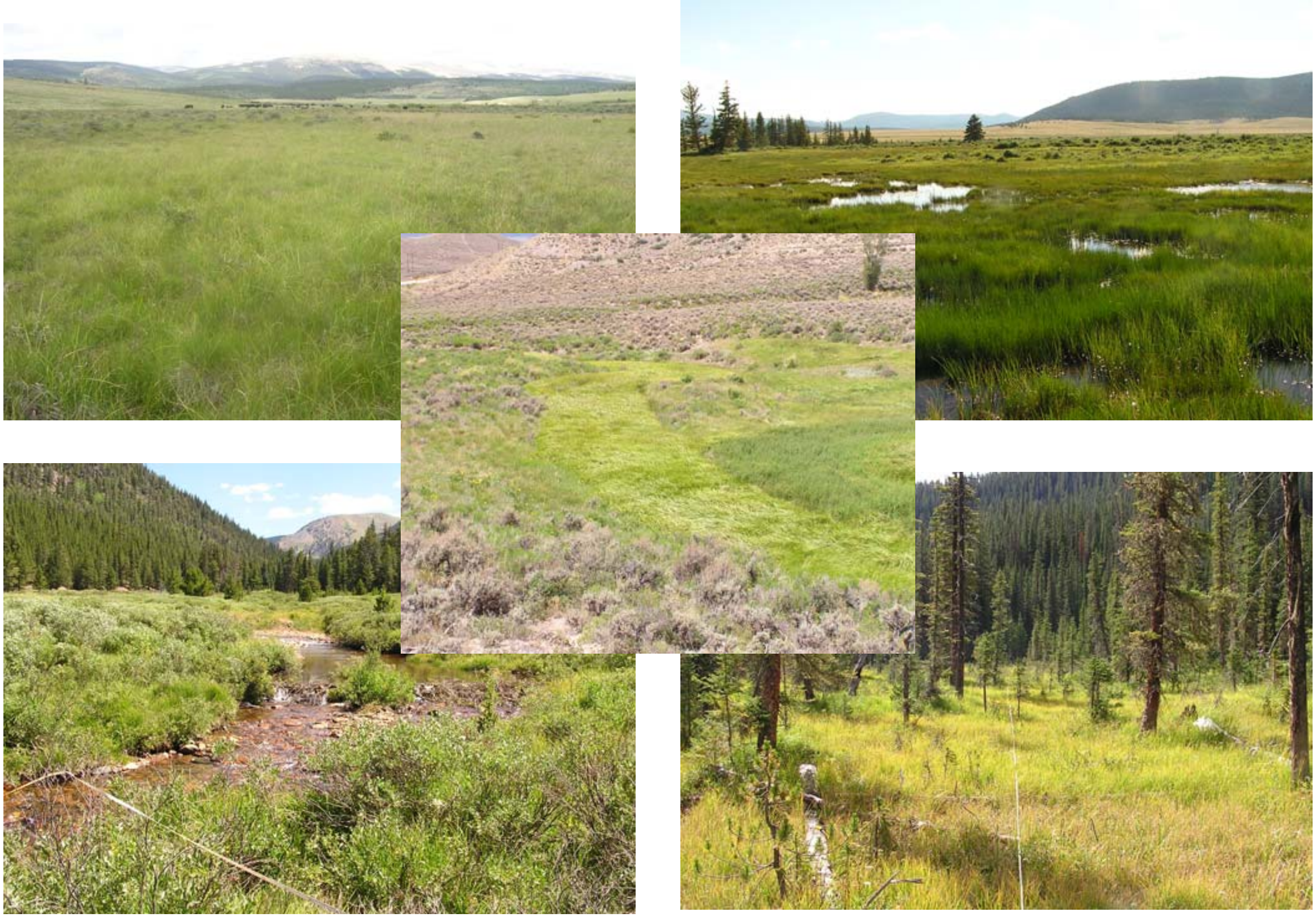
Assessing Ecological Condition of Headwater Wetlands in the Southern Rocky Mountains Using a Vegetation Index of Biotic Integrity

(Version 1.0)

May 22, 2007



Colorado Natural Heritage Program
Colorado State University
254 General Services Building
Fort Collins, CO 80523

Assessing Ecological Condition of Headwater Wetlands in the Southern Rocky Mountains Using a Vegetation Index of Biotic Integrity

(Version 1.0)

Prepared for:

Colorado Department of Natural Resources
Division of Wildlife, Wetlands Program
6060 Broadway
Denver, CO 80216

U.S. Environmental Protection Agency, Region 8.
1595 Wynkoop Street
Denver, CO 80202-1129

Prepared by:

Joe Rocchio
May 22, 2007

Colorado Natural Heritage Program
Warner College of Natural Resources
Colorado State University
254 General Services Building
Fort Collins, Colorado 80523

Cover photograph: *Clockwise* (1) Slope Wet Meadow, Four Mile Creek, Park County, CO; (2) High Creek Fen, Park County, CO; (3) Riverine Wet Meadow, tributary to Blue River, Grand County, CO; (4) Riparian Shrubland, Middle Fork Swan River, Summit County, CO; and (5) Fen, Iron Creek, Grand County, CO.

All photos taken by Colorado Natural Heritage Program Staff.

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 includes wetlands. Wetlands in Colorado have not only been lost from the landscape but have and continue to be impacted or degraded by multiple human activities associated with water use, transportation, recreation, mineral extraction, grazing, urbanization, and other land uses. In order to make informed management decisions aimed at minimizing loss or protecting wetland acreage, quality, and function credible data on the ecological condition of these wetlands need to be collected (U.S. EPA 2002a). In addition, in order to better prioritize management, protection, and restoration activities an efficient and effective method is needed to identify high-quality wetlands, monitor restoration projects, and assess the effects of management activities.

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. An index of biotic integrity is a cost-effective and direct way to evaluate the biotic integrity[1] of a wetland by measuring attributes of the biological community known to respond to human disturbance. Vegetation-based indices of biotic integrity have been shown to be a useful measure of wetland condition and have been successfully developed throughout the United States.

A vegetation index of biotic integrity (VIBI) is developed by sampling various attributes of the vegetation assemblage in wetlands exposed to varying degrees of human disturbance. An important component to VIBI is that it moves beyond the simple diversity approach to assessing the status of a vegetation community, which has been criticized as a method for assessing ecological condition. The underlying assumption of the VIBI approach to wetland assessment is that vegetation effectively integrates the hydrological, physical, chemical, and biological status of a wetland and thus provides a cost-effective and efficient method of assessing wetland integrity. Because of their ability to reflect current and historical ecological condition, plants are one of the most commonly used taxa for wetland bioassessment. In other words, if the chemical, physical, and/or processes of an ecosystem have been altered, vegetation composition and abundance will reflect those alterations. In summary, the ecological basis for using vegetation as an indicator in wetlands is as follows (U.S. EPA 2002a, b):

- Vegetation is known to be a sensitive measure of human impacts;
- Vegetation structure and composition provides habitat for other taxonomic groups such as waterbirds, migratory songbirds, macroinvertebrates, fish, large and small mammals, etc.;
- Strong correlations exist between vegetation and water chemistry;
- Vegetation influences most wetland functions (Tabacchi et al. 1998);
- Vegetation supports the food chain and is the primary vector of energy flow through an ecosystem;
- Plants are found in all wetlands and are the most conspicuous biological feature of wetland ecosystems; and

---

[1] Biotic integrity is defined by Karr and Dudley (1981) 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"

- 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.

The objective of this project was to develop a Vegetation Index of Biotic Integrity (VIBI) which can be used to assess ecological condition of headwater wetlands in the Southern Rocky Mountains of Colorado.

To accomplish this objective, the following tasks were completed:

- Vegetation plots were sampled from headwater wetlands exposed to varying degrees of human-induced disturbance in the Upper Blue and South Platte River Headwaters watersheds while a few reference quality study sites were sampled from the Colorado Headwaters watershed.
- A classification analysis was conducted to confirm the utility of the *a priori* classification system in minimizing natural variability within wetland types.
- Human disturbance was scored at each site according to the type, severity, and duration of human-induced alterations to the wetland and surrounding area's ecological processes.
- Vegetation attributes which had strong discriminatory power and were strongly correlated to the human disturbance gradient were chosen as metrics for the VIBI.
- Each metric's field values were scaled to a numeric score resulting in a standardized scoring system across all metrics.
- The total VIBI score is derived by summing scores for all the metrics.

A total of 75 plots (28 reference plots) were sampled over three field seasons (2004, 2005, and 2006). Most data collection occurred in the Upper Blue River and South Platter River Headwaters watersheds while a few reference quality sites were sampled in the Colorado Headwater watershed. Sampling initially focused on three ecological system types (wet meadows, fens, and riparian shrublands) with the intended goal of obtaining at least 25 plots per type. However, and wet meadows and fens were both split into two types. Due to this, each ecological system type did not receive the same amount of sampling effort since the additional types were not initially targeted for sampling.

The nonmetric dimensional scaling ordination and multi-response permutation procedure showed that the reference condition dataset was best classified using NatureServe's ecological system classification. Because the ecological system classification utilizes both abiotic and biotic variables as classifying criteria, it essentially incorporates elements of the other classification systems tested (i.e. HGM class/subclass, soil type, and physiognomy). This integrative approach seems to be the reason ecological systems best explained natural variation in the dataset. Initially, the *a priori* ecological system classification only included three types (wet meadows, fens, and riparian shrublands); however, both classification and metric screening indicated that additional types were needed for fens and wet meadows and that an individual VIBI model is needed for each of the five ecological systems: (1) slope wet meadows; (2) riverine wet meadows; (3) fens; (4) extremely rich fens; and (5) riparian shrublands.

A total of 472 species were identified in the 75 plots sampled, with 347 (mean of 62/plot) species found in riparian shrublands, 243 (mean of 30/plot) in fens, 192 (mean of 46/plot) in slope wet meadows, 171 (mean of 37/plot) in riverine wet meadows, and 127 (mean of 41/plot) in extremely rich fens. The utility of a VIBI is its ability to reduce the information each species conveys regarding ecological condition into much smaller functional groupings (i.e. metrics). Thus, the diversity found in the dataset was able to be reduced into 25 sensitive and ecological meaningful metrics (out of 133 vegetation attributes that were tested) for the five VIBIs. The 25 metrics selected for the five VIBI models are surrogate measures of many different ecological processes, functions, and stressors.

The five VIBI models developed for this project all had strong correlations to an independent measure of human disturbance and were clearly able to differentiate between reference and highly impacted sites and offer an effective method for detecting change in ecological condition for these Southern Rocky Mountain wetland types. Each of the VIBI models, except the slope wet meadow, had a higher Spearman's rank correlation coefficient than any of their component metrics. This suggests that each VIBI effectively integrates the different types of ecological responses to human disturbance. Because the VIBI models integrate multiple quantitative vegetation metrics, they provide a much more thorough and consistent assessment of vegetation response to human disturbance than traditional measures of species diversity or percentage of native species, etc. However, until the minimum detection level for each VIBI is calculated (to be conducted during Phase 3) it is not known how many different classes of biological condition they can significantly detect. In addition, although strong correlations were found between VIBI scores and the HDI for extremely rich fens, slope wet meadows, and riverine wet meadows, until more data can be collected from these ecological systems, their VIBI models should be considered tentative since they were all based on approximately ten plots.

The VIBI models provide a tool to help prioritize permitting, management, restoration, and protection for these wetlands so that individual wetland and watershed water quality objectives can be effectively attained. For example, the VIBI models can be used for a variety of assessment and monitoring applications such as ambient monitoring of wetland condition within a targeted area, prioritizing wetlands for protection, restoration, or management efforts, and monitoring the effectiveness of these actions. In addition, the VIBI can be used for specific regulatory needs such as defining reference conditions, delineating designated use categories for wetlands, and assigning biocriteria (i.e. VIBI scores) to each of these uses. Once such a framework is established, periodic monitoring of wetland VIBI scores is then possible and would allow an assessment of the status and trends of wetland condition an activity required of each State in Section 305 (b) of the Clean Water Act. It would also allow the identification of impaired wetlands meeting the definition of Waters of the U.S., as required by Section 303(d) of the Clean Water Act. The National Park Service has also shown interest in adapting the VIBI models developed in this report into a wetland monitoring protocol for National Parks in the Rocky Mountains.

The VIBI and Ecological Integrity Assessments will be used by the Colorado Natural Heritage Program (CNHP) to improve our methodology in prioritizing wetland and riparian conservation targets. CNHP also intends to use the VIBI to calibrate a few other wetland assessment tools currently in development. These include Level 1 (remote-sensing based) and Level 2 (rapid, field assessments) methods which, when calibrated with a quantitative measure such as the VIBI, will provide alternative methods to assess wetland condition depending on the project objectives or the time, money, and level of effort available to the user. CNHP will also seek funding to utilize the VIBI, as well as the Level 1 and Level 2 assessments associated with the Ecological Integrity Assessments to conduct probabilistic surveys of wetland condition throughout select watersheds in Colorado. These results will be made available to the Colorado Department of Public Health (CDPHE) so that the data are available for reporting wetland status/trends to the U.S. EPA should CDPHE decide to use them as such.

The VIBI and associated Ecological Integrity Assessments could be used by the Colorado Division of Wildlife to assist in the identification of high-quality wetlands and riparian habitats.

Although these assessments are not tailored to specific species habitat needs, high-quality wetlands and riparian areas do serve as excellent habitat for any species that would naturally utilize such ecological systems.

The VIBI models can also be used within the context of compensatory mitigation. For example, because degradation of wetland ecological integrity does not necessarily result in a linear response of ecological function and functional performance is not necessarily correlated with ecological integrity, a comprehensive wetland assessment should include both a condition assessment, such as a VIBI, as well as a functional assessment to compensate for these nonlinear relationships. This would provide a more accurate approach to ensuring the objective to maintain and restore the chemical, physical, and biological integrity of our Nation's waters is achieved.

One approach to integrating HGM and an IBI would entail incorporating an IBI model, such as the VIBI, as a variable and/or functional capacity index into an HGM assessment. Another approach might use rule-based decisions to prioritize permitting and restoration projects based on a wetland's ecological integrity and functional performance. In Colorado, there are opportunities to integrate functional assessments such as the Functional Assessment for Colorado Wetlands with condition-based assessments such as the VIBI and the Ecological Integrity Assessment approach to implement a rule-based framework for improving wetland management and restoration decisions.

During the next iteration of this project (Phase 3 – 2007/2008), a bootstrap analysis will be conducted to test the statistical precision and power of each VIBI. This process will provide an estimate of measurement error and interannual variance which allows for a determination of the number of statistically significant biological condition classes each VIBI can detect (e.g. minimal detection level). Such information will further enhance the utility of the VIBI models for monitoring and assessing wetland condition both within a regulatory and non-regulatory context. Phase 3 of this project (2007-2008) will also validate the VIBI models presented in this report.

The VIBI models presented here do not apply to all the wetland and riparian types found in the Southern Rocky Mountains. For example, other ecological system types such as the Rocky Mountain Subalpine-Montane Riparian Woodlands, Rocky Mountain Lower Montane Riparian Woodlands and Shrublands, North American Arid Freshwater Marsh, and Intermountain Basin Playas all occur within this ecoregion. The latter three mostly occur in the mountain parks and the large intermountain valleys found in the ecoregion (e.g. North Park, Middle Park, San Luis Valley, Gunnison Basin, etc.) and will be targeted next for VIBI development. Completing these systems would provide a VIBI for most wetland types in the Southern Rocky Mountains, allowing a more comprehensive, large-scale assessment of wetland condition throughout ecoregion.

ACKNOWLEDGEMENTS

I'd like to acknowledge the U.S. Environmental Protection Agency, Region 8, Colorado Department of Natural Resources, and Colorado Division of Wildlife, Wetlands Program for their financial support and encouragement of this project. I'd especially like to recognize Bill Goosemann, former Coordinator for the Colorado Division of Wildlife's Wetland Program, and Jill Minter, U.S. EPA Region 8 Wetland Monitoring and Assessment Coordinator, for their continued support of developing bioassessment tools for Colorado. Many folks provided suggestions for sample site locations and their input is much appreciated. I'd specifically like to thank Anna Higgins for taking a morning of her time to point out potential sample locations she felt would be useful to the project. I'd also like to thank Rich McEldowney and Science Applications International Corporation for sharing data he and others collected as a part of the Summit County wetland functional assessment project and Brian Lorch with Summit County Open Space and Trails for suggesting potential sample sites, allowing access to Summit County Open Space properties, and sharing data collected for the Summit County Special Area Management Plan. The U.S. Forest Service and Bureau of Land Management provided very useful GIS data. I very much appreciate the time Shawn DeKeyser (North Dakota State University), Marc Jones (formerly with Montana Natural Heritage Program), and John Mack (Ohio EPA) spent discussing their experience developing Vegetation Index of Biotic Integrity models and for providing extremely useful guidance. Brad Johnson (Colorado State University) was gracious in the time he spent providing advice and thoughtful discussion. Amy Jacobs (Delaware Dept. of Natural Resources and Environmental Control) kindly shared the Delaware Rapid Assessment Procedure which was of great assistance toward calibrating the Human Disturbance Index developed for this project. I'd also like to extend much gratitude to Jack Siegrist, Becky Schillo, Kirsten Romig, and Gwen Kittel for their assistance and hard work in collecting the data for this project. Josh Haddock was an immense help with developing spreadsheet functions which have made data reduction and metric calculations a breeze. I very much appreciate the hallway discussions, technical assistance, and overall guidance my colleagues at the Colorado Natural Heritage Program have provided during the course of this project, especially, John Sovell, Renee Rondeau, Denise Culver, Stephanie Neid, and Joe Stevens. I'd especially like to thank Joe Stevens, Stephanie Neid, and Renee Rondeau for reviewing and offering many suggested improvements to this document. Finally, I would like to thank Tara Larwick with the Colorado Department of Natural Resources , Paula Nicholas with the Colorado Division of Wildlife, and Mary Olivas and Carmen Morales with Colorado State University for the logistical support they've provided toward this project.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

1.0 INTRODUCTION

The primary objective of the Clean Water Act (CWA) is to "maintain and restore the chemical, physical, and biological integrity of the Nation's waters," which includes wetlands (Federal Water Pollution Control Act, Public Law 92-500). Wetlands in Colorado have not only been lost from the landscape but have and are continued to be impacted or degraded by multiple human activities associated with water use, transportation, recreation, mineral extraction, grazing, urbanization, and other land uses (Winters et al. 2004). Simply calculating the amount of wetland acreage lost or protected does not provide information as to the quality of wetlands destroyed, impacted, restored, or protected. In order to make informed management decisions aimed at minimizing loss or protecting wetland acreage, quality, and function credible data on the ecological condition of these wetlands need to be collected (U.S. EPA 2002a). In addition, in order to better prioritize management, protection, and restoration activities an efficient and effective method is needed to identify high-quality wetlands, monitor restoration projects, and assess the effects of management activities.

