate for stream flow, medium diversion or ditches (1-3 ft. deep) or moderate flow additions.	
20pts POOR High intensity alteration such as 4-lane Hwy., large dikes, diversions, or ditches (>3 ft. deep) capable to lowering water table, large amount of fill, or artificial groundwater pumping or high amounts of flow additions	
2b Upstream Surface Water Retention (RIPARIAN ONLY) Measured as the % of the contributing watershed that occurs upstream of a surface water retention facility. (1) Sum the area of the contributing watershed. (2) Determine/sum area of the contributing watershed upstream of the surface water retention facility furthest downstream for each contributing stream reach (e.g., main channel and/or tributaries). (3) Divide this by the total area of the contributing watershed, (4) multiply by 100. For example if a dam occurs on the main channel, then the entire watershed upstream of that dam is calculated whereas if only small dams occur on tributaries then the contributing watershed upstream of each dam on each of the tributaries would be calculated then summed.	
0pts EXCELLENT < 5% of drainage basin drains to surface water storage facilities	
3pts GOOD >5 - 20% of drainage basin drains to surface water storage facilities	
7pt FAIR >20 - 50% of drainage basin drains to surface water storage facilities	
10pts POOR > 50% of drainage basin drains to surface water storage facilities	
2c. Upstream/Onsite Water Diversions/Additions (RIPARIAN ONLY). Calculate the total number of water diversions occurring in the contributing watershed as well as those onsite. Consider the number of diversions with the size of the contributing watershed to assess their impact.	
0pts EXCELLENT No upstream or onsite water diversions/additions present	
3pts GOOD Few diversions/additions present or impacts minor relative to contributing watershed size. Onsite diversions/additions, if present, have minor impact on local hydrology.	
7pt FAIR Many diversions/additions present or impacts moderate relative to contributing watershed size. Onsite diversions/additions, if present, have a major impact on local hydrology.	
10pts POOR Water diversions/additions are very numerous or impacts high relative to contributing watershed size. Onsite diversions/additions, if present, have drastically altered local hydrology.	
2d. Floodplain Interaction (RIPARIAN ONLY) This metric is estimated in the field by observing signs of overbank flooding, channel migration, and geomorphic modifications that are present within the riparian area.	
0pts EXCELLENT Floodplain interaction is within natural range of variability. There are no geomorphic modifications (incised channel, dikes, levees, riprap, bridges, road beds, etc.) made to contemporary floodplain.	
3pts GOOD Floodplain interaction is disrupted due to the presence of a few geomorphic modifications. Up to 20% of streambanks are affected.	
7pts FAIR Floodplain interaction is highly disrupted due to multiple geomorphic modifications. Between 20 – 50% of streambanks are affected.	
10pts POOR Complete geomorphic modification along river channel. The channel occurs in a steep, incised gulley due to anthropogenic impacts. More than 50% of streambanks are affected.	

	Calculation	Subtotal Score
Non-Riparian	(Score/20) * 100	
Riparian	(Sum of two highest scores/20) * 100	

Physical/Chemical Disturbance	Score
3a. Substrate/Soil Disturbance[6] (ALL) Select one or double check and average. This metric evaluates physical disturbances to the soil and surface substrates of the area. Examples include filling and grading, plowing, pugging (hummocking from livestock hooves), vehicle use (motorbikes, off-road vehicles, construction vehicles), sedimentation, dredging, and other mechanical disturbances to the surface substrates or soils.	

Circle one answer.	YES	NO	NOT SURE
Have any of soil or substrate disturbances caused or appear to have caused more than trivial alterations to the assessment area's natural soils or substrates, or have they occurred so far in the past that current conditions should be considered to be "natural."?	Assign a score 1, 2 or 3, or an intermediate score, depending on degree of recovery from the disturbance.	Assign a score of 4 since there are no apparent modifications.	Choose “none apparent" and "recovered" and assign a score of 3.5.

0pts EXCELLENT No Apparent Modifications	
3pts GOOD Past Modification but Recovered; OR Recent but Minor Modifications	
7pts FAIR Recovering OR Recent and Moderate Modifications	
10pts POOR Recent and Severe Modifications	
3b. Onsite Land Use. (ALL) This metric is measured by documenting onsite land use(s) occurring in the assessment area. Follow the same procedures as in Metric 1a. Adjacent Land Use	
0pts EXCELLENT Average Land Use Score = 1.0-0.95	
3pts GOOD Average Land Use Score = 0.80-0.94	
7pt FAIR Average Land Use Score = 0.4-0.79	
10pts POOR Average Land Use Score = < 0.4	
3c. Bank Stability (RIPARIAN ONLY) Walk the streambanks and observe signs of eroding and unstable banks. These signs include crumbling, unvegetated banks, exposed tree roots, exposed soil, as well as species composition of streamside plants. Stable streambanks are vegetated by native species that have extensive root masses (*Alnus incana*, *Salix* spp., *Populus* spp., *Betula* spp., *Carex* spp., *Juncus* spp., and some wetland grasses). In general, most plants with a Wetland Indicator Status of OBL (obligate) and FACW (facultative wetland) have root masses capable of stabilizing streambanks while most plants with FACU (facultative upland) or UPL (upland) do not.	
0pts EXCELLENT Banks stable; evidence of erosion or bank failure absent or minimal; < 5% of bank affected. Streambanks dominated (> 90% cover) by Stabilizing Plant Species (OBL & FACW)	
3pts GOOD Mostly stable; infrequent, small areas of erosion mostly healed over. 5-30% of bank in reach has areas of erosion. Streambanks have 75-90% cover of Stabilizing Plant Species (OBL & FACW)	
7pt FAIR Moderately unstable; 30-60% of bank in reach has areas of erosion; high erosion potential during floods. Streambanks have 60-75% cover of Stabilizing Plant Species (OBL & FACW)	
10pts POOR Unstable; many eroded areas; "raw". Areas frequent along straight sections and bends; obvious bank sloughing; 60-100% of bank has erosional scars. Streambanks have < 60% cover of Stabilizing Plant Species (OBL & FACW)	