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 (Karr 1981; Karr 1998; Karr and Chu 1999; U.S. EPA 2002a). An index of biotic integrity 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 and Chu 1999; U.S. EPA 2002a). Vegetation-based indices of biotic integrity have been shown to be a useful measure of wetland condition and have been successfully developed throughout the United States in areas such as Ohio (Mack 2004a), Massachusetts (Carlisle et al. 1999), along southern Lake Michigan (Simon et al. 2001), Michigan (Kost 2001), Minnesota (Gernes and Helgen 2002), Wisconsin (Lillie et al. 2002), Florida (Reiss 2006; Lane 2003), North Dakota (DeKeyser et al. 2003), Montana (Jones 2004, 2005), and Pennsylvania (Miller et al. 2006).

The objective of this project was to develop a Vegetation Index of Biotic Integrity (VIBI) which can be used to assess ecological condition of headwater wetlands in the Southern Rocky Mountains of Colorado.

To accomplish this objective, the following tasks were completed:

- Vegetation plots were sampled from headwater wetlands exposed to varying degrees of human-induced disturbance in the Upper Blue and South Platte River Headwaters watersheds while a few reference quality study sites were sampled from the Colorado Headwaters watershed;
- A classification analysis was conducted to confirm the utility of the *a priori* classification system in minimizing natural variability within wetland types;
- Human disturbance was scored at each site according to the type, severity, and duration of human-induced alterations to the wetland and surrounding area's ecological processes;

---

[2] Biotic integrity is defined by Karr and Dudley (1981) 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"

- Vegetation attributes which had strong discriminatory power and were strongly correlated to the human disturbance gradient were chosen as metrics for the VIBI;
- Each metric's field values were scaled to a numeric score resulting in a standardized scoring system across all metrics; and
- The total VIBI score is derived by summing scores for all the metrics.

The VIBIs developed here will allow land managers to monitor and evaluate:

- Performance of wetland restoration, enhancement, and creation projects;
- Success of preserving ecological integrity via wetland protection projects;
- Success of management practices;
- Overall statewide wetland quality;
- Water quality within a watershed; and
- Prioritization of funds for wetland restoration and protection projects.

1.1 Headwater Wetlands of the Southern Rocky Mountains

Headwater wetlands are those wetland and riparian areas found in the upper reaches of watersheds. Within a stream network, the headwaters are often referred to as that portion of a watershed drained by first and second order streams (American Rivers 2003). Other definitions include mean annual stream flow (federal regulations 33CFR Section 330.2(d)) or watershed size (Ohio EPA 2001) to define headwater streams. Although most headwater streams and wetlands are small, their contribution to watershed integrity is disproportionately high (Day 2003). For example, headwater wetlands and riparian area provide critical ecological services (e.g. flood attenuation, water quality maintenance, nutrient retention, etc.), as well as critical and unique ecological functions such as biogeochemical cycling, hydrological conveyance, recharge/discharge of groundwater, and ecological corridors (American Rivers 2003). In addition, many headwater wetlands such as fens, seeps and springs, and hanging gardens are comprised of a unique, diverse, and often rare assemblage of species (Comer et al. 2005; American Rivers 2003).

Examples of headwater wetlands in the Southern Rocky Mountain ecoregion include fens, wet meadows, riparian shrublands, and riparian woodlands. Fens are found in areas where perennial groundwater discharge is sufficient to allow the development of organic soils, or peat. Many fens in the Southern Rocky Mountains are the origin for first order streams, although some are isolated with no discernable outlet. They are found throughout the upper reaches of watersheds mostly between 8,000 – 11,000 feet in elevation. The biodiversity of fens is incredibly unique, especially concerning floristics. Numerous rare species, many of which have circumboreal distribution and occur near the edge of their range in the Southern Rocky Mountains, are found in fens (Weber 1965; Sanderson and March 1995; Johnson 1996; Heidel and Laursen 2003; Weber 2003; Cooper and Gage, *In Press*). Fens with unique biogeochemistry such as iron and extremely rich fens also support their own suite of rare species. Wet meadows are common along riparian areas and can also be found in areas groundwater discharge. However, the groundwater discharge that supports wet meadows is typically more seasonal than that of fens. Riparian shrublands occur mostly in glaciated mountain valleys where broad expanses of willows form (e.g. willow carrs). Riparian woodlands in headwater areas are mostly dominated by conifers and are common along steep, confined stream reaches. Additional ecological descriptions of these headwater wetlands and riparian areas can be found in Rocchio (2006a).

Urban development, roads, recreation, hydrological alterations, grazing, non-native species, and mining (both hardrock and peat) exert ecological stress on all headwater wetlands. A more thorough understanding of the ecological integrity of headwater wetlands and riparian areas would help improve the ability to restore, protect, and manage these ecological systems. A vegetation index of biotic integrity would establish biological standards from which restoration performance standards and management objectives could be developed as well as provide a tool that can be used to monitor such efforts.

The study area is in the heart of the Southern Rocky Mountain ecoregion and contains very steep and mountainous topography. Thus, wetlands and riparian areas along first, second and third order streams were considered to be part of that watershed's headwaters and targeted for sampling for this project. The ecological systems targeted in this study included Rocky Mountain Alpine-Montane Wet Meadows (wet meadows), Rocky Mountain Subalpine-Montane Fens (fens), and Rocky Mountain Subalpine-Montane Riparian Shrublands (riparian shrublands) (see Comer et al. 2003; Rocchio 2006a). The ecological systems are mostly restricted to the headwaters area; however, riparian shrublands and wet meadows are also found along fourth and fifth order streams. Within the study area, fourth and fifth order streams appear to be the transition zone between a predominance of riparian shrublands and wet meadows to one dominated by the Lower Montane Riparian Woodland and Shrubland ecological system, an entirely different riparian type associated with lower elevations (see Comer et al. 2003; Rocchio 2006a). Most sample points for this study occurred along first, second and third order streams ; however, a few sample points from the fourth and fifth order stream occurrences of the riparian shrublands and wet meadows were sampled and included in the dataset analyzed for this project.

1.2 Assessment of Wetland Condition

Numerous wetland assessment methods have been developed for both regulatory and non-regulatory purposes. Most methods focus on the performance of specific wetland functions. Recently, more attention is being focused on developing methods to assess wetland condition, of which the vegetation index of biotic integrity is emerging as one of the more commonly used tools. The following sections are intended to provide an overview of the historical context from which condition-based methods have evolved. Specifically, the concept of ecological integrity and methods to assess it (such as the VIBI) are discussed. Most of the discussion is placed within the context of regulatory programs associated with Clean Water Act; however the discussion is also relevant to non-regulatory uses of these assessments. Given the important role a VIBI can play in these applications, these sections are intended to provide the reader with a solid understanding of how the VIBI evolved and its specific application toward wetland assessment.

1.2.1 Definition of Ecological Integrity

Ecological integrity has been defined in many ways. For example, the USGPO (1972) defines ecological integrity as a "condition in which the natural structure and function of an ecosystem is maintained." Karr (1993) noted that "ecological integrity is the sum of the elements (biodiversity) and processes" in an ecosystem and that "integrity implies an unimpaired condition or the quality or state of being complete or undivided." In its simplest form, ecological integrity can be defined as "the summation of chemical, physical, and biological integrity." (Karr and Dudley 1981).

The concept of ecological health has sometimes been used interchangeably with ecological integrity (Costanza et al. 1992), however many researchers consider each term to represent unique ecosystem properties which are related in a nested hierarchy. For example, ecological integrity has been described as those areas that resemble their natural state and have been exposed to minimal human impact whereas ecological health describes the preferred state of ecosystems where the maintenance of nature's services remain intact despite some modification by human impacts (Karr 1994; Rapport 1998). Campbell (2000) delineates the two concepts based on the integrity of ecosystem structure and function (e.g. processes), noting that ecological integrity must exhibit both whereas ecological health only pertains to whether ecological processes are optimally functioning. In the context of wetland regulatory programs, this would suggest that ecological integrity is a higher standard than functional replacement in determining success of attaining the objectives of the CWA. Karr and Chu (1999) summarize these concepts by stating that ecological integrity and health occur along a continuum of human influence on biological condition. At one end are "pristine" or minimally impacted biological systems which support a biota that is the product of evolutionary and biogeographic processes and thus possess ecological integrity while ecological health represents a portion of the continuum where the biological system is able to provide many of the goods and services valued by society, although it may not possess ecological integrity

The concept of biological integrity is often used as a surrogate measure of ecological integrity. Frey (1975) suggested that biological integrity is the "capability of supporting and maintaining a balanced, integrated, and adaptive community of organisms having a composition and diversity comparable to that of the natural habitats of the region." Karr (1996) expanded on this to more explicitly show the relationship of biological integrity to a site's underlying ecological processes:

> "Biological integrity refers to the capacity to support and maintain a balanced, integrated, adaptive biological system having the full range of elements (genes, species, assemblages) and processes (mutation, demography, biotic interactions, nutrient and energy dynamics, and metapopulation processes) expected in the natural habitat of a region. Although somewhat long-winded, this definition carries the message that (1) biology acts over a variety of scales from individuals to landscapes, (2) biology includes items one can count (the elements of biodiversity) plus the processes that generate and maintain them, and (3) biology is embedded in dynamic evolutionary and biogeographic contexts.

This definition provides the foundation for which biological assessments have been used as an effective surrogate measure of ecological integrity for aquatic ecosystems, including wetlands. In other words, the complex evolutionary interactions between biological communities and their chemical and physical environmental suggest that the very presence of a wetland's natural biological community indicates the wetland is resilient to the normal variation in that environment (U.S. EPA 2002a; Karr and Chu 1999).

It should be noted that some have argued that ecological integrity and health are not observable, objective properties of an ecosystem and therefore cannot be measured (Suter 1993; Wicklum and Davies 1995). Suter's (1993) critique also points out that ecological integrity is a concept that excludes inevitable human interactions with nature and thus is not a realistic public policy goal. However, Noss (1995) suggests that measurable indicators that correspond to the qualities associated with ecological integrity and/or health can indeed be defined and quantified. As described above, these measurable qualities include the presence and abundance of biota and ecological process expected in areas with no or minimal human influence. In addition, wild places void of human impact are said by many to possess intrinsic and cultural value and provide an objective baseline from which society can measure loss or gain of valued ecological components, even if restoration of those components is not realistic (Westra 1995). While it would be hard to argue that there are truly pristine areas remaining, there are many areas which still exist in a relatively unaltered (minimally impacted by human influence) ecological condition where public policy goals such as ecological integrity might ensure that further degradation or loss of our natural heritage does not occur. Since many separate ecological integrity from ecological health based on the degree of human impact, the terms can be useful for guiding public policy to better inform management and protection of natural resources against the threat of human activities as well as to sustain those areas which provide valued ecological services (Lemons and Westra 1995; Karr and Chu 1999).

1.2.2 Assessment of Ecological Integrity (Condition-Based Assessments)

Collectively, bioassessments and ecological integrity assessments can be termed "condition-based", as opposed to "functional", assessments (Mack et al. 2004). Condition-based assessments have mostly been used to assist in the implementation of legislative mandates such as Section 303 401 associated with CWA while functional assessments have been used to implement Section 404 activities. Specifically, these mandates establish the following (Danielson 1998):

(1) Water quality goals of a water body (i.e. designated uses) (Section 303);
(2) Water quality criteria which define the limit at which water quality goals will be protected; (Section 303);
(3) Provisions to protect water bodies (i.e. antidegradation rules) (Section 303);
(4) Certification that federally permitted or licensed activities comply with State water quality standards (Section 401); and
(5) Conditions for permitting the discharge of dredged material or fill into water bodies, including wetlands (Section 404).

Historically, chemical and physical criteria were used to establish criteria associated with these mandates since they are easy to apply to different regions and ecosystems and directly protect human health (Karr 1998). However, this approach can be expensive, doesn't account for synergistic or other interactions among various chemicals, and does not address other human-induced impacts on ecological integrity such as habitat alteration, hydrological alterations, and nonnative species (Karr 1998; U.S. EPA 2002a). For example, wetlands are rarely impacted by a single stressor and are often exposed to various chemical, physical, and biological stressors (Karr 1991; U.S. EPA 2002a).

In contrast to chemical elements, biological elements are often more sensitive to degradation, integrate the effects of multiple stressors, are more fully understood, and are less expensive to monitor than chemical/physical parameters (Ohio EPA 1988; Vitousek 1990; Angermeier and Karr 1994; Karr 1996; Karr 1998; Noss et al. 1999; U.S. EPA 2003; U.S. EPA 2006). In addition, since the CWA mandates that biological, as well as physical and chemical, integrity be restored in all degraded waters, the EPA has encouraged the development of bioassessment[3] methods as a complementary tool to improve the ability to monitor, assess, and attain water quality goals (U.S. EPA 2003; U.S. EPA 2006).

Bioassessments are used to detect deviation of biological systems from an expected baseline condition (i.e. reference condition). As such, they are not likely to under-protect wetlands or water resources since they focus on the entities at risk from degradation (Karr 1998; Karr and Chu 1999; U.S. EPA 2002a). Thus, the biological condition of a wetland is a direct measurement of the extent to which the objective of the CWA is being attained (Karr 1998). Bioassessments

---

[3] Bioassessments evaluate the health of a waterbody by directly measuring the condition of one or more of its taxonomic assemblages under the assumption that the community of plants and animals will reflect the underlying health of the waterbody in which they live. (US EPA 2002a).

offer an approach which can reconnect wetland regulatory programs to the biological integrity mandate stipulated in the CWA (Karr (1998). This is accomplished by using biological assessments to define designated uses, establish water quality criteria, and delimit antidegradation standards. In addition, Section 401 of the CWA provides States the authority to certify federally permitted or licensed activities that may result in a discharge into a waterbody to comply with their water quality standards. In other words, Section 401 provides a nexus between water quality standards and Section 404 permitting activities and allows bioassessments to play a role in the latter. However, Steiner et al. (1994) found that most state wetland regulatory programs have a weak connection to wetland water quality antidegradation standards suggesting this nexus is not used to effectively protect wetlands. Some states, such as Ohio, have incorporated bioassessments directly into their Section 404 permitting process in lieu of the traditional "functional" assessment (Mack et al. 2004).

Although bioassessment offers a cost-effective approach to assessing ecological integrity, it still only directly measures biological integrity. Noss et al. (1999) suggest that a comprehensive assessment of ecological integrity should focus on the composition, structure, and function of an ecosystem. Implementing such an approach using measured, quantitative data is not feasible for all type of projects as monies and time often limit the amount of effort that can be utilized. However, NatureServe has recently developed an ecological integrity assessment (EIA; Faber-Langendoen et al. 2006; Rocchio 2006a) which is a structured rapid or intensive assessment that can be implemented, depending on the user's resources. The EIAs are based on the response of ecological (biotic, abiotic, and landscape) attributes which respond to human stressors to provide a more comprehensive assessment of ecological condition. The EIA approach is a multi-metric index which incorporates both rapid and intensive metrics to provide flexibility in application. These indicators are rated and then aggregated into an overall score or rating for four major ecological categories: (1) Landscape Context; (2) Biotic Condition; (3) Abiotic Condition; and (4) Size. The rating for these four categories are then aggregated into an Overall Ecological Integrity Score for each site. These scores or ratings can then be used to track changes or trajectory toward management goals and objectives or used to establish wetland mitigation performance standards (Faber-Langendoen et al. 2006). The EIA incorporates the VIBI as a reliable measure of biotic condition and thus extends the utility of the VIBI.

Multimetric Indices

One approach to bioassessment is the use of multimetric indices which measure many different aspects of complex ecological systems at once (Karr 1998). There are a few key components to these indices: (1) *attributes*, which are quantifiable characteristics of a biological system; (2) *metrics*, which are attributes found to be correlated to human disturbance; and (3) *the multimetric index*, which integrates several metrics into a single value to indicate biological condition. These types of indices typically aim to isolate, through sample design and analysis, patterns caused by natural variation (i.e. noise) from those resulting from human-induced impacts (i.e. signal) (Karr 1998). In summary, they rely on empirical knowledge of how a wide range of biological attributes respond to varying degrees of human disturbance (Karr and Chu 1999). The concept of reference condition (i.e. sites without human influence) is integral to the proper use of multimetric indices (Karr 1998). Karr (1998) provides a list of the key features of a multimetric index:

- Provides both numeric and narrative descriptions of resource condition
- Incorporates the concept of reference condition, providing an objectively defined baseline from which to assess and monitor biological condition
- Only utilizes biological attributes known to respond to human-induced disturbance

- Incorporates multiple biological attributes that are sensitive to different types and intensities of human activities
- Incorporates a broad range of biological signals (e.g. functional groups, composition, structure, etc.)

The result is an indication of whether, and by how much, an ecosystem has diverged from biological integrity (Karr 1998). Karr (1998) summarizes that multimetric indexes can:

- Detect degradation of biological systems
- Diagnose the likely causes of degradation
- Identify management actions that can improve biological condition
- Monitor biological systems to determine management or restoration success
- Monitor biological systems within a mitigation context to determine whether they have achieved performance standards

Multimetric indices are not without their critics (Calow 1992; Suter 1993; Wicklum and Davies 1995). The following are common critiques of the multimetric approach:

- Biological systems are too variable to monitor
- Biological assessment is circular
- Indexes combine and thus lose or mask information
- Statistical properties of multimetric indices are unknown
- Sensitivity of multimetric indices is unknown
- Biological monitoring is too expensive

Karr and Chu (1999) address and rebut each of these points and conclude that with proper sample design multimetric indices have a high signal-to-noise ratio with a known sensitivity, that systematic documentation and testing can help avoid circularity, that information is condensed not lost within the overall index, and that thoughtful sample design can meet the assumptions of many statistical tests.

Index of Biotic Integrity

One example of a multimetric index is the index of biotic integrity (IBI) which was first developed in 1981 and focused on using the status of fish communities to indicate the biological condition of Midwestern streams (Karr 1981). IBIs identify attributes of a biological assemblage which exhibit empirical and predictable response to increasing human disturbance to quantify the status of biological integrity (Karr 1981; Karr et al. 1986; Karr 1991). These attributes are chosen as metrics within the IBI. The IBI explicitly avoids assumptions about “optimal” habitat and focuses solely on biological integrity as defined by the reference condition (Karr 1998).

The IBI approach incorporates metrics representing different characteristics of a biological community such as functional groups, trophic status, species diversity and composition, tolerance to human impact, vigor, etc. (Angermeier and Karr 1994). These metrics are measured in sites exposed to various degrees of human-induced disturbance ranging from those possessing ecological integrity to those highly impacted by human activity, providing an ecological dose-response curve from which to assess the relationship between each metric and human disturbance. This process allows each metric to be quantitatively described along a continuum of human disturbance and provides a means of assessing the deviation of biological condition from a state of integrity (Karr 1996). Each metric is then individually scored on a comparable scale then combined to produce an overall index score. The IBI has been well documented as an effective tool for assessing biological condition in a variety of management settings, with numerous taxa (e.g. macroinvertebrates, fish, algae, amphibians, plants, birds), and in a variety of ecosystem types (streams, lakes, wetlands, and terrestrial shrublands) (Karr 1981; Karr 1998; Carlisle et al. 1999; Simon et al. 2001; Kost 2001; Blocksom et al. 2002; Bryce et al. 2002; Gernes and Helgen 2002; Guntenspergen et al. 2002; Lillie et al. 2002; Blocksom 2003; DeKeyser et al. 2003; Lane 2003; Mebane et al. 2003; Jones 2004, 2005; Mack 2004c; Teels et al. 2004; Ferreira et al. 2005; Griffith et al. 2005; Noson and Hutto 2005; Miller et al. 2006; Reiss 2006;). The IBI approach is the most common method used in wetland bioassessment applications (U.S. EPA 2002a). The vegetation index of biotic integrity models presented in this report will provide the first empirical, condition-based approach for assessing Colorado wetlands.

1.2.3 Vegetation Index of Biotic Integrity

A vegetation index of biotic integrity (VIBI) is developed by sampling various attributes of the vegetation assemblage in wetlands exposed to varying degrees of human disturbance in order to identify suitable metrics for assessing biological integrity. An important component to VIBI is that it moves beyond the simple species diversity approach to assessing the status of a vegetation community, which has been criticized as a method for assessing ecological condition due to its weak correlation to ecological degradation and functions (NRC 1995). The VIBI utilizes metrics which focus on the functional composition, nativity, and conservatism of the vegetative community. These metrics are based on a comprehensive species list, which is beyond what many conventional functional assessment plant metrics utilize. Those assessments often use metrics based only on dominant species but most species within a plant community are not dominant (Whittaker 1965). Thus excluding them from a vegetation assessment ignores an abundance of potentially useful information.

To develop a VIBI, vegetation attributes are grouped to account for various characteristics of the vegetation community such as functional and compositional guilds. Plant functional groups, which are groups of species which show a similar response to disturbance through similar mechanisms, have been suggested as useful indicators of ecological change (Hobbs 1997; Adams 1992). Functional groups might be aggregated using attributes such as reproductive strategies, physiological types, physiognomic types, growth form, longevity, tolerance to stressors, tolerance to inundation, conservatism, etc. (Hobbs 1997; Reed 1988; Wardrop and Brooks 1998; Swink and Wilhelm 1994; Mack 2004a; U.S. EPA 2002c). Those attributes that show a predictable response to increasing human disturbance are chosen as metrics to be incorporated into the VIBI (U.S. EPA 2002a). The resulting VIBI provides a numerical value which can be used to evaluate biotic integrity of a specific wetland over time or used to compare quality of wetlands of a similar type (e.g., same HGM class or ecological system type).

The underlying assumption of the VIBI approach to wetland assessment is that vegetation is one of the most effective integrators of the hydrological, physical, chemical, and biological status of a wetland and thus provides a cost-effective and efficient method of assessing wetland integrity (NRC 2001: Swink and Wilhelm 1994, Taft et al. 1997; U.S. EPA 2002). Because of their ability to reflect current and historical ecological condition, plants are one of the most commonly used taxa for wetland bioassessment (Cronk and Fennessy 2001; U.S. EPA 2002a). In other words, if the chemical, physical, and/or processes of an ecosystem have been altered, vegetation composition and abundance will reflect those alterations. The ecological basis for using vegetation as a surrogate of measure of ecological condition of wetlands can be summarized as follows (U.S. EPA 2002a, b):

- Vegetation is known to be a sensitive measure of human impacts including hydrological alterations, sedimentation, vegetation removal, physical disturbance, watershed development, mining, presence of invasive plants, and nutrient enrichment (Elmore and Kauffman 1984; Kauffman and Krueger 1984; Fulton et al. 1986; Kantrud et al. 1989; Cooper 1990; Wilcox 1995; Johnson 1996; Weixelman et al. 1997; Bedford et al. 1999; Galatowitsch et al. 2000; Adamus et al. 2001; Azous and Horner 2001; Cronk and Fennessy 2001; Flenniken et al. 2001; DeKeyser et al. 2003; Jones 2003;Kauffman et al. 2004; Zedler and Kercher 2004; Cooper et al. 2005; Reiss 2006);

- Vegetation structure and composition provides habitat for other taxonomic groups such as waterbirds, migratory songbirds, macroinvertebrates, fish, large and small mammals, etc. (Kattleman and Embury 1996; Panzer and Schwarz 1998;Nelson *In Press;* Johnson and Anderson 2003; Miller et al. 2003; Baker et al. 2005);
- Strong correlations exist between vegetation and water chemistry (Bedford et al. 1999; Reiss 2006);
- Vegetation influences most wetland functions (Reed 1988; Wilcox 1995; Goslee et al. 1997; Tabacchi et al. 1998; Williams et al. 1998; Winward 2000; Cronk and Fennessy 2001; Lopez and Fennessy 2002;; Simon and Collision 2002; Baker et al. 2005; Jones 2005; Magee and Kentula 2005; Reiss 2006);
- Vegetation supports the food chain and is the primary vector of energy flow through an ecosystem (Baxter et al. 2005);
- Plants are found in all wetlands and are the most conspicuous biological feature of wetland ecosystems; and
- 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.

2.0 STUDY AREAS

The objective of this project is to develop VIBI models for the Southern Rocky Mountain Ecoregion (Figure 1). Sampling for VIBI development focused on three watersheds: Upper Blue River, South Platte River Headwaters and Colorado Headwater watersheds (Figure 1). This was done to minimize any potential geographic variation associated with the dataset. During Phase 3, additional data will be collected from southwestern Colorado (San Juan Mountains; Figure 1) in order to validate the VIBIs applicability to the entire Southern Rocky Mountain Ecoregion. General descriptions of the study areas for this report are provided below.

2.1 Upper Blue River Watershed

The Upper Blue River watershed 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 feet) on Quandary Peak to 2,274 m (7,580 feet) where the Blue River leaves Summit County. More than 85% of the county is above 9,000 feet. 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 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 41.58 cm (16.37 in.) of precipitation each year. Average minimum and maximum temperatures are -7.9^{o} C (17.7^{o} F) and 11^{o} C (51.8^{o} F) respectively. The average total snow fall is 334.8 cm (131.8 in.) (Western Regional Climate Center 2006).

The geology of Summit County is complex, as evidenced by the Geological Map of Colorado (Tweto 1979). 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).

Typical Southern Rocky Mountain flora is prevalent in Summit County. Elevations between approximately 2,274 m (7,580 ft) to 2,400 m (8,000 ft) are dominated by *Amelanchier alnifolia* (service berry), *Artemisia tridentata* ssp. *vaseyana* (mountain sagebrush) and *Symphoricarpos rotundifolius* (snowberry). At these elevations, wetlands along riparian areas 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 which are supported by groundwater discharge. These wetland types are mostly dominated by various 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

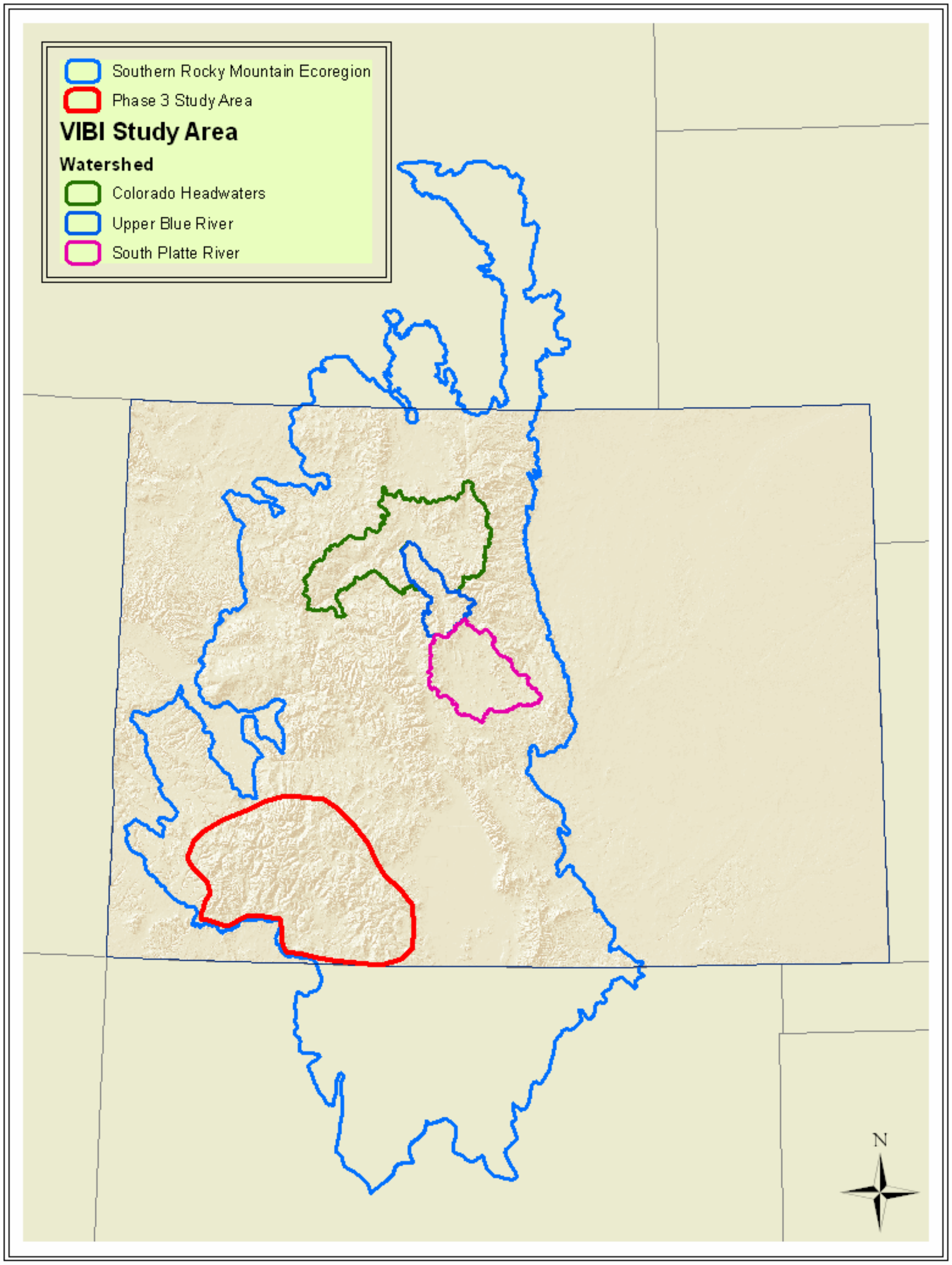


Figure 1. VIBI Study Area

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 which are 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 elevational zone between 3,000 m to 4,267 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 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 encompasses much of Park County and is approximately 415,244 hectares (1,026,097 acres). Elevations range from over 4,267 meters (14,000 feet) to approximately 2,225 meters (7,300 feet). 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 the Town of Fairplay indicate that South Park receives approximately 33 cm (13 inches) of precipitation each year. Average minimum and maximum temperatures in Fairplay are -12^{o} and 20^{o} C (9^{o} and 69^{o} F), respectively. The average total snowfall in Fairplay is 213 cm (84 inches) (Western Regional Climate Center 2005). Climatic for the higher elevations in this area but precipitation and snowfall would be much higher and average temperatures lower for the higher elevations. In sub-alpine basins, 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). The upper glaciated reaches are in wide U-shaped valleys. Below elevations 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 snow-melt 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 unique.

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 and March 1995).

Other wetland types include playa lakes, springs, wet meadows, and riparian wetlands. At higher elevations the vegetation is dominated by willows (*Salix* spp.), spruce-fir *(Picea engelmannii-Abies lasiocarpa)*, ponderosa pine (*Pinus ponderosa*), lodgepole pine (*Pinus contorta* ssp. *latifolia*), bristlecone pine (*Pinus aristata*), quaking aspen *(Populus tremuloides)* and alpine communities.

There are a high percentage of private lands in the watershed, particularly in South Park and on the immediately 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 Colorado Headwaters Watershed

This watershed encompasses approximately 751,180 hectares (1,856,199 acres) of north central Colorado. The elevation ranges for this portion are from 2,225 meters (7,300 feet) where the Colorado River cuts through the Gore Range at Gore Canyon, to 4,066 meters (13,553 feet) at the summit of Pettingell Peak in the Front Range. The principal mountain ranges are: Rabbit Ears Range, Front Range, and Gore Range. The Continental Divide defines the northern and eastern county lines while the Gore Range delineates the southwest boundary. The watershed also encompasses Middle Park intermountain basin. Major tributaries of the Colorado River include the Fraser River, Williams Fork River, Willow Creek, Blue River, Troublesome Creek, and Muddy Creek.

The climate is generally characterized by long, cold, and moist winters, and short, cool, dry summers. Climatic data from the Grand Lake area indicate that this area receives approximately 51 cm (20 inches) of precipitation each year. Average minimum and maximum temperatures are, respectively, -6.5 ^{o} and 11.5^{o} C (20.2 ^{o} and 52.8 ^{o} F). The average total snowfall in Fairplay is 368 cm (145 inches) (Western Regional Climate Center 2006).

Watershed geology consists of crystalline Precambrian rocks underneath thousands of feet of sedimentary rocks including the Jurassic Morrison Formation, Dakota Sandstone, Benton Shale, Niobrara Formation, and Pierre Shale (Tweto 1979). The diversity of climate, geology, elevation, and soils within the Colorado Headwaters watershed leads to a wide range of ecological systems. At the highest elevations, alpine tundra dominated by cushion plants grades into subalpine forests dominated by Engelmann spruce and subalpine fir, which in turn grade into upper montane forests of lodgepole or limber pine (*Pinus flexilis*). Lower montane forests are strongly dominated by lodgepole pine, especially on dry slopes, although Douglas-fir can intermingle on moister, often north-facing slopes with aspen. The basins between mountain ranges are characterized by mountain big sagebrush and Wyoming big sagebrush (*A. tridentata* ssp. *wyomingensis*) shrublands, which dominate the clay soils within Middle Park. Scattered throughout the watershed are riparian forest and shrublands and other wetland types such as fens, kettle ponds, wet meadows, and freshwater marshes.

Historically, the basin's economy was based on agriculture and livestock activities. Presently, the economy is largely based on recreation and tourism. Approximately 28% of Grand County is privately owned and the majority of private lands are located within Middle Park. The towns of Granby, Fraser, and Winter Park are all located only one hour from Denver and offer easily accessible fishing and hiking in the summer, and snowmobiling, tubing, and skiing in the winter.