[6] Adapted from Mack 2001

3d. Algae[7] Large patch = 50% cover of standing water	
0pts EXCELLENT Algae growth is minimal	
3pts GOOD Algae growth in small patches	
7pt FAIR Algae growth in large patches	
10pts POOR Abundant algae growth in continuous mats	
3e. Cattail Dominance Dominance = 70% of vegetated component	
0pts EXCELLENT Cattails, if present, occur in sporadic stands but do not dominate the assessment area.	
10pts POOR Cattails dominate and form a monoculture in the assessment area. Very few, if any, additional species are present. Co-dominants may include other aggressive native/non-native species.	
3f. Sediment & Turbidity	
0pts EXCELLENT No evidence of excessive sediment in assessment area due to human-induced activities (bare ground, row crops, erosion, etc.); Water is not turbid.	
3pts GOOD Slight evidence of excessive sediment in assessment area due to human-induced activities (bare ground, row crops, erosion, etc.); Water is slightly turbid.	
7pt FAIR Moderate evidence of excessive sediment in assessment area due to human-induced activities (bare ground, row crops, erosion, etc.); Water is moderately turbid.	
10pts POOR High evidence of excessive sediment in assessment area due to human-induced activities (bare ground, row crops, erosion, etc.); Water is highly turbid.	
3g. Toxics/Heavy Metals Mine tailings, mine drainage, hydrocarbons, pesticides, etc. Indicators include different color of water (e.g. orange), odors, no aquatic life, or obvious point source. For oil sheens…poke with stick. If the sheen immediately comes back together it is likely petroleum, otherwise it is natural.	
0pts EXCELLENT No evidence of toxics	
5pts GOOD/FAIR Evidence of toxics; diversity/abundance of organism slightly affected.	
10pts POOR Evidence of toxics with drastic affect on organisms.	

	Calculation	**Subtotal Score**
All Types	(Sum of two highest scores/20) * 100	

Human Disturbance Index (HDI) Score	**Subtotal**	**Weight**	**Final Score**
Buffers and Landscape Context		0.33	
Hydrology		0.34	
Physical Disturbances/Water Quality		0.33	
		HDI Final Score	

[7] Metrics 3d, 3e, 3f, and 3g are adapted from Montana Department of Environmental Quality 2005

Table1. Land Use Coefficient Table (modified from Hauer et al. 2002)

Current Land Use	Coefficient
Paved roads/parking lots/domestic or commercially developed buildings/gravel pit operation	0.0
Unpaved Roads (e.g., driveway, tractor trail) / Mining	0.1
Agriculture (tilled crop production)	0.2
Heavy grazing by livestock / intense recreation (ATV use/camping/popular fishing spot, etc.)	0.3
Logging or tree removal with 50-75% of trees >50 cm dbh removed	0.4
Hayed	0.5
Moderate grazing	0.6
Moderate recreation (high-use trail)	0.7
Selective logging or tree removal with <50% of trees >50 cm dbh removed	0.8
Light grazing / light recreation (low-use trail)	0.9
Fallow with no history of grazing or other human use in past 10 yrs	0.95
Natural area / land managed for native vegetation	1.0

Land Use Calculations:

LU Type #1 Coeff _______ x % of Area = _____________ /100 = Sub-land use score ______
LU Type #2 Coeff _______ x % of Area = _____________ /100 = Sub-land use score ______
LU Type #3 Coeff _______ x % of Area = _____________ /100 = Sub-land use score ______
LU Type #4 Coeff _______ x % of Area = _____________ /100 = Sub-land use score ______
LU Type #5 Coeff _______ x % of Area = _____________ /100 = Sub-land use score ______

Total Land Use Score______

APPENDIX F: Vegetation Metrics

The following table includes all 133 vegetation metrics calculated and screened for inclusion in the Version 2.0 VIBI models. Correlation to the HDI is shown for each model. Correlations < │0.50│ are in bold. Metrics selected for the Version 2.0 models are indicated with an asterisks (*).

Metric	Correlation to HDI (Spearman's Rank Correlation Coefficient)		
	Riparian Shrubland	Fen	Slope Wet Meadow
Mean C (all species)	**-0.70**	**-0.75**	-0.48
Mean C (native)	**-0.58***	**-0.71***	-0.50
Cover-weighted Mean C (all species)	**-0.68**	-0.48	**-0.67**
Cover-weighted Mean C (native)	**-0.55**	-0.45	-0.35
FQI (all species)	**-0.60**	-0.42	**-0.68**
FQI (native)	**-0.55**	-0.33	**-0.55**
Cover-weighted FQI (all species)	**-0.62**	-0.24	**-0.74***
Cover-weighted FQI (native)	**-0.57**	-0.27	**-0.56**
AFQI	**-0.66**	**-0.74**	-0.48
Cover-weighted AFQI	**-0.67**	**-0.50**	-0.50
Count Intolerant	**-0.59**	-0.48	**-0.62***
% Intolerant	**-0.64***	**-0.74***	-0.49
Absolute Cover Intolerant	**-0.60**	-0.49	-0.43
Relative Cover Intolerant	**-0.55**	-0.40	-0.35
Tolerant : Intolerant Ratio	**0.64**	**0.68**	0.38
Absolute Cover Tolerant : Intolerant Ratio	**0.69**	**0.67**	0.40
Count Tolerant	**0.60**	**0.65**	0.35
% Tolerant	**0.70***	**0.67***	0.41
Relative Cover Tolerant	**0.69**	**0.64**	**0.54**
Absolute Cover Tolerant	**0.58**	**0.59**	**0.52**
Count All Species	-0.31	-0.04	-0.34
Count Native	-0.48	-0.14	-0.49
% Non-native	**0.74***	**0.65***	0.45
Absolute Cover Native	-0.39	-0.32	**-0.75***
Relative Cover Native	**-0.67**	-0.46	**-0.55**
Nonnative : Native Ratio	**0.74**	**0.65**	0.45
Count Dominant Native	-0.03	0.10	-0.36
% Dominant Native	0.16	0.03	-0.14
Absolute Cover Dominant Native	-0.31	-0.31	**-0.60**
Relative Cover Dominant Native	-0.29	-0.08	-0.39
Count Invasive	**0.64***	**0.52**	0.37
% Invasive	**0.75**	**0.59**	0.49
Absolute Cover Invasive	**0.59**	**0.54**	**0.52**
Relative Cover Invasive	**0.71**	**0.60**	**0.58**
Count Annual	0.21	0.41	0.06
% Annual	0.32	0.38	0.10
Absolute Cover Annual	0.08	0.30	0.10