3.0 METHODS

The following list of tasks, which are described in more detail below, were implemented to develop the VIBI models in Colorado:

- Classify wetlands;
- Target sample sites to ensure data are collected across human disturbance gradient;
- Collect vegetation data; assign Human Disturbance Index (HDI) score;
- Screen vegetation attributes for discriminatory power, correlation to HDI, and redundancy resulting in list of metrics;
- Scale metric field values to standardized 'score'; and
- Construct VIBI model.

3.1 Classification

One objective of this project was to determine which classification system, ecological systems (Comer et al. 2003), hydrogeomorphology (HGM; Brinson 1993; Johnson 2005), physiognomy, soils, etc., best explains the natural variation of the wetland reference sites. The VIBI model seeks to discriminate useful vegetation "signals" which indicate ecological degradation from the natural variation or "noise" that is ubiquitous in ecological data sets. Classification aids in constraining or minimizing natural variation by categorizing wetlands into units which share similar biotic and abiotic characteristics. Classification units that are too large may have too much internal variability to provide useful signals whereas units that are too small may pose practical difficulties in application. For monitoring and assessing biological integrity, the purpose of classification is to group ecosystems based on biotic similarities in the absence of human disturbance as well as with regard to similarities in their response to human disturbance (Karr 1998). Classifications based only on chemical or physical criteria may not be sufficient for biological monitoring (Karr 1998).

Classifications based on HGM are often used for wetland functional assessments due to their ability to distinguish unique abiotic processes. Vegetation types associated with each HGM class often reflect these different abiotic scenarios and consequently may share similar responses to human disturbance (DeKeyser et al. 2003). This suggests that HGM would be a useful and practical classification for VIBI development. However, there is often much overlap of physiognomic vegetation types (e.g., herbaceous vs. shrubland) among HGM classes. Since physiognomic type has been shown to be an important distinguishing variable for VIBI development, HGM may not be the best sole classification system to use for VIBI development (Mack 2004a). Thus, a classification system which utilizes vegetation as well as aspects of HGM is desirable. The ecological system classification (Comer et al. 2003), which incorporates both biotic and abiotic criteria, appears to meet such a need. As such, ecological systems were the chosen *a priori* classification scheme and consequently were used to help determine sample site selection and design.

Comer et al. (2003) define ecological systems as "a group of plant community types that tend to co-occur within landscapes sharing similar ecological processes, substrates, and/or environmental gradients". In the Southern Rocky Mountain ecoregion, physiognomy, elevation, water source, landform, and substrate were the diagnostic criteria used to define the following wetland and riparian ecological system types (Rondeau 2001):

- Rocky Mountain Alpine-Montane Wet Meadow
- Rocky Mountain Subalpine-Montane Fen
- Rocky Mountain Subalpine-Montane Riparian Woodlands,
- Rocky Mountain Subalpine-Montane Riparian Shrublands,
- Rocky Mountain Lower Montane Riparian Woodland and Shrublands,
- North American Arid Freshwater Marsh
- Intermountain Basins Playa

Although aspects of HGM and other environmental variables are an integral component to the ecological system classification, there is not always a 1-1 relationship. For example, there are instances where ecological system types cross HGM classes (e.g. wet meadows) and physiognomic types (e.g. fens). In order to test that ecological systems are indeed the most useful classification scheme to reduce natural variability, each sample site was classified according to multiple classification schemes (Table 1). Nonmetric dimensional scaling ordination was then used to discern the most useful classification scheme (see Section 3.8.1).

Descriptions and a key to ecological system types were used to classify the targeted wetland's ecological system type (Appendix A). The HGM type of each site was classified using the keys provided in Johnson (2005). Physiognomic class was determined based on the dominance or lack of shrubs at a site and soil type was determined by digging multiple soil pits within the vegetation plot to determine whether organic or mineral soils were predominant.

Table 1. Classification Systems

Classification System	Class	Subclass
Ecological Systems (Comer et al. 2003)	Rocky Mountain Alpine-Montane Wet Meadows	Slope Wet Meadows*
		Riverine Wet Meadows*
	Rocky Mountain Subalpine-Montane Fens	Extremely Rich Fens*
		Intermediate Fens*
	Rocky Mountain Upper Montane-Subalpine Riparian Shrublands	
Hydrogeomorphic Types (Brinson 1993 and Johnson 2005)	Slope	Isolated Slope
		Outflow Slope
		Throughflow Slope
	Riverine	Low-order, low-gradient, unconfined Riverine
Physiognomy	Herbaceous	
	Shrub	
Soil Types	Mineral	
	Organic	

*based on classification and metric screening performed in this report (see Sections 4.2 and 4.4)

3.2 Reference Condition

3.2.1 Purpose

In order to assess floristic or ecological response to human-induced disturbance a baseline reference condition consisting of no or minimal human impacts must be defined and described.

By describing the natural variability associated with reference condition wetlands, the response of these wetlands to human-induced disturbances is more easily understood. In other words, it becomes easier to separate the signal (response to human disturbance) from noise (natural variability) when sampling wetlands across a human disturbance gradient. It follows that, if ecological response to stressors can be identified then better informed restoration, management, and protection projects can be implemented.

3.2.2 Conceptual Definition

Conceptually, the biotic reference condition for this project uses the concept of natural range of variability (NRV). NRV is based on the temporal and spatial range of climatic, edaphic, topographic, and biogeographic conditions under which contemporary ecosystems evolved (Morgan et al. 1994; Quigley and Arbelbide 1997). The NRV delimits the range of ecosystem processes that remain relatively consistent over a specified temporal period (Morgan et al. 1994). Regional climatic regimes have undergone more recent changes than geological parameters, thus the climate under which contemporary biota have evolved is most useful for delineating a temporal limit to the NRV. Whitlock et al. (2002) suggest modern climatic conditions in the Rocky Mountain region began about 3,000 years before present while Vierling (1998) estimates that current climatic conditions in central Colorado began about 1800 years before present. Thus, the NRV is not considered to be static for any given variable but rather a range of responses to climatic fluctuations which have occurred over the past few thousand years.

Another consideration for describing the NRV is the degree to which anthropogenic impacts have altered natural ecosystems. There is disagreement over whether disturbances resulting from Native Americans' interaction with the landscape occurred over spatial and temporal scales in which native flora and fauna were able to adapt (see Vale 1998 and Denevan 1992). The hypothesis offered by Vale (1998), which notes that Native American impacts were not ubiquitous across the landscape, is accepted for this project. Furthermore, where Native American impacts did occur, it is accepted here that they occurred over spatial and temporal scales in which native biota were able to adapt and thus are included within the NRV (Quigley and Arbelbide 1997; Wilhelm and Masters 1996). European settlement of the Southern Rocky Mountains began in earnest during the 1860s although fur-trappers were present in the area well before then (Wohl 2001). With settlement, came a profusion of impacts which occurred at a spatial and temporal scale, intensity, and duration unprecedented in the evolutionary history of contemporary ecosystems (Morgan et al. 1994; Poff et al. 1997; Quigley and Arbelbide 1997). Beavers were extirpated from the region by 1830 exerting major changes to the hydrology of streams and wetlands (Wohl 2001). Most low-elevation forests in the Rocky Mountains were cut over by 1900; domestic livestock operations boomed after 1880 affecting large areas of the Rocky Mountain landscape; and to date, there are more than 7,000 abandoned mines in Colorado (Rueth et al. 2002). Water resources were drastically affected by human and livestock consumption via irrigation and impoundments (Wohl 2001). For example, Solley et al. (1998) estimated that there are over 67,000 surface water diversions within and Colorado's National Forests and Grasslands and nearby private lands. These alterations have resulted in many aquatic, riparian, and wetland environments being ecologically very different from which resident biota evolved (Poff et al. 1997). In summary, past and current human impacts have become one of the most dominant environmental variables affecting ecosystems (Vitousek et al. 1997) and there is no doubt that European settlement has had a unique impact to the landscape. Thus, the NRV for this project spans the period between 3000 years BP until European settlement (approximately mid-1800s).

3.2.3 Practical Definition

Practically speaking, the NRV is difficult to empirically define since long-term ecological data as well as data prior to European settlement are rarely available (Swetnam et al. 1999). Thus, a more practical definition of the reference condition is needed. The concept of Minimally Disturbed Condition (MDC), or the biotic condition of sites in the absence of significant human disturbance, is used here to define the reference condition for Southern Rocky Mountain wetlands and riparian areas (Stoddard et al. 2006). Stoddard et al. (2006) consider the MDC to be the "best approximation or estimate of biotic integrity". Recognizing that most sites have likely been exposed to some minimal human stressor (e.g. atmospheric contaminants), the definition incorporates the disclaimer of "significant" human disturbances. The reference condition represents one end of a continuum ranging from sites with minimal or no exposure to human-induced disturbance to those in a highly degraded condition due to such impacts (Bailey et al. 2003; Stoddard et al. 2006).

Current and historical land use information was used to determine whether a specific site met the MDC criteria. As previously mentioned, historical and contemporary human disturbances directly or indirectly affect much of the Southern Rocky Mountain landscape (Wohl 2001); however, many areas in the Southern Rocky Mountains still meet the MDC criteria and thus allow direct observation and measurement of conditions which are likely very similar to what occurred prior to European settlement. Data from such sites allow the natural variability of the MDC to be quantified and/or described. Literature sources can also be used to describe the MDC. For example, Cooper and Gage (*In Progress*) provide a thorough review and synthesis of historic and contemporary climatic, geological, hydrological, and biological data as it relates to the concept of the historic range of variation for wetlands and riparian areas found within the mountainous portions of Colorado and adjacent states. Based on such literature resources as well as on-the ground experience, a general description of the MDC for the targeted wetland types can be found in the Rocky Mountain Sublapine-Montane Riparian Shrubland, Alpine-Montane Wet Meadow, and Subalpine-Montane Fen Ecological Integrity Assessment reports which are located online at http://www.cnhp.colostate.edu/reports.html (Faber-Langendoen et al. 2006).

The natural variation of the MDC provides a baseline from which biotic or abiotic variables can be assessed to determine whether ecological integrity has been compromised at a site. Similarly, sites exposed to varying types and intensities of human disturbance are also sampled in order to characterize how each variable of interest (e.g. vegetation) responds to such impacts (Davies and Jackson 2006). This approach allows the construction of multi-metric indices as well as a framework for interpreting changes in ecological condition (Faber-Lagendoen et al. 2006; Davies and Jackson 2006).

For this project, contemporary and historic literature, GIS data concerning land use, observable signs of human disturbances, and best professional judgment were used to determine whether a sample site met or how much it has deviated from the MDC criteria. This was accomplished by applying this information toward the assignment of a Human Disturbance Index score (see Section 3.5.1). By sampling wetlands representing the continuum from reference to highly degraded, this project will seek to correlate the response of vegetation attributes to the Human Disturbance Index in order to create a Vegetation Index of Biotic Integrity.

3.3 Site Selection and Wetland Assessment Area

3.3.1 Sample Site Selection

Sample sites were subjectively chosen to strive for adequate representation of the human-disturbance gradient and equal representation of each ecological system (U.S. EPA 2002b). A potential list of sample sites was first developed by categorizing the study area into *a priori* disturbance categories and identifying wetland sites within each category. This was accomplished using a Landscape Integrity Model (LIM), a GIS-based algorithm which plugs various land use GIS layers (roads, land cover, water diversions, groundwater wells, dams, mines, etc.) weighted according to their perceived impact on ecological integrity, into a distance-based, decay function to determine what effect these stressors have on landscape integrity. The result is that each grid-cell (30 m) is assigned an integrity “score”. The product is a watershed map depicting areas according to their potential “integrity”. A LIM was developed for this project’s study area to provide an initial stratification of potential sample sites (Figure 2).

Additionally, the following resources were used to identify and categorize potential sample sites into broad disturbance categories (as depicted in Figure 2):

- Digital orthophoto Quadrangles (1 m resolution)
- GIS layers (roads, utility lines, trails, mines, wilderness areas, National Land Cover Dataset, irrigation, ditches, groundwater wells, etc.),
- Element occurrence records from the Colorado Natural Heritage Program’s Biodiversity Tracking and Conservation System (Colorado Natural Heritage Program 2004),
- Bureau of Land Management Proper Functioning Condition data (Bureau of Land Management 2004),
- Site data from the Summit County Wetland Functional Assessment (SAIC 2000),
- U.S. Forest Service wetland surveys (Summit County 1999), and

Coupled with the LIM, these qualitative determinations helped stratify and target sampling efforts. However, onsite assessment often placed a wetland into a different disturbance category than the one identified using the LIM and other resources. Sample site selection was adjusted accordingly to strive for equal representation of disturbance across ecological system types. Once onsite, a different set of criteria was used to assign a human disturbance index score (see Section 3.5.1). Sample site selection and data collection occurred during the summers of 2004 (Plots 1-20), 2005 (Plots 21-52), and 2006 (Plots 53-78). Notes: Plot 12 was removed as it was resampled (Plot 21) due to data quality issues. Plots 66 and 67 were removed because they represented wetland type (e.g. salt flats) not included in this study. Thus, a total of 75 plots were included for data analysis.

3.3.2 Wetland Assessment Area

At each sample site, a wetland assessment area (AA) was defined. The AA is simply the boundary of the wetland (or a portion thereof) in which analysis will occur. The AA is defined for the purpose of developing a vegetation index of biotic integrity, thus different criteria may be used for other project objectives such as those associated with regulatory projects. For example, regulatory projects also have “project boundaries” and such projects may require assessing multiple AAs within each project area. For this project, typically only one AA was assessed at each site. The steps below were taken to delineate the AA for this project:

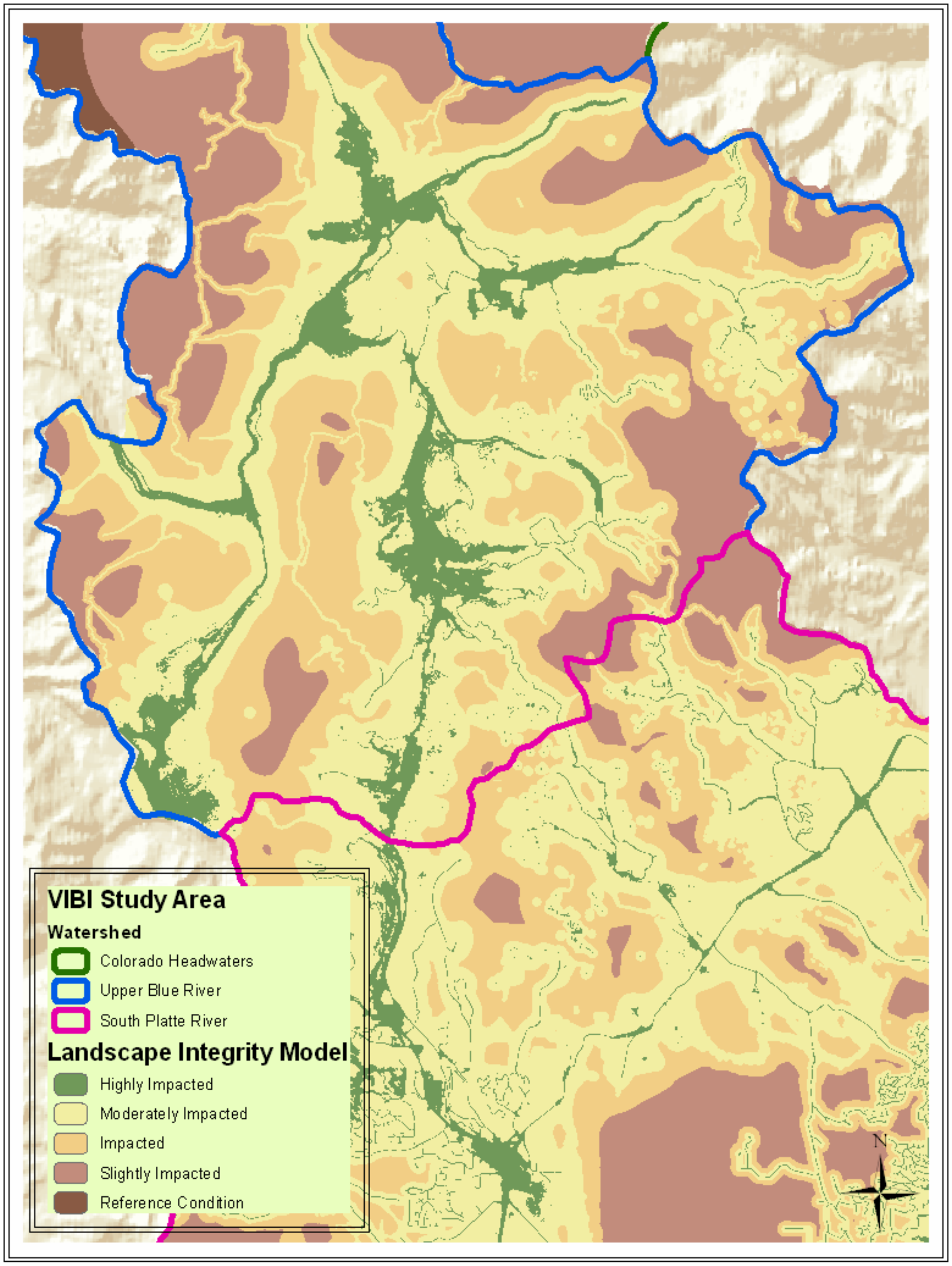


Figure 2. Example of Landscape Integrity Model Results for a Portion of the Study Area

1. Estimation of Wetland Boundaries

The first step in identifying the wetland assessment area was to delineate 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 CWA.

2. Delineating Ecological System Boundaries

The second step was to delineate the targeted ecological system type present within the wetland boundary. Ecological system descriptions (Appendix A) were used to guide a subjective determination of the target system's boundaries in the field. A confounding factor is that ecological systems often co-occur in the landscape. For example, fens may occur together with riparian shrublands in a basin or along a riparian corridor (Figure 3). Similarly, wet meadows are often interspersed with riparian shrublands. For such scenarios, it was necessary to delineate the boundaries of these separate ecological systems based on the minimum size criteria associated with each system (Appendix A). Each patch of ecological system meeting its minimum size would be considered a separate potential AA and thus as an independent sample point (Figure 3). If an ecological system patch was less than its minimum size then it would be considered to be an inclusion within the ecological system type in which it is embedded.

There were a few cases where wet meadows and fens which were smaller than their minimum size criteria were chosen as sample AAs because they were limited in size only by their hydrogeomorphic position (Plots 01, 39, and 51) (i.e. small areas of groundwater discharge surrounded by uplands).

3. Size and Land Use Related Boundaries

Once the targeted ecological system's boundaries were delineated, then 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 a clearly defined boundary (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. For other project purposes such as regulatory wetland projects, there may be multiple AA in one large wetland. A few samples sites contained multiple AAs due to abrupt changes in land use or human-induced disturbances. These distinct AAs were treated as separately in data analysis (Figure 3)

The following size and land use guidelines were used to make final adjustments to the AA boundaries[4]:

Wetland AA Boundaries:

1. Wet meadows and fens were often spatially distinct from surrounding uplands or adjacent wetland types and easily identified. For these cases, the AA was often the entire wetland area.
2. Significant change in management or land use which result in distinct ecological differences dictated distinct AAs. For example, a heavily grazed wetland on one side of a fence line and ungrazed wetland on the other would result in two AAs.
3. Natural changes in hydrology. For example, a drastic change in water table levels or fluctuations, confluence with a tributary, etc. would dictate separate AAs.

---

[4] These guidelines are mostly based on those identified by Mack (2001), Washington State Dept. of Ecology (1993), and Collins et al. (2006).

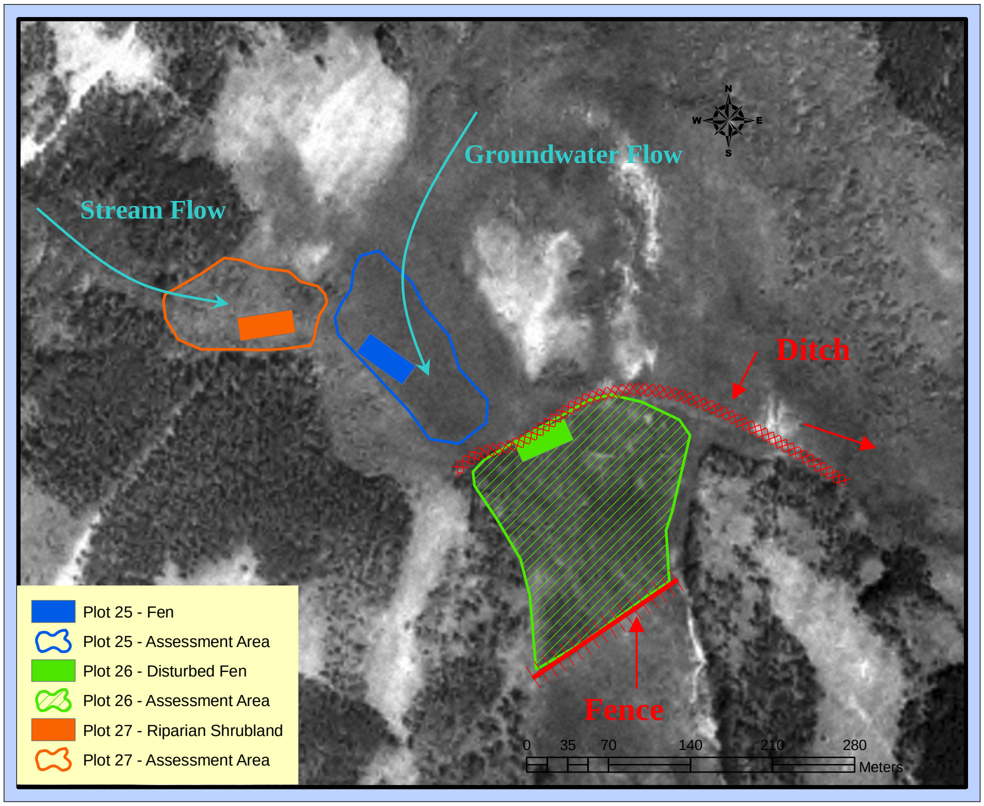


Figure 3. Examples of Delineated Wetland Assessment Areas. Although contiguous with each other, three distinct AAs were delineated because either they were distinct ecological system types (e.g. fen vs. riparian shrubland) or due to a human-induced disturbance (e.g. ditch) which significantly altered a large portion of an otherwise contiguous wetland type (e.g. intact vs. disturbed fen).

4. Anthropogenic changes in hydrology. For example, ditches, water diversions, irrigation inputs, roadbeds, etc. which substantially alter a site's hydrology relative to adjacent areas would dictate separate a AA.

5. For large wetlands, representative sub-samples of the floristic and abiotic micro-variation with the wetland/riparian type in question was used as the AA. For example, in a large wetland such as High Creek Fen, sedge meadows, water tracks, and rills represented micro-variation within the fen ecological system type. A representative sub-sample included portions of these variations within the AA.

<u>Riparian AA Boundaries:</u>

1. Lateral boundaries were defined by:
    - Abrupt changes in geomorphology (e.g., upland slopes)
    - Transition of wetland vegetation to upland species.
2. Longitudinal boundaries were defined by:
    - Natural changes in hydrology. For example, a change in channel type (e.g. Rosgen 1996), geomorphic constrictions, the presence/absence of beaver ponds, confluence with a tributary, or rapids/waterfalls.

- Anthropogenic changes in hydrology. For example, dams, water diversions, dikes, berms, roadbeds, etc. which substantially alters a site's hydrology relative to adjacent reaches.
- Significant change in management or land use which result in distinct ecological differences. For example, a heavily grazed shrubland on one side of a fence line and ungrazed shrubland on the other.
- Sub-sample of riparian area that is representative of local human-induced disturbances and floristic variation. For example, if hydrological changes and/or management criteria aren't helpful in defining the AA because the wetland in question is so large (longitudinally or laterally), then a representative sub-sample of the wetland was defined as the AA.

3.4 Plot Establishment and Vegetation Sampling

3.4.1 Plot Location

Vegetation plots were subjectively placed within the AA to maximize abiotic/biotic heterogeneity within the plot. 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[5]

- 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 2004b).

The structure of the plot consists of ten 100 m^2 modules (total of 1000 m^2 or 0.1 hectare) which are typically arranged in a 20 m x 50 m array (Figure 4). Floristic measurements included presence/absence and abundance (e.g. cover) and were made within at least four of the 100 m^2 intensive modules. These are referred to as "intensive" modules. In addition, nested quadrats within each module are established in at least two corners providing data from multiple scales

---

[5] Many of the guidelines are based on Mack 2004b.

(Figure 4). The remaining six modules are considered "residuals" and are searched for any species not documented in the intensive modules.

To lay out the plot, a 50 m measuring tape was extended as the centerline of the plot from a subjectively chosen origin (see Section 3.4.1). Starting at zero, a stake flag (or flagging tied to a shrub /tree) was placed every 10 m. Red stake flags or flagging were placed at the 0, 40, and 50 m marks and green stake flags/flagging at the 10, 20 and 30 m marks. This helped visualize the four "intensive modules" which occur on either side of the centerline between the 10-30 m marks. Next, a 10 m rope was extended perpendicular on either side of the centerline at each 10 m mark. Red or green flags were placed at the end of the rope to mark the lateral boundaries of each module and the plot.

If the wetland had an irregular shape and the plot did not "fit", 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.

If the wetland was so large that the 20 m x 50 m plot did not capture a significant amount of variation of the wetland, then the 2 x 5 array of 100 m^2 modules was separated into ten individual modules which were subjectively established throughout the wetland to ensure variation of the wetland type was captured (Figure 5). In this case, all ten modules were intensively sampled. For other types of projects, the locations of these modules might be randomly placed throughout the wetland (Mack 2004b).

Each module in the plot was numbered by standing at the 0 m mark facing the 50 m end, the modules were assigned from 1-5 starting on the right side and modules 6-10 were assigned using a similar method then from the 50 m mark (Figure 4). Intensive modules were typically modules 2, 3, 8, and 9. Within intensive modules, a $\log_{10}$ series of nested subquadrats were established to obtain estimates of species composition at multiple spatial scales (e.g., 0.01, 0.1, 1.0, and 10 m^2) (Figure 4). 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. When standing at the 0 m mark and facing the 50 m end, the corners of each intensive module are numbered in a clockwise direction within each module. To maximize spatial distinction of the sampled corners, the following sequence of corners was sampled: Module 2 (corners 2 and 4), Module 3 (corners 2 and 3), Module 8 (corners 2 and 4), and Module 9 (corners 2 and 3) (Figure 4). For those plots that did not use a 2x5 array of modules (e.g. 1x5 or 2x2), the module numbers may be different (and were randomly chosen); however the same sequence of corners was used.

The number of subquadrats in a nest is referred to as depth, where a depth of 5 indicates species presence was recorded in the 0.01 m^2 subquadrat, depth of 4 (0.1 m^2), depth of 3 (1.0 m^2), depth of 2 (10.0 m^2), and depth of 1 (100.0 m^2). Sampling began at the smallest subquadrat and each species received a number corresponding to the depth at which it was initially encountered. During 2004, all five depths (subquadrats) were sampled; however, to increase efficiency and due to a lack of utility of the finer scaled depths, only 3 subquadrats (1, 10, and 100 m^2) were sampled in 2005 and 2006. 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.

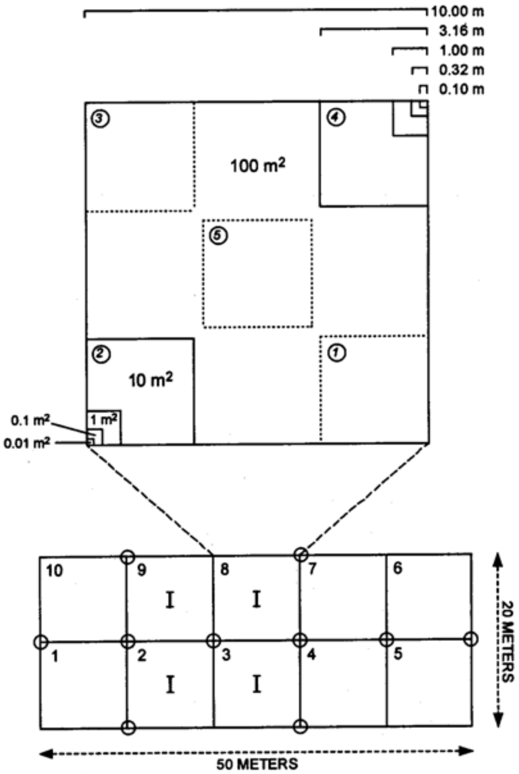


Figure 4. Reléve Plot Method (from Peet et al. 1998). I = intensive modules. Nested subquadrats are shown in the inset diagram at the top.

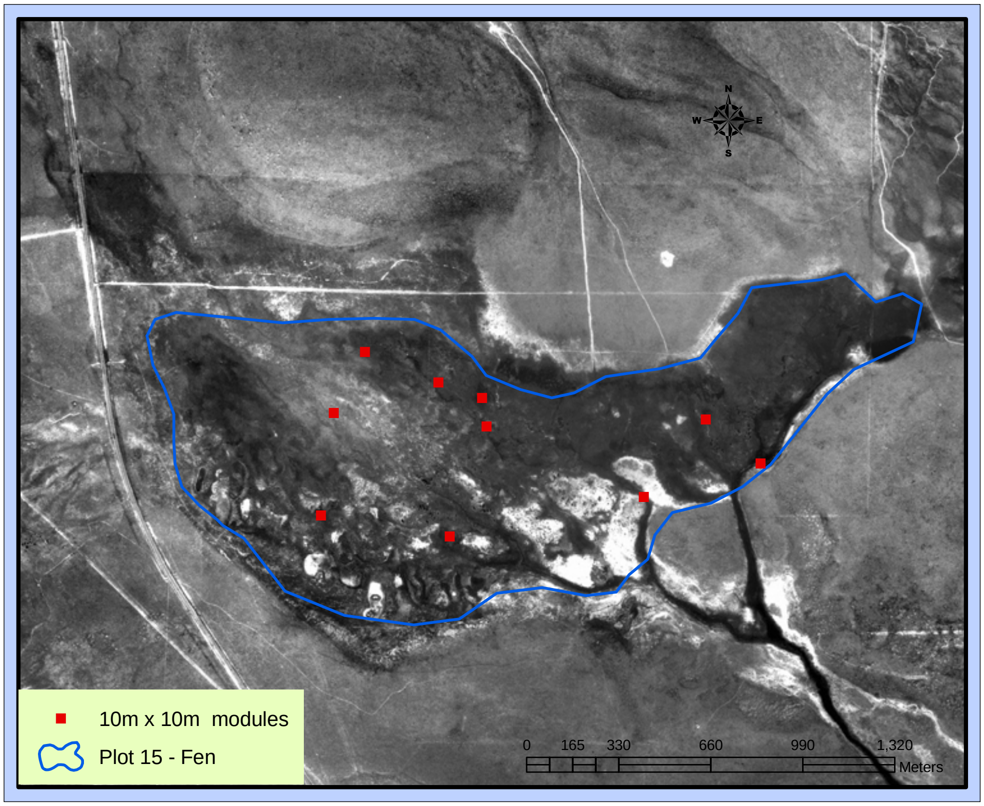


Figure 5. Example of 20m x 50m plot broken into ten 100m^2 modules.

3.5 Human Disturbance Gradient

3.5.1 Human Disturbance Index

The Human Disturbance Index (HDI) is a semi-quantitative index which provides an independent measure of wetland condition against which vegetation attributes are assessed to determine their relationship with increasing human disturbance (Appendix B). 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 (MDC). 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 (Montana Department of Environmental Quality 2005; Mack 2001).

In order to calibrate the HDI, each sample site was also scored using both the HDI and the Delaware Rapid Assessment Procedure V. 2.0 (Delaware Dept. of Natural Resources and Environmental Control 2005), which has been successfully calibrated against site-level quantitative data (Amy Jacobs, personal communication). Both the HDI and Delaware methods adopt the MDC definition of 'reference condition' and assume that the absence of historic and/or contemporary human disturbance indicates that the wetland or riparian area possesses biotic and ecological integrity and that increasing human disturbance results in a predictable deviation from the ecological reference condition (Figure 6).

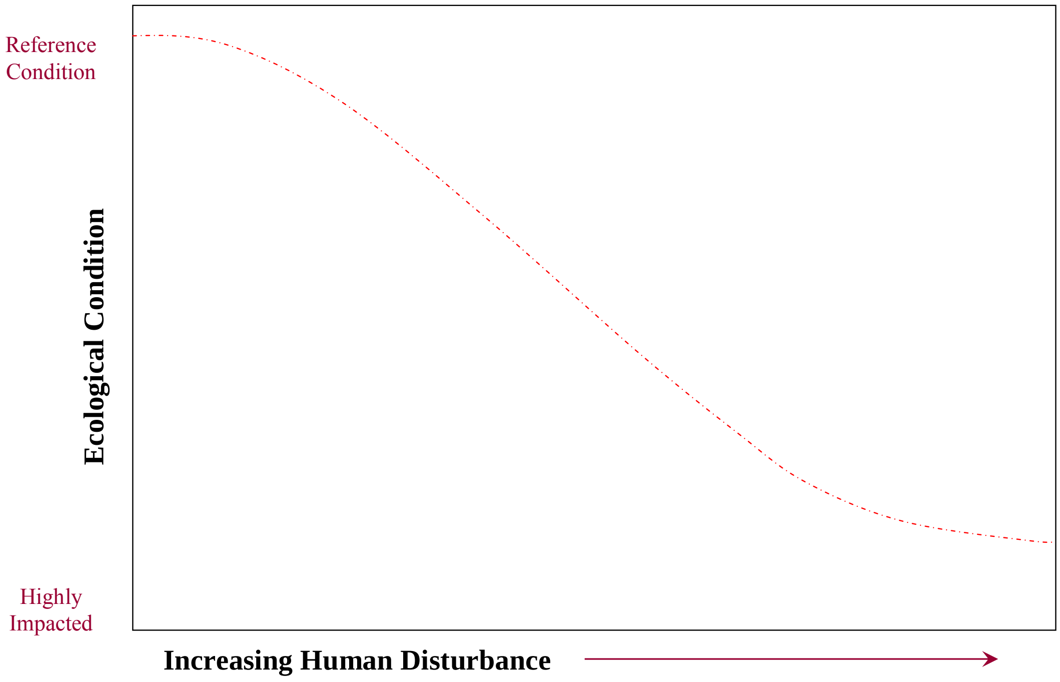


Figure 6. Human Disturbance and Ecological Condition. Graph adapted from: Davies and Jackson (2006).

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 how many points are assigned to it (see form in Appendix B). 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).