Relative Cover Annual	0.20	0.35	0.13
Annual : Perennial Ratio	0.31	0.35	0.12
Absolute Cover Annual : Perennial Ratio	0.20	0.30	0.14
Count Native Annual	-0.11	0.37	0.02
% Native Annual	-0.02	0.32	0.03
Absolute Cover Native Annual	-0.10	0.28	0.06
Relative Cover Native Annual	-0.02	0.31	0.07
Native Annual : Native Perennial Ratio	0.06	0.32	0.12
Absolute Cover Native Annual : Native Perennial Ratio	0.03	0.28	0.25
Count Perennial	-0.39	-0.07	-0.48
% Perennial	-0.17	-0.03	-0.25
Absolute Cover Perennial	-0.23	-0.25	**-0.51***
Relative Cover Perennial	0.03	0.12	0.07
Count Native Perennial	**-0.52**	-0.12	**-0.62***
% Native Perennial	**-0.59***	-0.24	**-0.58**
Absolute Cover Native Perennial	-0.43	-0.25	**-0.63**
Relative Cover Native Perennial	-0.27	0.03	**-0.53**
Count Woody	-0.10	-0.24	-0.07
% Woody	0.02	-0.32	0.23
Absolute Cover Woody	-0.18	-0.28	-0.09
Relative Cover Woody	-0.10	-0.17	0.00
Count Native Woody	-0.10	-0.24	-0.07
% Native Woody	0.02	-0.32	0.23
Absolute Cover Native Woody	-0.17	-0.28	-0.09
Relative Cover Native Woody	-0.10	-0.17	0.00
Count Forb	-0.38	-0.02	-0.50
% Forb	-0.03	0.10	**-0.58**
Absolute Cover Forb	-0.03	-0.08	-0.46
Relative Cover Forb	0.05	0.05	-0.37
Forb : Graminoid Ratio	0.01	-0.05	-0.46
Absolute Cover Forb : Graminoid Ratio	0.14	0.11	-0.29
Count Native Forb	-0.49	-0.13	**-0.64**
% Native Forb	-0.47	-0.17	**-0.69***
Absolute Cover Native Forb	-0.21	-0.14	**-0.57**
Relative Cover Native Forb	-0.05	0.02	-0.39
Native Forb : Native Graminoid Ratio	0.01	-0.10	-0.45
Absolute Cover Native Forb : Native Graminoid Ratio	0.28	0.07	-0.14
Count Graminoid	-0.34	0.13	-0.01
% Graminoid	-0.05	0.16	0.27
Absolute Cover Graminoid	-0.23	-0.21	-0.15
Relative Cover Graminoid	-0.10	0.06	0.23
Count Native Graminoid	-0.47	0.06	-0.17
% Native Graminoid	-0.38	0.07	0.20
Absolute Cover Native Graminoid	-0.43	-0.23	-0.35
Relative Cover Native Graminoid	-0.33	0.03	-0.21
Count Shrub	-0.03	-0.19	0.14
% Shrub	0.11	-0.25	0.35
Absolute Cover Shrub	-0.17	-0.25	0.05

Relative Cover Shrub	-0.09	-0.15	0.07
Count Native Shrub	-0.04	-0.19	0.14
% Native Shrub	0.12	-0.25	0.35
Absolute Cover Native Shrub	-0.17	-0.25	0.05
Relative Cover Native Shrub	-0.09	-0.15	0.07
Count Hydrophytes	**-0.60**	-0.21	-0.22
% Hydrophytes	**-0.61***	-0.33	0.25
Absolute Cover Hydrophytes	-0.38	-0.35*	**-0.51***
Relative Cover Hydrophytes	**-0.54**	-0.12	-0.31
Mean Wet Indicator	**0.56***	0.31	-0.01
Count *Salix*	-0.18	0.02	0.18
% *Salix*	-0.10	-0.03	0.29
Absolute Cover *Salix*	-0.18	-0.35	0.14
Relative Cover *Salix*	-0.14	-0.28	0.12
Count *Salicaceae*	-0.20	0.01	0.01
% *Salicaceae*	-0.12	-0.04	0.18
Absolute Cover *Salicaceae*	-0.18	-0.35	-0.05
Relative Cover *Salicaceae*	-0.14	-0.28	-0.05
Count *Carex*	**-0.70***	-0.23	-0.19
% *Carex*	**-0.66**	-0.32	0.07
Absolute Cover *Carex*	**-0.52**	-0.16	-0.20
Relative Cover *Carex*	**-0.51**	-0.04	-0.14
Count *Cyperaceae*	**-0.67**	-0.22	-0.21
% *Cyperaceae*	**-0.59**	-0.25	0.02
Absolute Cover *Cyperaceae*	**-0.52**	-0.20	-0.21
Relative Cover *Cyperaceae*	-0.49	-0.10	-0.14
Cyperaceae : Poaceae Ratio	**-0.66**	-0.37	-0.09
Absolute Cover *Cyperaceae : Poaceae* Ratio	**-0.54**	-0.34	-0.19
Count *Poaceae*	-0.02	0.28	0.11
% *Poaceae*	0.49	0.36	0.31
Absolute Cover *Poaceae*	0.13	0.19	0.15
Relative Cover *Poaceae*	0.35	0.35	0.40*
Count *Asteraceae*	0.10	0.26	0.18
% *Asteraceae*	0.45	0.39	0.19
Absolute Cover *Asteraceae*	0.22	0.26	-0.22
Relative Cover *Asteraceae*	0.39	0.36	-0.03
Count *Brassicaceae*	0.14	0.01	-0.02
% *Brassicaceae*	0.31	-0.01	0.11
Absolute Cover *Brassicaceae*	-0.31	-0.04	-0.07
Relative Cover *Brassicaceae*	-0.22	-0.02	-0.02
Count Rhizomatous	**-0.53**	0.12	-0.16
% Rhizomatous	-0.35	0.11	0.08
Absolute Cover Rhizomatous	0.02	0.24	-0.15
Relative Cover Rhizomatous	0.14	0.38	0.04
Rhizo : Nonrhizo Ratio	-0.35	0.11	0.08
Absolute Cover Bryophytes	-0.43	**-0.53***	-0.40
Absolute Cover Litter	-0.35	-0.49*	-0.43
Absolute Cover Bare Ground	0.26	0.50*	**0.50***