3.5.2 Delaware Rapid Assessment Score

This method is a rapid assessment of wetland condition based on the presence/absence of human-induced stressors (Delaware Dept. of Natural Resources and Environmental Control 2005). The stressors are placed into three categories of impacts: Hydrology, Habitat/Plant Community, and Buffer. Each stressor is assigned points according to its relative impact to wetland condition. Each category starts with 10 points and stressor points are subtracted from this to arrive at a final score for each category. Category scores are summed to arrive at a final score between 0 (extremely disturbed) to 30 (reference condition; no/minimal human-induced disturbance). A second grazing stressor (-5 points; included as “Other”) was added to both the Habitat/Plant Community and Buffer sections to reflect the variable and widespread impact livestock grazing has on Colorado wetlands.

3.6 Other Data Collected

Standard site data were collected from each sample location. This included:

- HGM classification (Johnson 2005)
- Classification of plant association(s) (Carsey et al. 2003)
- Cowardin classification (Cowardin et al. 1979)
- GPS location
- Elevation
- Slope between 0 and 50 m mark of vegetation plot
- Compass direction of plot
- Selected soils data – depth and identification of soil horizons, texture, and color.
- Water table depth
- Nearby landforms (alluvial fans, narrow bedrock valley, alluvial valley, etc.)
- Description of onsite and adjacent ecological processes and land use.
- Description of general site characteristics.
- Photos
- Water pH, conductivity, and temperature were measured using a Hanna Instruments hand-held meter (Model # HI98129).

3.7 Data Management

Vegetation data were entered into a Microsoft Excel^{TM} spreadsheet where data were “reduced” from raw cover class scores to cover values (the midpoint of each cover class). Relative and mean cover for each species was averaged across the intensive modules and used 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 drop-down 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.

The Colorado Floristic Quality Assessment (FQA) database (Rocchio 2007) was used to populate life history traits, wetland indicator status, and C-values in the data reduction spreadsheet for each species in the plot. Species nomenclature follows USDA PLANTS Database (http://plants.usda.gov/) as of January 2005. Since many practitioners in Colorado use Dr. William Weber's Colorado East/West Slope floras as a field key and nomenclature reference (Weber and Wittmann 2001a, 2001b), these names were cross-referenced to the PLANTS names in the FQA database. Life history traits and wetland indicator status were downloaded from PLANTS. The USFWS Region 5 and 8 Wetland Indicator Status lists were also used to ensure that PLANTS information was correct (Reed 1988). However, these lists are not complete and some species did not have a wetland indicator status listed. For some of these species, a wetland indicator status was estimated using input from members of the Colorado Floristic Quality Assessment Panel as well as the author's personal experience with the Colorado flora.

Life history traits and cover data were used to calculate metric values using pivot tables in Microsoft Excel^{TM}. Calculations made by pivot tables were randomly checked via hand-calculations to ensure that pivot tables were constructed correctly. Environmental data and human disturbance rating scores were also entered into a Microsoft Excel^{TM} spreadsheet. These data were combined with metric values from each plot into a new spreadsheet. This spreadsheet served as the basis for analysis.

3.8 Data Analysis

3.8.1 Classification Analysis

The *a priori* classification systems tested were (1) Ecological systems; (2) HGM; (3) Physiognomy, and (4) Soil type. Data analysis from the VIBI Phase 1 report (Rocchio 2006b) showed that the *a priori* ecological system classification explained variation in the reference plot dataset better than the other classification schemes. However, because additional reference plot data (three additional plots) were collected in 2006, the classification analysis was conducted again to confirm the results from Phase 1.

Classification serves the purpose of identifying groupings of the dataset which constrain natural variability and thus allows more sensitive detection of signals resulting from increasing human disturbance. In order to constrain noise in the dataset, only those plots considered "reference" were analyzed. This is both ecologically and practically useful since natural variability is best constrained using only reference quality sites. Disturbed sites introduce variability outside the natural range of variation. Using the Human Disturbance Index (HDI) scores, the 75 reléve plots were categorized into three HDI classes: Highly impacted (scores 0-33), Impacted (scores 34-67) and Reference (68-100). Twenty eight plots were identified as Reference and were used in the classification analysis.

Multivariate analysis of species composition and abundance (mean cover) from each of the 28 reference plots was conducted using PCORD Software (McCune and Mefford 1999) to determine which *a priori* classification system accounts for the most variation and best explains the separation of the data. Unknown or ambiguous species were removed and species occurring in less than three plots were deleted.

Ordination

Nonmetric multidimensional scaling (NMS) ordination (Kruskal 1964) was performed in PCORD. NMS is increasingly used for ecological data analysis due to its suitability for nonnormal, arbitrary, or discontinuous scaled data (McCune and Grace 2002). NMS avoids the assumption of linearity among variables, relieves the "zero-truncation" issue common with biological data through its use of ranked distances, and allows the use of any distance measure (McCune and Grace 2002). NMS seeks a reduced representation or dimensional configuration of the multidimensional relationship among samples and species (McCune and Grace 2002). The difference between ranked distance in the original multidimensional space and ranked distance in the reduced ordination space is called "stress" (McCune and Grace 2002). Final stress values less than 20 (lower values are most accurate) are sought for ecological community data (McCune and Grace 2002).

Multi-response Permutation Procedure

A multi-response permutation procedure (MRPP) using the Sorenson (Bray-Curtis) distance measure was used to determine whether significant differences exist between various classification groups of the reference plot data. MRPP is a nonparametric procedure comparable to discriminate analysis or multivariate analysis of variance and thus is recommended for ecological data which often do not meet the required assumptions of parametric statistical methods (McCune and Grace 2002). MRPP tests the hypothesis that samples within an *a priori* group are clumped in multivariate space by reassigning the *a priori* group memberships (i.e. permutations) and determining the degree to which *a priori* group is more clumped than randomly assigned samples. The test statistic T-statistic describes the separation between the groups with a more negative value of T indicating a stronger separation. The *p*-value (α=0.1) assisted in evaluating how likely it is that an observed difference was due to chance. The 'average distance within group' measure indicates the dispersion within each grouping, with higher values indicating more dispersion. The A-statistic describes the within-group homogeneity compared to random expectation. An A=1 indicates all items within a group are identical while an A=0 indicates heterogeneity within groups equals expectation by chance. McCune and Grace (2002) indicate that in community ecology, A values are typically < 0.1 while an A > 0.3 is considered fairly high.

3.8.2 Human Disturbance Index

Scatterplots depicting the Human Disturbance Index (HDI) against the Delaware Rapid Assessment Procedure score for each plot were constructed. Spearman's rank correlation coefficient was used to assess the strength of the correlation between the two methods. Strong agreement between the two methods would be considered a validation of the HDI. Analysis was conducted using Minitab® Release 14.

3.8.3 Metric Screening

Vegetation attributes representing differing aspects of the vegetation community, such as functional and compositional guilds, were calculated from the plot dataset (total of 75 plots). Different 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 were screened for inclusion in the VIBI models. Data analysis was conducted using Minitab® Release 14.

The following protocol was implemented in the order shown to screen and identify which of the vegetation attributes were worthy of being included as a metric in the VIBI models (Jones 2005; Blocksom et al. 2002; Barbour et al. 1996):

1. Discriminatory Power: Box plots were used to assess the ability of each attribute to discriminate between reference and highly impacted site (reference: HDI≥68; highly impacted: HDI≤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, 0= both medians overlap the others interquartile range). Those attributes which scored a 2 or 3 were retained for further screening.

2. 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]). Spearman's rank was used because the HDI consists of ordinal data. The Spearman's correlation coefficient measures the strength of correlation between the ranks of two variables. Those attributes with a correlation coefficient (r[s]) > 0.5, or those which exhibited a nonlinear pattern were kept for further screening.

3. Scope of Detection: Attribute variability under the reference condition is another consideration to identify effective metrics (U.S. EPA 1998). An attribute which is highly variable relative to the scope of detection is not useful. The scope of detection is the range from 0 to the lower quartile (25th percentile) of an attribute's distribution (75th percentile for those metrics which increase with increasing human disturbance) (USEPA 1998). A larger scope of detection, relative to the interquartile range, results in a higher ability to detect change from the reference condition. The "interquartile coefficient" (IC) was used here to determine the level of attribute variability. The IC is a ratio of the interquartile range to the scope of detection. 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. Attributes which had an r[s]) >0.9 were considered to be redundant. When redundant attributes were identified, the one with the strongest correlation to human disturbance and most effective discriminatory power was retained. If redundant attributes (e.g. % of hydrophytes and % non-native species) were providing unique ecological information (change in abundance of wetland dependent species vs. change in abundance of non-native species) they were retained.

5. Final Selection of Metrics: Vegetation attributes were reviewed once more to ensure correlations were not based on outliers and that each was ecologically meaningful. Attributes which passed this final screen were selected as metrics for the VIBI models.

3.8.4 Metric and VIBI Scoring

Metric Scoring

For individual metrics in each of the VIBI models, metric scores were identified by using a continuous scoring procedure as 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 was taken for metrics which increase with the HDI). Blocksom (2003) found that because this continuous method used almost the entire range of measured values, it was less variable, avoided data gaps, and provided a more accurate depiction of the actual data than other continuous or discrete scoring procedures.

The following calculations were used to convert each metric value into a score:

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

  $$[\text{Metric Score} = (\text{Max} - \text{observed value})/(\text{Max} - 5^{\text{th}} \text{ percentile of metric range})]$$

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

  $$[\text{Metric Score} = \text{Observed value}/95^{\text{th}} \text{ percentile of metric range}]$$

The 95th percentile of the data was used in lieu of the maximum value to eliminate strong outliers. Metric scores were truncated so that they ranged between 0.0 – 1.0, with 1.0 representing reference conditions.

VIBI Scoring

A total VIBI score was calculated by summing metric scores and dividing by the number of metrics in each individual VIBI. This resulted in a VIBI score ranging from 0.0 to 1.0, with 1.0 representing reference conditions. The 0.0 – 1.0 range was used in order to facilitate integration with other wetland assessment approaches such as HGM which uses the 0.0 to 1.0 scale. As such, the VIBI models in this report can be used as an HGM variable or “function” without any further effort.

3.8.5 Correlation of VIBI to Human Disturbance Index

A Spearman’s Rank correlation coefficient was used to determine the strength of the relationship between each VIBI model and the HDI.

4.0 RESULTS

4.1 Sample Sites

A total of 75 plots (28 reference plots) representing five ecological systems were sampled over three field seasons (2004, 2005, and 2006; Figure 7). Most data collection occurred in the Upper Blue River and South Platter River Headwaters watersheds while a few reference quality sites were sampled in the Colorado Headwater watershed (Figure 8). Ten of the riverine plots (i.e. riparian shrubland and riverine wet meadows) were located on 4th or 5th order streams. The remaining 65 plots occurred along 3rd or lower order streams. Of these, slope plots were the origin of 1st order streams or were isolated. Thus, about 87% of the plots sampled were considered headwater wetlands and riparian areas. Site information for the 75 plots sampled can be found in Appendix C. A total of 480 plant species were identified in the 75 plots (Appendix D).

Sampling initially focused on three ecological system types (wet meadows, fens, and riparian shrublands) with the intended goal of obtaining at least 25 plots per type. However, as described in the classification analysis below, fens and wet meadows were both split into two types. Due to this, each ecological system type did not receive the same amount of sampling effort since the additional types were not initially targeted for sampling (Figure 7).

Riparian shrublands and fens have adequate representation across the human disturbance gradient (Figure 7). However, the newly defined types (extremely rich fens, slope wet meadows, and riverine wet meadows) generally need more data collection.

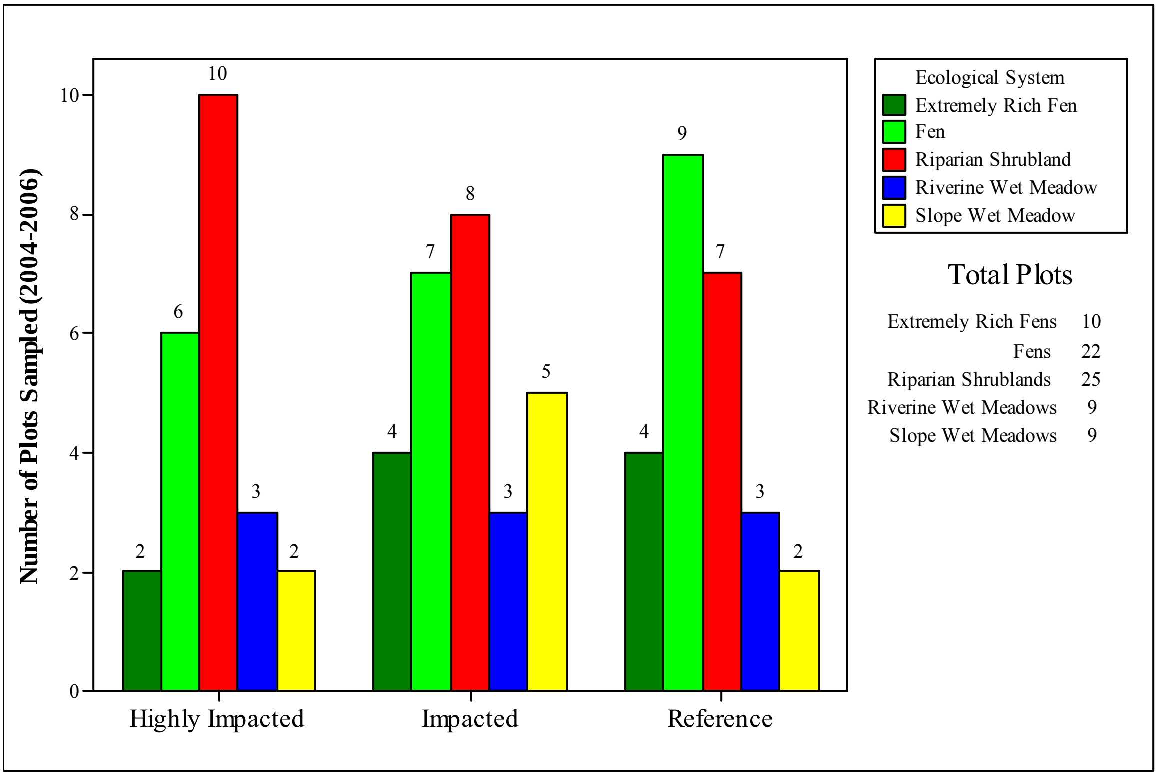


Figure 7. Plot Distribution Across Ecological System Types and Degree of Human Disturbance

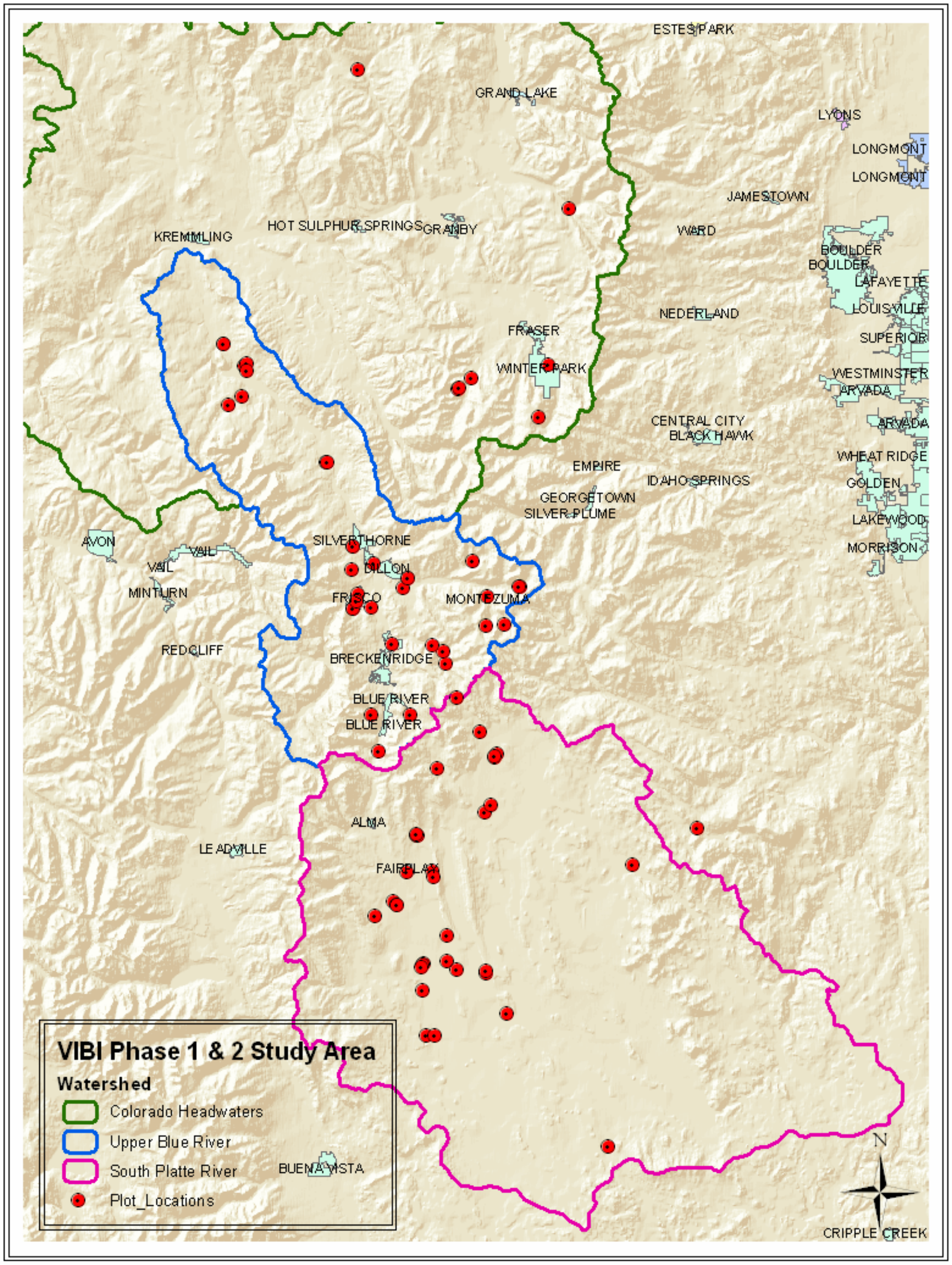


Figure 8. Plot Locations

4.2 Classification

4.2.1 Nonmetric Dimensional Scaling Ordination

The species dataset had high coefficient of variation (CV) (Table 2), for which McCune and Grace (2002) recommend transforming using arcsine square root (for proportion data) or Beal's smoothing. Data transformations (arcsine square root and Beal's Smoothing) did improve the CV; however, the resulting ordinations from those transformations did not improve the interpretability of the data relative to ordinations of the untransformed dataset. Consequently, the original, untransformed dataset was used for the analysis.

The summary and results of the nonmetric dimensional scaling ordination (NMS) are shown in Table 3 and Figures 9-13. The NMS ordination, which seeks the least amount of dimensions to explain variation in the dataset (i.e., reduction of stress), resulted in a two dimensional solution. Axis 1 explained 26% while Axis 2 explained 30% of the variation in the dataset. Axis 1 appears to represent soil type with mineral soil wetlands (wet meadows and riparian shrublands) located on the left side and organic soil wetlands (fens and extremely rich fens) located to the right (Figure 10). Axis 2 is less straightforward but appears to represent two distinct gradients: shrub cover and pH. Shrub cover is the most obvious split between riparian shrublands from wet meadows (Figure 13) and pH in distinguishing fens from extremely rich fens (Figure 9).

The Ecological System classification clearly separates plots into their *a priori* assigned groups and appears to be the most useful classification system for constraining natural variation of the reference plot dataset (Figure 9). Considering that Ecological Systems incorporate elements of the other classification systems analyzed, this result was expected. Soil type and HGM Class are useful classification criteria (Figure 10 and 11); however their binary groupings provide less information than using the Ecological System types. HGM sub-class and physiognomy did not adequately explain variation in the dataset relative to the ecological system classification (Figures 12 & 13).

The Ecological System ordination shows four distinct groups: wet meadows, riparian shrublands, fens, and extremely rich fens (Figure 9). The *a priori* ecological system classification did not include an extremely rich fen type; however, the ordination clearly indicates they constitute a unique type, at least for the purpose of VIBI development.

There are a few anomalies within three of the four groups: Plots 10, 18, and 39 all occur in different Ecological System types than originally classified in the field (Figure 9). Plot 10 was located in an expansive riparian shrubland with numerous beaver ponds and very wet conditions. Although many of the other reference riparian shrubland plots were located near or encompassed beaver activity, Plot 10 has a much higher abundance of beaked sedge (*Carex utriculata*) than found in other riparian shrubland plots but comparable to what is found in the wet meadow plots. In addition, although occurring at similar elevations as the other plots, Plot 10 has nearly 40% cover of Rocky Mountain willow (*Salix monticola)* whereas most of the other riparian shrubland plots were dominated by planeleaf (*S. planifolia*) and/or Wolf's willow (*S. wolfii*), pushing Plot 10 further away from other riparian shrubland plots in ordination space based on species distinction and not on structure. Both of these factors appear to have resulted in Plot 10 aligning with wet meadow plots in ordination space.

Table 2. Statistics for Plot x Species Matrix

	Gamma Diversity	Average Alpha Diversity	Beta Diversity	% Empty Cells	Average Skewness	Coefficient of Variation of Species Total
Reference Plot Dataset Rows (Plots) (No Transformations)	115	35.4	3.25	69.19%	8.70	23.87 %
Reference Plot Dataset Columns (Species) (No Transformations)	28	8.6	3.26	69.19%	2.93	308 %

Table 3. Nonmetric Dimensional Scaling Ordination Results.

	NMS All Reference Plots
Software	PCORD
Distance Measure	Sorenson
Starting Configuration	Random
Number of Runs with Real Data	40
Number of Dimensions Assessed	2
Number of Dimensions in Final Solution	2
Monte Carlo Test Result	50 randomized runs; Axis 1: $p = 0.0196$ Axis 2: $p = 0.0392$
Number of Iteration in Final Result	49
Stability Criterion	0.005
Proportion of Variance of Each Axis (Sorenson Distance)	*Increment* Axis 1: $r^2 = 0.258$ Axis 2: $r^2 = 0.294$ *Cumulative* $r^2 = 0.552$
Final Stress (2-D solution)	21.66
Final Instability	0.00343

Plot 18 was dominated by Wolf's willow and water sedge (*Carex aquatilis*), a community type which is often found in organic soils (Carsey et al. 2003). In addition to Plot 18, Plots 31 (riparian shrubland), 04 (fen), and 40 (riparian shrubland) were also dominated by Wolf's willow; however only Plots 18 and 04 had significant cover of water sedge, resulting in their close proximity in ordination space (Figure 9). Although Plot 18 had mineral soils, it appears that its deep, rich A-horizon has resulted in a species composition more similar to fens than other riparian shrublands.

Plot 39 was located in a small patch of subalpine wet meadow supported by discharging groundwater and surrounded by spruce-fir forest. The plot was dominated by wet forbs such as false hellebore (*Veratrum tenuipetalum*), marsh marigold (*Caltha leptosepala*), and arrowleaf groundsel (*Senecio triangularis*), species which, if present, were in much lower abundance in other wet meadow plots. In addition, subalpine fir (*Abies lasiocarpa*) had nearly 7% cover and was entirely absent from other wet meadow plots. Except for Plot 39, wet meadow plots had a high cover of graminoid species. The location of the plot among tall conifers appears to have resulted in less cover of graminoid species and higher abundance of shade-tolerant forb species, as might be found in riparian shrublands.

Plot 27 did not group with a particular ecological system (Figure 9). This plot was dominated by shrubs, had organic soils, received both surface and groundwater inputs, and supported a few extremely rich fen species thus its transitional position between riparian shrublands and extremely rich fens.

The NMS ordination suggests that the ecological systems classification should guide VIBI development. In order to determine if individual VIBI models needed to be developed for each ecological system or whether ecological systems types could be used to define unique scoring criteria within one or two broader VIBI models, metric screening was conducted across all classification groups to ensure the most efficient and effective VIBI models were developed (see Section 4.4). This process showed that vegetation attributes in each ecological system exhibited unique relationships with HDI and that broader classification groups (i.e. physiognomy and HGM) did not adequately nest the metrics into coarser-scale VIBI models. Metric screening also showed that wet meadows were extremely noisy and thus did not adequately constrain natural variability. However, when wet meadows were subdivided by HGM Class and thus split into “slope wet meadows” and “riverine wet meadows” preliminary metric relationships greatly improved and resulted in unique assemblages of metrics for these two wet meadow types. An NMS ordination of reference wet meadow plots also supported this split (Figure 14).

4.2.2 Multi-response Permutation Procedure

The ecological system classification as a whole, as well as all but one of the associated pairwise comparisons, had negative T-statistics indicating that between group differences are strong and that this classification scheme resulted in statistically significant groupings (Table 4). As indicated previously, A-values in community ecology are typically < 0.1, while an A > 0.3 is considered to be high (McCune and Grace 2002). This would suggest that within group homogeneity in this dataset is relatively high but still within the values expected by chance providing further confirmation that ecological systems adequately explain variation in the reference plot dataset. The pairwise comparison of slope wet meadow vs. riparian shrubland reference plots did not show a significant difference. There were only two reference slope wet meadow plots and as discussed previously, one of them (Plot 39) grouped with riparian shrubland plots in the NMS ordination (Figure 8). Slope wet meadows were found to be significantly different than both fen types but only by a slight margin (Table 4). The fact that slope wet meadows, fens, and extremely rich fens are all supported by groundwater discharge may explain why they are only marginally separated. Additional reference plots from slope wet meadows are needed to better understand their distinction from other systems. However, as discussed above, metric screening showed that slope wet meadows possess a unique assemblage of metrics compared to the other systems suggesting they are justified as a unique class. A-values for pairwise comparisons ranged from 0.13 to 0.29.

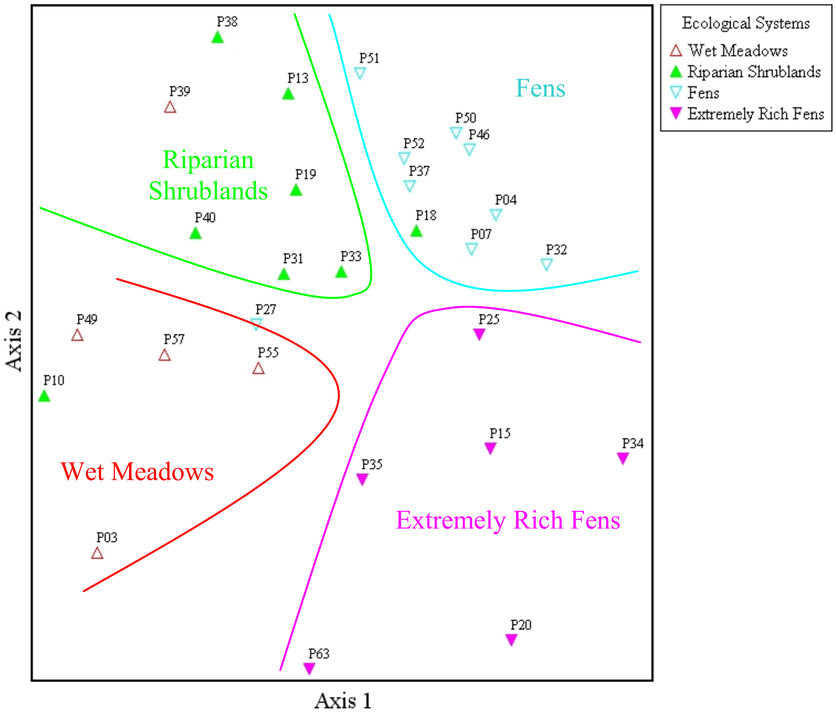


Figure 9. NMS Ordination of Reference Plots (Grouped by *a priori* Ecological systems classification)

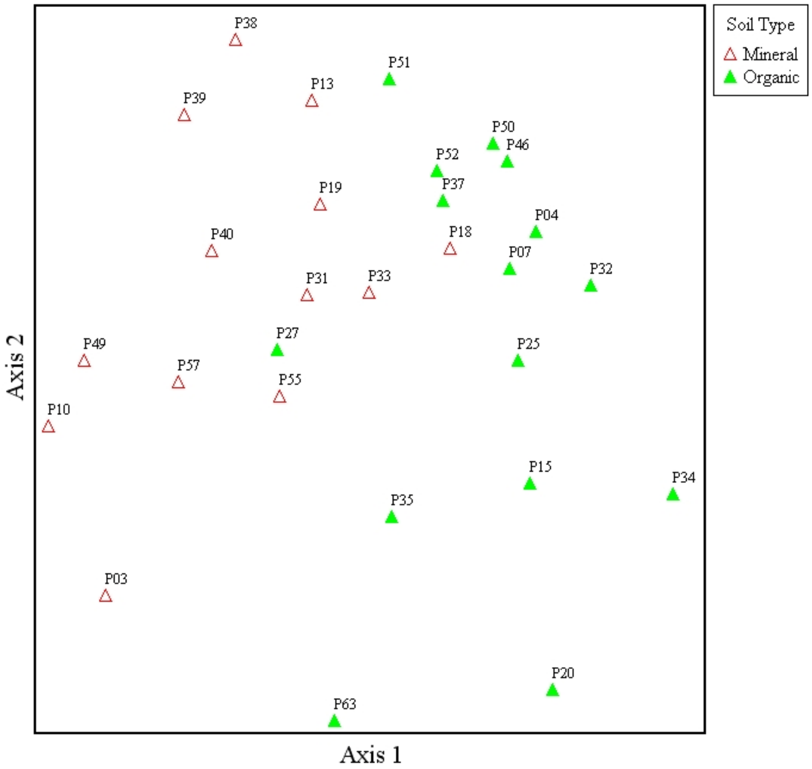


Figure 10. NMS Ordination of Reference Plots (Grouped by *a priori* Soil Type classification)

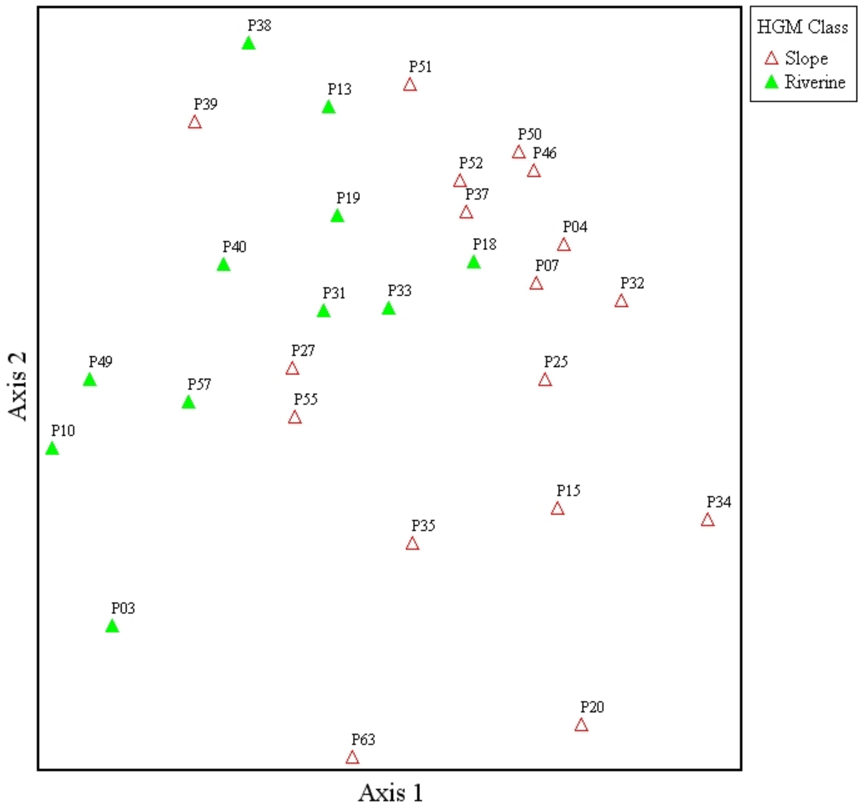


Figure 11. NMS Ordination of Reference Plots (Grouped by *a priori* HGM classification)

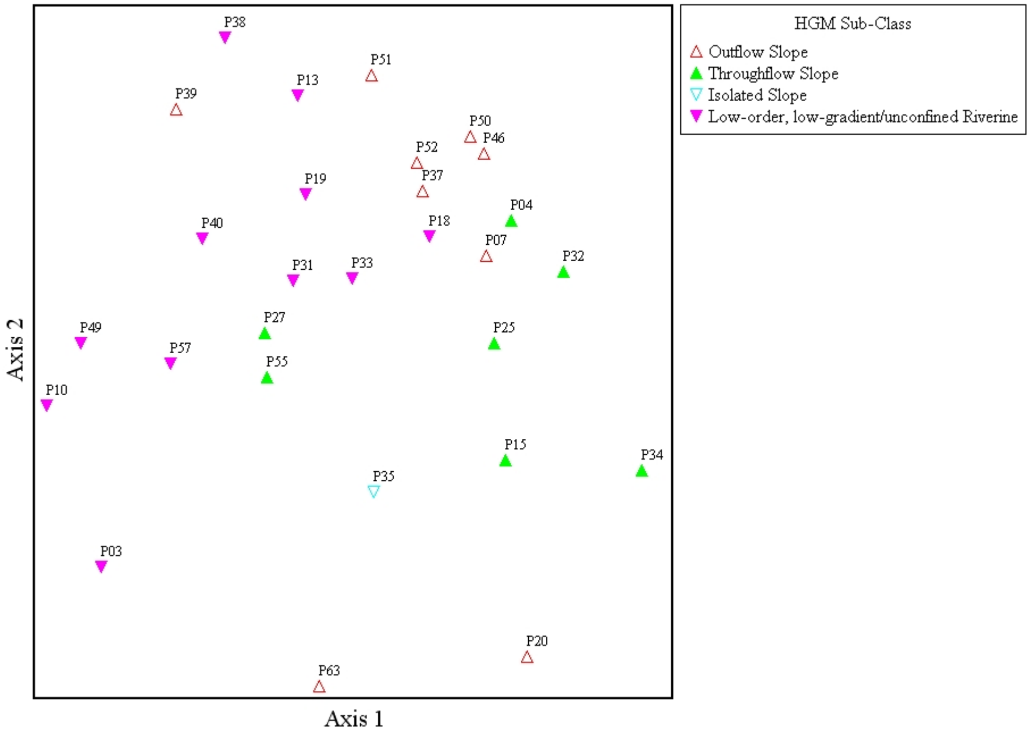


Figure 12. NMS Ordination of Reference Plots (Grouped by *a priori* HGM-subclass classification)