APPENDIX G: Site Information for Calibration Plots

Plot Code	Ecological System	HGM Class	Watershed	County	Ownership	UTM z13 NAD83 Easting*	UTM z13 NAD83 Northing*	Elevation (ft)	Disturbance Category	VIBI Score	HDI Score	Sampling Date
Plot 3-001	Slope Wet Meadow	Slope	Upper South Platte River	Park	State	456893	4306439	8590	Impacted	5.87	48.45	07/31/2007
Plot 3-009	Fen	Slope	Upper South Platte River	Park	Denver Water Board/State Parks	423366	4316999	8960	Reference	6.26	13.20	07/03/2007
Plot 3-010	Slope Wet Meadow	Slope	Blue River	Summit	Private	-------	-------	8920	Impacted	6.88	53.20	07/25/2007
Plot 3-011	Fen	Slope	Upper South Platte River	Park	CDOW	426941	4359692	9720	Reference	8.63	23.10	08/01/2007
Plot 3-014	Fen	Slope	Blue River	Summit	Town of Frisco	405671	4381686	9070	Impacted	7.40	53.40	07/26/2007
Plot 3-016	Slope Wet Meadow	Slope	Blue River	Summit	Private	-------	-------	8400	Highly Impacted	4.96	69.08	07/16/2007
Plot 3-017	Riparian Shrubland	Riverine	Upper South Platte River	Park	USFS	463664	4306307	8640	Impacted	3.32	40.85	07/10/2007
Plot 3-018	Riparian Shrubland	Riverine	Blue River	Summit	Summit Co	416520	4375524	9610	Highly Impacted	5.39	84.85	08/28/2007
Plot 3-021	Slope Wet Meadow	Slope	Upper South Platte River	Park	Denver Water Board/State Parks	452737	4310001	8600	Impacted	6.21	39.80	07/03/2007
Plot 3-026	Fen	Slope	Blue River	Summit	Private	-------	-------	9010	Reference	6.84	23.10	07/27/2007
Plot 3-030	Fen	Slope	Blue River	Summit	Summit Co	407312	4386061	9100	Reference	6.69	16.50	07/18/2007
Plot 3-031	Fen	Slope	Blue River	Summit	USFS	420101	4379757	11310	Reference	9.39	4.95	07/28/2007
Plot 3-056	Riparian Shrubland	Riverine	Upper South Platte River	Park	Private	-------	-------	11100	Impacted	7.27	51.50	08/07/2007
Plot 3-065	Riparian Shrubland	Riverine	Upper South Platte River	Park	USFS	463251	4304655	8890	Reference	7.12	21.75	08/21/2007

* No UTM Coordinates are given for plots on private land.

Plot 3-082	Riparian Shrubland	Riverine	Blue River	Summit	USFS	418562	4373332	9880	Highly Impacted	4.01	100.00	08/24/2007
Plot 3-102	Riparian Shrubland	Riverine	Blue River	Summit	USFS	393290	4377249	10980	Reference	9.29	19.80	08/23/2007
Plot 3-131	Slope Wet Meadow	Slope	Blue River	Summit	Denver Water Board	412004	4385311	9080	Impacted	5.87	51.55	08/21/2007
Plot 3-133	Fen	Slope	Upper South Platte River	Park	Private	-------	-------	9000	Impacted	4.92	60.00	08/23/2007
Plot 3-134	Riparian Shrubland	Riverine	Upper South Platte River	Park	USFS	404187	4334739	10670	Reference	7.20	4.95	08/22/2007
Plot 3-135	Slope Wet Meadow	Slope	Upper South Platte River	Park	USFS	415735	4307434	9290	Highly Impacted	1.48	90.10	08/24/2007
Plot 3-136	Riparian Shrubland	Riverine	Blue River	Summit	USFS	418586	4373364	9840	Highly Impacted	6.30	85.00	08/27/2007
Plot 3-150	Fen	Slope	Upper South Platte River	Park	Denver Water Board/State Parks	425136	4316885	8800	Highly Impacted	4.34	76.50	08/20/2007
Plot 3-151	Slope Wet Meadow	Slope	Blue River	Summit	USFS	407285	4374043	10220	Reference	7.52	9.90	08/28/2007
Plot 3-152	Riparian Shrubland	Riverine	Blue River	Summit	USFS	408301	4373606	9650	Reference	8.25	16.50	08/30/2007
Plot 3-153	Fen	Slope	Blue River	Summit	USFS	408207	4372443	9880	Impacted	5.31	43.50	08/27/2007
Plot 3-154	Riparian Shrubland	Riverine	Upper South Platte River	Teller	Private	-------	-------	8900	Highly Impacted	4.15	90.10	08/23/2007
Plot 3-155	Slope Wet Meadow	Slope	Blue River	Summit	USFS	407780	4376602	10120	Reference	8.34	4.95	08/29/2007
Plot 3-156	Riparian Shrubland	Riverine	Blue River	Summit	USFS	420218	4378574	10860	Reference	9.73	16.50	08/30/2007
Plot 3-157	Slope Wet Meadow	Slope	Blue River	Summit	USFS	427705	4378557	11040	Reference	7.70	4.95	08/29/2007
Plot 3-359	Fen	Slope	San Juan Mtns	San Miguel	USFS	249238	4197052	10980	Reference	6.19	26.40	07/13/2007
Plot 3-360	Riparian Shrubland	Riverine	San Juan Mtns	La Plata	Private/USFS	-------	-------	8900	Highly Impacted	5.73	68.35	07/31/2007
Plot 3-363	Fen	Slope	San Juan Mtns	San Juan	BLM	263518	4182447	10760	Reference	7.83	11.55	07/16/2007
Plot 3-374	Fen	Slope	San Juan Mtns	San Juan	USFS	281127	4153376	11150	Reference	7.38	31.35	07/24/2007

Plot 3-375	Riparian Shrubland	Riverine	San Juan Mtns	San Juan	USFS	258877	4188657	9680	Impacted	7.77	44.55	07/17/2007
Plot 3-379	Fen	Slope	San Juan Mtns	Hinsdale	BLM	263963	4180813	10500	Reference	6.16	21.45	07/15/2007
Plot 3-383	Fen	Slope	San Juan Mtns	Ouray	USFS	261744	4198956	11060	Reference	7.26	26.40	07/14/2007
Plot 3-387	Fen	Slope	San Juan Mtns	San Juan	USFS	262095	4179883	10880	Impacted	7.17	36.70	07/16/2007
Plot 3-388	Fen	Slope	San Juan Mtns	Dolores	USFS	222130	4173235	10600	Reference	7.54	23.10	07/25/2007

APPENDIX H: Species Frequency within Calibration Plots

Species	C-Value	Fen			Riparian Shrubland			Slope Wet Meadow			Total Plots
		High Imp	Imp	Ref	High Imp	Imp	Ref	High Imp	Imp	Ref	
Achillea lanulosa Nuttall	4		2	2	4	3	5	2	3	3	24
Achnatherum nelsonii (Scribner) Barkworth	6					1					1
Aconitum columbianum Nuttall ex Torrey & Gray	8						1				1
Agoseris aurantiaca (Hooker) Greene	6			1			1				2
Agoseris glauca (Pursh) Rafinesque	6	1	1				1			1	4
Agropyron desertorum Fischer ex Link	0							1	1		2
Agrostis gigantea Roth	0				1						1
Agrostis scabra Willdenow	4		2	1	3		5			2	13
Allium cernuum Roth	5			1		1					2
Alnus incana (L.) Moench ssp. tenuifolia (Nuttall) Breitung	6		1			1	2			2	6
Alopecurus aequalis Sobolewski	4				1						1
Alopecurus alpinus L. ssp. glaucus (Lessing) Hultén	7			1						2	3
Alopecurus pratensis L.	0				1				2		3
Amerosedum lanceolatum (Torrey) Löve & Löve	5					1					1
Androsace filiformis Retzius	8				1						1
Androsace septentrionalis L.	6					1	1				2
Angelica ampla A. Nelson	4					1	2				3
Angelica grayi (Coulter & Rose) Coulter & Rose	10					1					1
Angelica pinnata S. Watson	5					1	3				4
Anisantha tectorum (L.) Nevski	0							1			1
Antennaria corymbosa E. Nelson	5						1				1
Antennaria luzuloides Torrey & Gray	5			1							1
Antennaria media Greene	5									1	1
Antennaria rosea Greene	5						2		1	1	4

Argentina anserina (L.) Rydberg	3	1	1		2		1	2	3		10
Arnica mollis Hooker	7			2		1	3			1	7
Artemisia frigida Willdenow	4					1		1	1		3
Aster foliaceus Lindley ex De Candolle	5					1				1	2
Aster lanceolatus Willdenow ssp. hesperius (A. Gray) Semple & Chmielewski	5		2	2	3	1	4	2	1	2	17
Aster orthophyllus Greene	5	1									1
Aster spathulatus Lindley ex De Candolle	6	1		1	1	1		2	2		8
Astragalus alpinus L.	6					1			1		2
Astragalus tenellus Pursh	6						1				1
Bassia sieversiana (Pallas) W. A. Weber	0							1			1
Batrachium trichophyllum (Chaix) van den Bosch	10				1						1
Beckmannia syzigachne (Steudel) Fernald ssp. baicalensis (Kuznetzow) Koyama & Kuwano	4				1						1
Betula glandulosa Michaux	9		2	1	1	1	1				6
Bistorta bistortoides (Pursh) Small	7			4		2	2			1	9
Bistorta vivipara (L.) S. Gray	8			3	1	1	2				7
Boechera drummondii (A. Gray) Löve & Löve	5		1		1		1			1	4
Breea arvensis (L.) Lessing	0		1		2	1	1	2	4		11
Bromopsis canadensis (Michaux) Holub	5				2						2
Bromopsis inermis (Leysser) Holub	0				1		1	1	2		5
Bromopsis pumpelliana (Scribner) Holub	6		2			1	1			1	5
Calamagrostis canadensis (Michaux) P. Beauvois	6		2	6	3	2	4	1	1	3	22
Calamagrostis stricta (Timm) Koeler	7		1	1					1		3
Campanula parryi A. Gray	7					1					1
Campanula rotundifolia L.	5						2				2
Cardamine cordifolia A. Gray	8		1	5	2	2	4			1	15
Carex aquatilis Wahlenberg	6	1	4	10	1	2	5	1	3	2	29
Carex athrostachya Olney	7								1		1
Carex aurea Nuttall	7			3			2				5
Carex bebbii (L. H. Bailey) Fernald	7		1		1				1		3
Carex buxbaumii Wahlenberg	9		1	1							2
Carex canescens L.	8		2	1		1	1		1		6
Carex capillaris L.	9		1	3			1				5
Carex diandra Schrank	9			1							1
Carex dioica L. ssp. gynocrates (Wormskiold) Hultén	10			1							1

Carex disperma Dewey	9			2		1	2				5
Carex ebenea Rydberg	4					1	1			1	3
Carex egglestonii Mackenzie	Not Assigned			2			1				3
Carex festivella Mackenzie	5	1	1	3	2		2	1		2	12
Carex foenea Willdenow	6						1			1	2
Carex jonesii L. H. Bailey	9						1				1
Carex lanuginosa Michaux	6								1		1
Carex magellanica Lamarck ssp. irrigua (J. E. Smith) Hultén	9			1							1
Carex nebrascensis Dewey	5							1	1		2
Carex norvegica Retzius	8		2	2		2	3				9
Carex nova L. H. Bailey	10		1	1		1	2				5
Carex petasata Dewey	Not Assigned			1							1
Carex praeceptorum Mackenzie	9			1							1
Carex praegracilis F. Boott	5		2				3		2	1	8
Carex scopulorum Holm	7		1	3			1				5
Carex simulata Mackenzie	6	1		2				1			4
Carex stenophylla Wahlenberg ssp. eleocharis (L. H. Bailey) Hultén	7					1					1
Carex stevenii (Holm) Kalea	8			1			1				2
Carex utriculata F. Boott	5		3	7	3	2	3	1	2	2	23
Castilleja rhexifolia Rydberg	8			3		1	1				5
Castilleja sulphurea Rydberg	7			1		1	1		1		4
Catabrosa aquatica (L.) P. Beauvois	7							1			1
Cerastium beeringianum Chamisso & Schlechtendal ssp. earlei (Rydberg) Hultén	7						1			1	2
Cerastium fontanum Baumgartner	0					1					1
Cerastium strictum L. {emend.} Haenke	5					1					1
Chamerion danielsii D. Löve	4		1	3	4	1	4	1		2	16
Chamerion subdentatum (Rydberg) Löve & Löve	7				1	1					2
Chenopodium album L.	0								1		1
Chenopodium glaucum L.	0							1			1
Chondrophylla prostrata (Haenke ex Jacquin) J. P. Anderson	9	1					1				2
Chondrosum gracile Humboldt, Bonpland, & Kunth	4								1		1
Chrysothamnus nauseosus (Pallas ex Pursh) Britton	3							1			1
Cirsium canescens Nuttall	6	1			2	1	2	1	1	1	9
Cirsium eatonii (A. Gray) B. L. Robinson	6				1						1

Cirsium pallidum Wooton & Standley	Not Assigned					1					1
Cirsium parryi (A. Gray) Petrak	5					1					1
Clementsia rhodantha (A. Gray) Rose	8		1	1	1	1	3			1	8
Cleome serrulata Pursh	2								2		2
Conioselinum scopulorum (A. Gray) Coulter & Rose	7		1	2	3		5			2	13
Conyza canadensis (L.) Cronquist	0								1		1
Critesion brachyantherum (Nevski) Barkworth & Dewey	Not Assigned						1	1	1		3
Critesion glaucum (Steudel) Löve	0		1								1
Critesion jubatum (L.) Nevski	2	1	1		1		1	1	3		8
Crunocallis chamissoi (Ledebour ex Sprengel) Rydberg	8	1		1	1						3
Cystopteris fragilis (L.) Bernhardi	9					1					1
Danthonia intermedia Vasey	8				1		2			1	4
Delphinium barbeyi (Huth) Huth	7				1	1	1				3
Delphinium geyeri Greene	5			1							1
Delphinium ramosum Rydberg	5					1					1
Delphinium robustum Rydberg	6		1			1	3			2	7
Deschampsia cespitosa (L.) P. Beauvois	4	1	4	7	1	1	5		3	2	24
Descurainia incisa (Engelmann ex A. Gray) Britton	2								1		1
Descurainia pinnata (Walter) Britton	2		1			1					2
Distegia involucrata (Banks ex Sprengel) Cockerell	7		1	3	3		2			1	10
Draba albertina Greene	Not Assigned			1							1
Draba aurea M. Vahl ex Hornemann	7						1				1
Dracocephalum parviflorum Nuttall	3					1					1
Dugaldia hoopesii (A. Gray) Rydberg	5			1							1
Eleocharis macrostachya Britton	3			2							2
Eleocharis quinqueflora (F. X. Hartman) Schwartz	8		2	2	1		1		1	1	8
Elymus trachycaulus (Link) Gould	4		1		3	2	3	1	4	2	16
Epilobium brevistylum Barbey	4	1	3	5	4	2	4	1	3	1	24
Epilobium ciliatum Rafinesque	4								1		1
Epilobium hornemannii Reichenbach	6		1				1				2
Epilobium lactiflorum Haussknecht	7							1			1
Epilobium leptophyllum Rafinesque	8		1	2	1		1		1		6
Equisetum arvense L.	4		1	4	3	3	5	1	1	1	19
Erigeron coulteri T. C. Porter	8					1	2				3
Erigeron elatior (A. Gray) Greene	7						2				2

Erigeron peregrinus (Banks ex Pursh) Greene ssp. callianthemus (Greene) Cronquist	7			1			2		1		4
Eriogonum subalpinum Greene	Not Assigned			1							1
Eriophorum angustifolium Honckeny	9		1	2							3
Erysimum cheiranthoides L. ssp. altum Ahti	0					1					1
Festuca brachyphylla Schultes ssp. coloradensis Fredriksen	7						2				2
Festuca rubra L.	5		1	1			2				4
Fragaria virginiana P. Miller ssp. glauca (S. Watson) Staudt	5		2	2	2	2	5			1	14
Galium bifolium S. Watson	7							1			1
Galium septentrionale Roemer & Schultes	6		1		1					2	4
Galium trifidum L. ssp. subbiflorum (Wiegand) Puff	7			1	1		2			1	5
Gaultheria humifusa (R. Graham) Rydberg	8						1				1
Gaura coccinea Nuttall ex Pursh	5								1		1
Gentianella acuta (Michaux) Hiitonen	8									1	1
Gentianella heterosepala (Engelmann) Holub	8						2				2
Gentianodes algida (Pallas) Löve & Löve	9									1	1
Gentianopsis thermalis (Kuntze) Iltis	8						2				2
Geranium caespitosum James ex Torrey	6								1		1
Geranium richardsonii Fischer & Trautvetter	6			1	1	1	1				4
Geum aleppicum Jacquin ssp. strictum (Aiton) Clausen	6		1		1				1		3
Geum macrophyllum Willdenow var. perincisum Raup	6		1	5	3	1	4	1	1	1	17
Geum rivale L.	5		2	3			1			1	7
Glaux maritima L. var. angustifolia Boivin	7								1		1
Glyceria elata (Nash ex Rydberg) Jones	6			2	1	1	1	2	1		8
Glyceria grandis S. Watson in A. Gray	6				1		1				2
Gutierrezia sarothrae (Pursh) Britton & Rusby	3								1		1
Hackelia floribunda (Lehmann) I. M. Johnston	3					1		1			2
Halerpestes cymbalaria (Pursh) Greene ssp. saximontana (Fernald) Moldenke	4							1			1
Heracleum sphondylium L. ssp. montanum (Schleicher ex Gaudin) Briquet in Schinz & Thellung	6		1	1	1	2	1			1	7
Heterotheca villosa (Pursh) Shinners	3						1				1
Hierochloë hirta (Schrank) Borbas ssp. arctica (J. Presl in K. Presl) G. Weimarck	9								1		1
Hippochaete laevigata (A. Braun) Farwell	4					1					1
Hippochaete variegata (Schleicher) Bruhin	5						1				1

Hippuris vulgaris L.	6		1								1
Hirculus prorepens (Fischer ex Sternberg) Löve & Löve	9			1							1
Holcus lanatus L.	0								1		1
Hypericum formosum Humboldt, Bonpland, & Kunth	7				1		1				2
Iris missouriensis Nuttall	4								1		1
Juncus arcticus Willdenow ssp. ater (Rydberg) Hultén	4	1	2	2	3	1	4	2	4		19
Juncus bufonius L.	3							1			1
Juncus confusus Coville	5									1	1
Juncus drummondii E. Meyer	6			1		1	2				4
Juncus ensifolius Wikström	6							1			1
Juncus longistylis Torrey	6						1	1	2		4
Juncus mertensianus Bongard	7						2				2
Juncus nevadensis S. Watson	Not Assigned								1		1
Juncus saximontanus A. Nelson	6								1		1
Juncus tracyi Rydberg	6				1		2			1	4
Juniperus communis L. ssp. alpina (J. E. Smith) Celakovsky	6					1					1
Lactuca serriola L.	0		1								1
Lappula redowskii (Hornemann) Greene	2					1					1
Lemna minuscula Herter	Not Assigned		1								1
Lemna trisulca L.	5				1						1
Lepidium ramosissimum A. Nelson	2					1			2		3
Leucanthemum vulgare Lamarck	0				1						1
Leymus cinereus (Scribner & Merrill) Löve	5								1		1
Ligularia bigelovii (A. Gray) W. A. Weber var. hallii (A. Gray) W. A. Weber	7			1			1				2
Ligusticum tenuifolium S. Watson	8						1				1
Limnorchis hyperborea (L.) Rydberg	7		1	1			2				4
Limnorchis stricta (Lindley) Rydberg	8			2							2
Linaria vulgaris P. Miller	0				1						1
Lomatogonium rotatum (L.) Grisebach ssp. tenuifolium (Grisebach) Porsild	9		1								1
Lonicera tatarica L.	0					1					1
Lupinus argenteus Pursh	5									1	1
Luzula comosa E. Meyer	7						1				1
Luzula parviflora (Ehrhart) Desvaux	7			4	1	2	4				11
Luzula spicata (L.) De Candolle	8						1				1
Lycopus americanus Mühlenberg ex W. Barton	5					1					1

Maianthemum amplexicaule (Nuttall) W. A. Weber	7									1	1
Maianthemum stellatum (L.) Link	7			2	1		3				6
Matricaria perforata Merat	0				1				1		2
Mentha arvensis L.	4				1	1	1	1	2		6
Mertensia ciliata (James ex Torrey) G. Don	7		1	5	3	3	5			2	19
Micranthes odontoloma (Piper) Heller	8			3	1	2	3				9
Micranthes oregana (T. J. Howell) Small	8						1				1
Mimulus guttatus De Candolle	8				1	1	2				4
Mitella pentandra Hooker	9			2			1				3
Muhlenbergia richardsonis (Trinius) Rydberg	8					1		1	1		3
Nassella viridula (Trinius) Barkworth	4					1					1
Neolepia campestris (L.) W. A. Weber	0			1							1
Noccaea montana (L.) F. K. Meyer	5					1	1				2
Oenothera villosa Thunberg ssp. strigosa (Rydberg) Dietrich & Raven	4					1					1
Oligosporus groenlandicus (Hornemann) Löve & Löve	5				1				1		2
Onopordum acanthium L.	0								1		1
Onopordum tauricum Willdenow	0					1					1
Oxypolis fendleri (A. Gray) Heller	7			4	1		2				7
Oxyria digyna (L.) J. Hill	7				1						1
Oxytropis parryi A. Gray	6						1				1
Oxytropis splendens Douglas ex Hooker	Not Assigned					1	1				2
Packera cana (Hooker) Weber & Löve	6				1						1
Packera pseudaurea (Rydberg) Weber & Löve	7			5			1				6
Packera streptanthifolia (Greene) Weber & Löve	Not Assigned						1				1
Parnassia fimbriata Konig	8						2				2
Parnassia parviflora De Candolle	7			1							1
Pascopyrum smithii (Rydberg) Löve	5				1	1					2
Pedicularis groenlandica Retzius	8		2	9			3				14
Penstemon whippleanus A. Gray	7			1							1
Pentaphylloides floribunda (Pursh) Löve	4		3	4	3	1	4		2	1	18
Phacelia alba Rydberg	2					1					1
Phalaroides arundinacea (L.) Rauschert	0								1		1
Phleum commutatum Gaudin	6		1	1	1	1	4			2	10
Phleum pratense L.	0		1		3	2	1	1	1	1	10
Picea engelmannii Parry ex Engelmann	5		1	4		1	4			1	11

Pinus contorta Douglas ex Loudon var. latifolia Engelmann	5		1		1		1				3
Plantago eriopoda Torrey	5								1		1
Plantago lanceolata L.	0				1						1
Plantago major L.	0							1			1
Pneumonanthe affinis (Grisebach) Greene	8			1			2			1	4
Pneumonanthe parryi (Engelmann) Greene	9									1	1
Poa alpina L.	7						1				1
Poa annua L.	0					1					1
Poa cusickii Vasey ssp. pallida Soreng	6		1			1			1		3
Poa juncifolia Scribner	6			1							1
Poa leptocoma Trinius	8			2			2				4
Poa nemoralis L. ssp. interior (Rydberg) W. A. Weber	6				1						1
Poa nervosa (Hooker) Vasey	7			1	1						2
Poa palustris L.	6			1	1	1					3
Poa pratensis L.	0	1	2	3	5	2	4	2	4	2	25
Pocilla biloba (L.) W. A. Weber	0						1				1
Podagrostis humilis (Vasey) Björkman	10						1				1
Podistera eastwoodiae (Coulter & Rose) Mathias & Constance	8			2							2
Polemonium caeruleum L. ssp. amygdalinum (Wherry) Munz	8		1	2			1				4
Polemonium foliosissimum (A. Gray) A. Gray	7								1		1
Polemonium pulcherrimum Hooker ssp. delicatum (Rydberg) Brand	8		1	1							2
Polygonum arenastrum Boreau	0								1		1
Polygonum douglasii Greene	3									1	1
Populus tremuloides Michaux	5			1						2	3
Potentilla diversifolia Lehmann	6		1		1		2			1	5
Potentilla effusa Douglas ex Lehmann	4								1		1
Potentilla hippiana Lehmann	5				1						1
Potentilla hookeriana Lehmann	Not Assigned									1	1
Potentilla norvegica L.	0				1						1
Potentilla pulcherrima Lehmann	5		2	1	1	2	1		2		9
Potentilla subjuga Rydberg	8								1		1
Primula parryi A. Gray	8			1			1				2
Pseudocymopterus montanus (A. Gray) Coulter & Rose	6		1	3		1					5
Psilochenia runcinata (James ex Torrey) Löve & Löve	6								1		1
Psychrophila leptosepala (De Candolle) W. A. Weber	7		1	7	1	2	3			1	15

Puccinellia airoides Watson & Coulter	6								1		1
Pyrola minor L.	8						1				1
Pyrola rotundifolia L. ssp. asarifolia (Michaux) Löve	8		1	1	1		1				4
Ranunculus abortivus L. ssp. acrolasius (Fernald) Kapoor & Löve	Not Assigned			1							1
Ranunculus macounii Britton	7							1			1
Ranunculus repens L.	0	1									1
Rhodiola integrifolia Rafinesque	8		1	5							6
Ribes inerme Rydberg	5		1				1				2
Ribes montigenum McClatchie	6			1							1
Rorippa palustris (L.) Besser	Not Assigned				1						1
Rorippa sinuata (Nuttall in Torrey & Gray) A. S. Hitchcock	4				1						1
Rorippa sphaerocarpa (A. Gray) Britton	4		1	1	1				1		4
Rorippa teres (Michaux) Stuckey	5				1				1		2
Rosa woodsii Lindley	5						1	1			2
Rubus idaeus L. ssp. melanolasius (Dieck) Focke	5				1						1
Rumex aquaticus L. ssp. occidentalis (S. Watson) Hultén	5			1			1	1	1		4
Rumex crispus L.	0								1		1
Rumex densiflorus Osterhout	5				2						2
Rumex stenophyllus Ledebour	0		1								1
Rumex triangulivalvis (Danser) Rechinger f.	4				1				1		2
Rumex utahensis Rechinger f.	4						1		2		3
Sagina saginoides (L.) Karsten	7				1						1
Salix brachycarpa Nuttall	8			1			2				3
Salix drummondiana Barratt	6		1		3	1	3		1		9
Salix eriocephala Michaux	6			1	1				1		3
Salix exigua Nuttall	3							1	1		2
Salix geyeriana Andersson	6		1	2	1			1	1		6
Salix monticola Bebb in Coulter	6		2	3	3	3	3	1	1		16
Salix planifolia Pursh	7		3	8	1	1	4		1		18
Salix wolfii Bebb	8		2	4	1	1	3				11
Salsola australis R. Brown	0							1			1
Schoenoplectus lacustris (L.) Palla ssp. acutus (Mühlenberg ex Bigelow) Löve & Löve	3			1							1
Schoenoplectus pungens (M. Vahl) Palla	4				1						1
Scirpus microcarpus J. & K. Presl	5								1		1

Scutellaria galericulata L. var. epilobiifolia (Hamilton) Jordal	7						1				1
Securigera varia (L.) Lassen	0								2		2
Senecio atratus Greene	5				3		1				4
Senecio eremophilus Richardson ssp. kingii (Rydberg) Douglas & R.-Douglas	4		1				1				2
Senecio hydrophilus Nuttall	6									1	1
Senecio integerrimus Nuttall	5			1	1						2
Senecio triangularis Hooker	7		1	4	1	2	4			2	14
Seriphidium canum (Pursh) W. A. Weber	5							1			1
Seriphidium tridentatum (Nuttall) W. A. Weber	4				1			1			2
Sibbaldia procumbens L.	6						1				1
Sidalcea candida A. Gray	5				1			1			2
Silene scouleri Hooker ssp. hallii (S. Watson) Hitchcock & Maguire	5				1						1
Silene vulgaris (Moench) Garcke	0				1						1
Sisyrinchium montanum Greene	6	1									1
Sisyrinchium pallidum Cholewa & Henderson	7								1		1
Solidago multiradiata Aiton	5		1			1	2			2	6
Sparganium angustifolium Michaux	7				1						1
Spiranthes romanzoffiana Chamisso	7			1						1	2
Stellaria calycantha (Ledebour) Bongard	8			4			1				5
Stellaria crassifolia Ehrhart	7	1								1	2
Stellaria longifolia Mühlenberg ex Willdenow	7		1	3	1	2	3				10
Stellaria longipes Goldie	8			2		1	2				5
Stellaria umbellata Turczaninov ex Karilin & Kirilow	8		1	1			1				3
Streptopus fassettii Löve & Löve	7			1							1
Swertia perennis L.	8		1	7	1	2	2				13
Symphoricarpos rotundifolius A. Gray	5				1						1
Taraxacum officinale G. H. Weber ex Wiggers	0	1	2	5	3	3	4	2	2	2	24
Teucrium canadense L. ssp. occidentale (A. Gray) W. A. Weber	3				1						1
Thalictrum alpinum L.	8			1			1				2
Thalictrum fendleri Engelmann ex A. Gray	6				1	1	2				4
Thelypodium integrifolium (Nuttall) Endlicher	6				1						1
Thermopsis montana Nuttall ex Torrey & Gray	6									1	1
Thlaspi arvense L.	0				1	1		2	3		7
Torreyochloa pauciflora (J. Presl in K. Presl) Church	5				1		1				2
Tragopogon dubius Scopoli ssp. major (Jacquin) Vollmann	0				1	1		1			3

Tragopogon pratensis L.	0								1		1
Trifolium parryi A. Gray	8						1				1
Trifolium pratense L.	0								1		1
Trifolium repens L.	0		1		3	2		1	1		8
Trifolium wormskioldii Lehmann	5				1						1
Triglochin maritima L.	6			1		1					2
Triglochin palustris L.	7	1		2		1		1			5
Trimorpha lonchophylla (Hooker) Nesom	5	1					1	1			3
Trisetum montanum Vasey	7				2	2	2			1	7
Trisetum wolfii Vasey in Rothrock	7	1	1				5			1	8
Trollius albiflorus (A. Gray) Rydberg	8			1			1				2
Urtica gracilis Aiton	3				1	1	1				3
Vaccinium cespitosum Michaux	7						3			1	4
Valeriana edulis Nuttall	7		1				1				2
Veratrum tenuipetalum Heller	4			3		1	2			2	8
Veronica americana Schweinitz ex Bentham	6	1	2	1	2	2	2	1			11
Veronica anagallis-aquatica L.	0				1						1
Veronica nutans Bongard	7			3		1	2				6
Veronica peregrina L. ssp. xalapensis (Humboldt, Bonpland, & Kunth) Pennell	0									2	2
Veronicastrum serpyllifolium L. ssp. humifusum (Dickson) W. A. Weber	6			1			1				2
Vicia americana Mühlenberg	5			1		1	1		1		4
Viola macloskeyi Lloyd ssp. pallens (Banks ex De Candolle) M. S. Baker	Not Assigned				1						1
Total Species per Category		23	123	291	181	145	318	68	133	97	