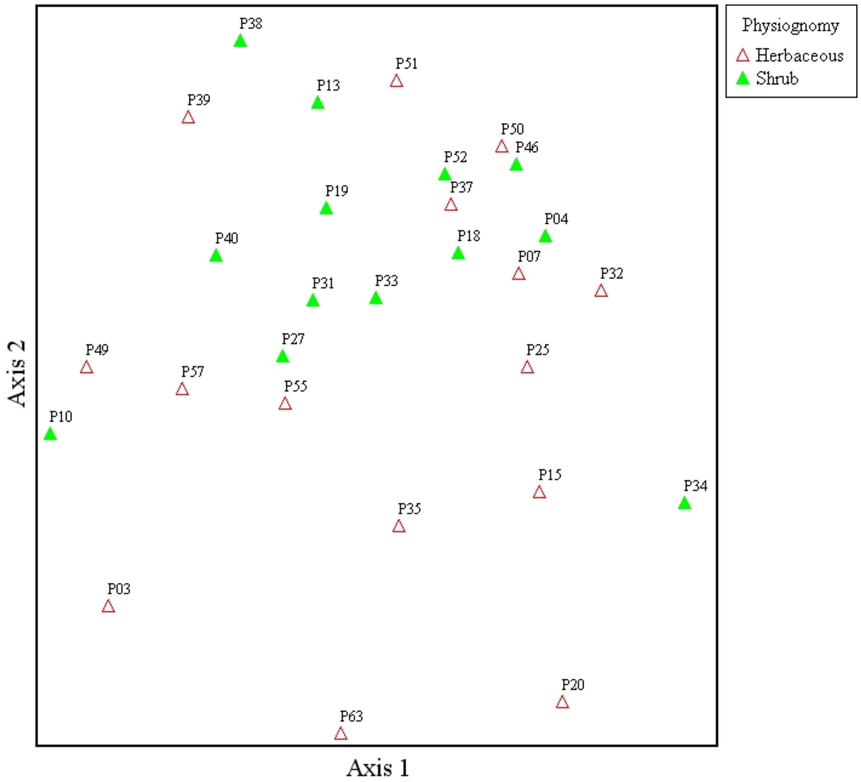


Figure 13. NMS Ordination of Reference Plots (Grouped by *a priori* Physiognomy classification)

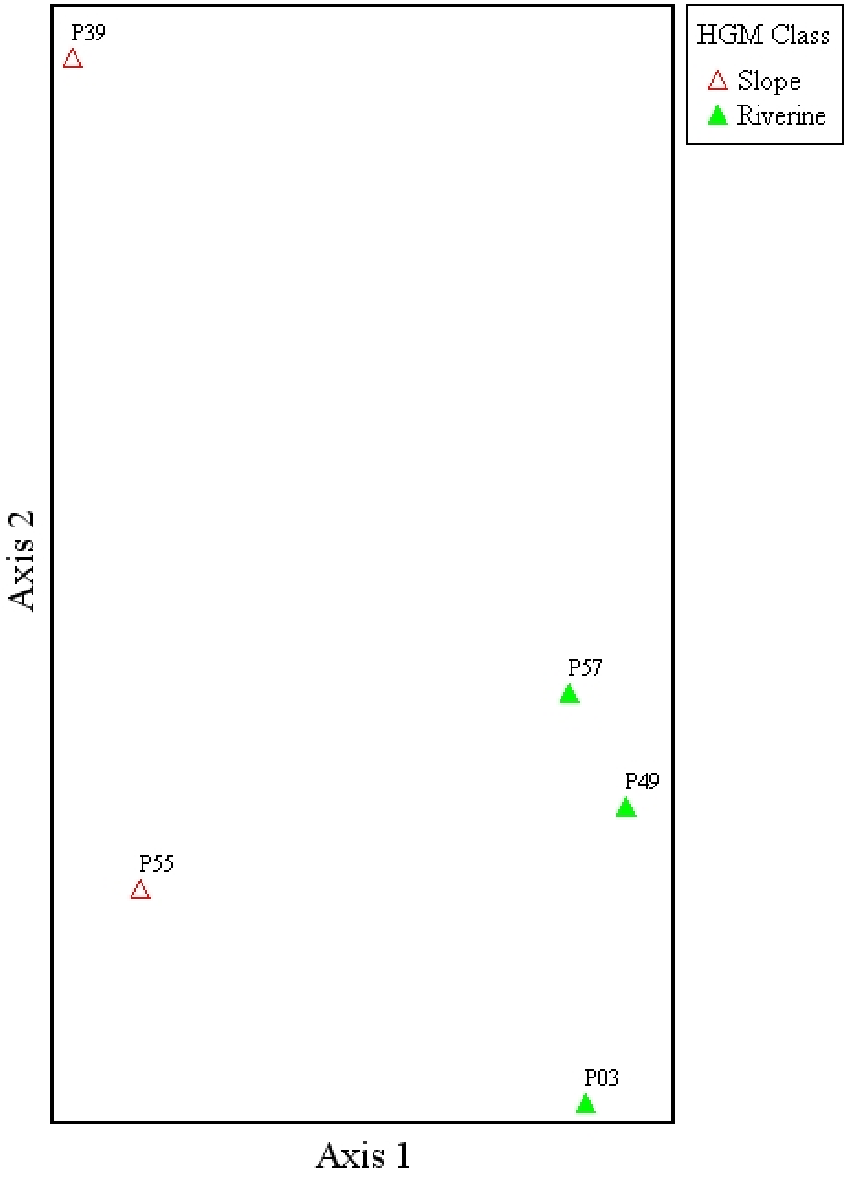


Figure 14. NMS Ordination of Reference Wet Meadow Plots (Grouped by HGM Class)

Table 4. Multi-Response Permutation Procedure Analysis

	Ecological Systems				
	Slope Wet Meadow	Riverine Wet Meadow	Riparian Shrubland	Fen	Extremely Rich Fen
Size of Group	2	3	8	9	6
Average within Group Distance	0.622	0.052	0.358	0.196	0.486
T	-7.1				
p	0.00000003				
A	0.361				

	Pairwise Comparison									
	Riverine Wet Meadow vs. Slope Wet Meadow	Riverine Wet Meadow vs. Fen	Slope Wet Meadow vs. Fen	Riverine Wet Meadow vs. Riparian Shrubland	Slope Wet Meadow vs. Riparian Shrubland	Riverine Wet Meadow vs. Extremely Rich Fen	Slope Wet Meadow vs. Extremely Rich Fen	Riparian Shrubland vs. Fen	Riparian Shrubland vs. Extremely Rich Fen	Fen vs. Extremely Rich Fen
T	-1.91	-5.64	-1.35	-3.51	0.71	-3.64	-1.34	-4.23	-5.85	-5.74
p	0.000	0.0007	0.1	0.007	0.741	0.002	0.1	0.002	0.00004	0.0001
A	0.147	0.371	0.068	0.267	-0.05	0.334	0.125	0.147	0.256	0.227

Note: See section 3.1.3 for explanation of T and A.

4.3 Human Disturbance Index

The Human Disturbance Index was strongly correlated to the Delaware Rapid Assessment Score (Figure 15) for each ecological system. All but one system (riverine wet meadows = r[s] -0.84) had correlation coefficients > -0.90. Thus, it was concluded that the Human Disturbance Index is able to produce a reliable semi-quantitative estimate of human-induced disturbance at each sample site.

4.4 Metric screening

Table 5 lists the 133 vegetation attributes that were screened for inclusion in the VIBI models as metrics. The reason metrics were removed during the screening process is displayed in Table 5. Those metrics with “No Discriminatory Power” were the first removed, followed by those with “Weak Correlation to the Human Disturbance Index”, “Redundant” metrics, and those with “Narrow Range/Noisy Scatterplot”, which eliminated those metrics which passed the previous screening steps but upon more detailed inspection were found to be marginally useful relative to the other metrics available for final selection.

Final metrics varied according to ecological system type and no metric was included in all five of the VIBI models (Table 6). Metric screening showed that all tested attributes were noisy for wet meadow plots. However, when these plots were split into two unique types based on their HGM class, a unique assemblage of metrics emerged for each type (e.g. slope wet meadows and riverine wet meadows). Only two metrics, percentage of non-native species and mean cover of dominant native species, were shared by three ecological system types. The percentage of non-native species metric was included in the riparian shrubland, fen, and riverine wet meadow VIBI models while mean cover of dominant native species metric was included in the fen, extremely rich fen, and slope wet meadow VIBI models. The remaining metrics only occurred in one or two VIBI models reiterating the strong effect of classification on vegetation attribute response to human disturbance. Because of this, it was concluded that individual VIBI models needed to be constructed for each of the five ecological system types.

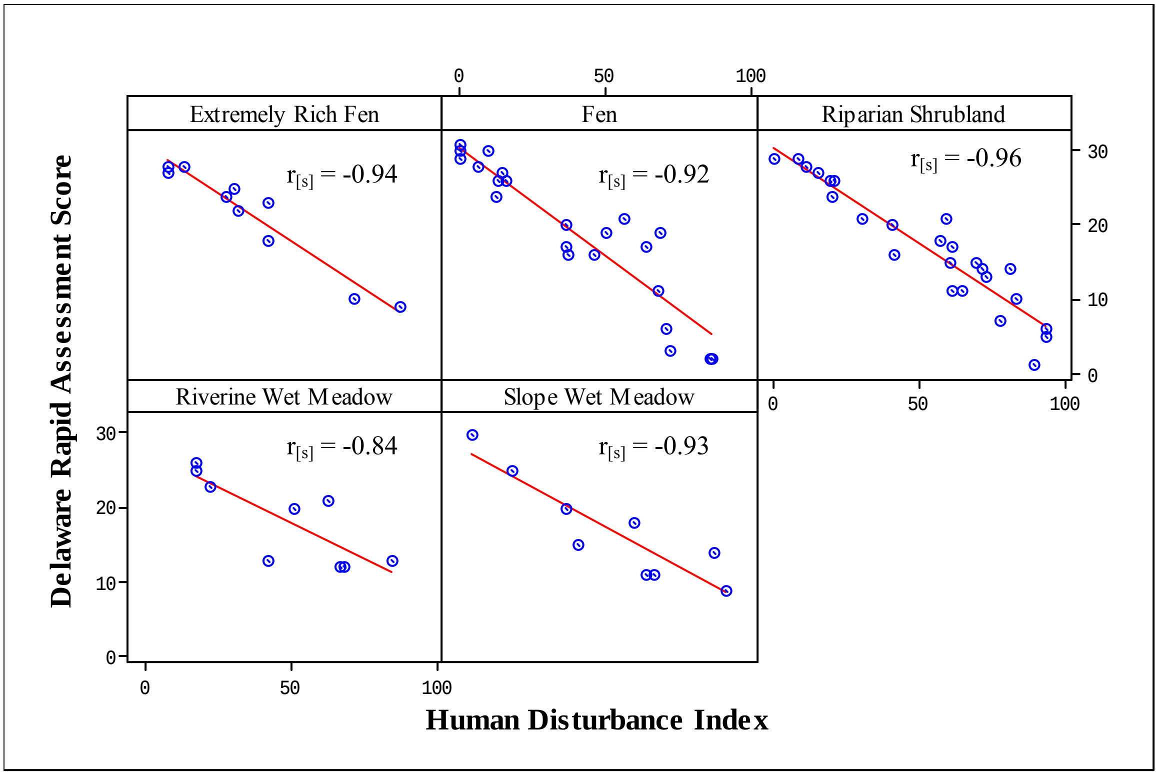


Figure 15. Correlation of Delaware Rapid Assessment Score and Human Disturbance Index (Spearman's Rank correlation coefficient was used)

Table 5. Results of Metric Screening (Results represent the stage of screening in which metrics were removed from analysis (see Section 3.8.3) For example, Stage 1: No Discriminatory Power; Stage 2: Weak Correlation to Disturbance; Stage 3: Limited Scope of Detection; Stage 4: Redundant; and Stage 5: Narrow range/noisy scatterplot.

Vegetation Attribute	Riparian Shrublands	Fen	Extremely Rich Fens	Slope Wet Meadows	Riverine Wet Meadows
% non-native species	**FINAL METRIC**	**FINAL METRIC**	No Discriminatory Power	Weak Correlation to HDI	**FINAL METRIC**
Mean cover of non-natives	Narrow range/noisy scatterplot	No Discriminatory Power	No Discriminatory Power	No Discriminatory Power	No Discriminatory Power
Relative cover of non-natives	Narrow range/noisy scatterplot	Narrow range/noisy scatterplot	Weak Correlation to HDI	Weak Correlation to HDI	No Discriminatory Power
Relative cover of dominant non-natives	No Discriminatory Power	No Discriminatory Power	No Discriminatory Power	No Discriminatory Power	No Discriminatory Power
Mean cover of dominant non-natives	Redundant	Weak Correlation to HDI	No Discriminatory Power	No Discriminatory Power	Weak Correlation to HDI
Relative cover of dominant native	Weak Correlation to HDI	Weak Correlation to HDI	No Discriminatory Power	No Discriminatory Power	No Discriminatory Power
Mean cover of dominant native	No Discriminatory Power	**FINAL METRIC**	**FINAL METRIC**	Weak Correlation to HDI	No Discriminatory Power
Species richness (all species)	No Discriminatory Power	No Discriminatory Power	No Discriminatory Power	Redundant	No Discriminatory Power
Species richness (native species)	No Discriminatory Power	No Discriminatory Power	No Discriminatory Power	Weak Correlation to HDI	No Discriminatory Power
Non-native richness	Redundant	Narrow range/noisy scatterplot	No Discriminatory Power	No Discriminatory Power	Weak Correlation to HDI
FQI (native species)	Redundant	No Discriminatory Power	Narrow range/noisy scatterplot	Redundant	No Discriminatory Power
FQI (all species)	Redundant	No Discriminatory Power	Narrow range/noisy scatterplot	Redundant	No Discriminatory Power
Adjusted FQI	Redundant	Redundant	Weak Correlation to HDI	Narrow range/noisy scatterplot	No Discriminatory Power
Mean C (native species)	**FINAL METRIC**	**FINAL METRIC**	Weak Correlation to HDI	Narrow range/noisy scatterplot	No Discriminatory Power
Mean C (all species)	Redundant	Redundant	Weak Correlation to HDI	Narrow range/noisy scatterplot	No Discriminatory Power
Mean cover of Mean C (native species)	No Discriminatory Power	No Discriminatory Power	Narrow range/noisy scatterplot	Redundant	Weak Correlation to HDI
Mean cover of Mean C (all species)	No Discriminatory Power	No Discriminatory Power	Narrow range/noisy scatterplot	Redundant	Weak Correlation to HDI
Mean cover of FQI (native species)	No Discriminatory Power	No Discriminatory Power	Narrow range/noisy scatterplot	**FINAL METRIC**	No Discriminatory Power
Mean cover of FQI (all species)	Weak Correlation to HDI	No Discriminatory Power	No Discriminatory Power	No Discriminatory Power	No Discriminatory Power
Mean cover of Adjusted FQI	No Discriminatory Power	Narrow range/noisy scatterplot	Narrow range/noisy scatterplot	Redundant	Weak Correlation to HDI
Wetland indicator status (all species)	**FINAL METRIC**	No Discriminatory Power	No Discriminatory Power	Weak Correlation to HDI	**FINAL METRIC**
Wet indicator status (native species)	No Discriminatory Power	No Discriminatory Power	No Discriminatory Power	No Discriminatory Power	Weak Correlation to HDI
% hydrophytes (OBL-FACW)	Redundant	No Discriminatory Power	No Discriminatory Power	No Discriminatory Power	Weak Correlation to HDI
Relative cover of hydrophytes	**FINAL METRIC**	No Discriminatory Power	No Discriminatory Power	No Discriminatory Power	No Discriminatory Power
Mean cover of hydrophytes	Narrow range/noisy scatterplot	**FINAL METRIC**	Weak Correlation to HDI	Weak Correlation to HDI	No Discriminatory Power
Relative cover of native hydrophytes	Redundant	No Discriminatory Power	Weak Correlation to HDI	No Discriminatory Power	No Discriminatory Power

Vegetation Attribute	Riparian Shrublands	Fen	Extremely Rich Fens	Slope Wet Meadows	Riverine Wet Meadows
Mean cover of native hydrophytes	Narrow range/noisy scatterplot	Redundant	**FINAL METRIC**	Weak Correlation to HDI	No Discriminatory Power
% forbs	No Discriminatory Power	No Discriminatory Power	No Discriminatory Power	Narrow range/noisy scatterplot	Narrow range/noisy scatterplot
% native forbs	**FINAL METRIC**	No Discriminatory Power	No Discriminatory Power	No Discriminatory Power	No Discriminatory Power
Relative cover of forbs	Weak Correlation to HDI	Weak Correlation to HDI	Weak Correlation to HDI	Weak Correlation to HDI	Weak Correlation to HDI
Mean cover of forbs	No Discriminatory Power	No Discriminatory Power	No Discriminatory Power	Redundant	No Discriminatory Power
% graminoids	No Discriminatory Power	No Discriminatory Power	No Discriminatory Power	Narrow range/noisy scatterplot	No Discriminatory Power
Relative cover of graminoids	No Discriminatory Power	No Discriminatory Power	No Discriminatory Power	Redundant	No Discriminatory Power
Mean cover of graminoids	No Discriminatory Power	No Discriminatory Power	Redundant	No Discriminatory Power	Weak Correlation to HDI
% annuals	Weak Correlation to HDI	No Discriminatory Power	Narrow range/noisy scatterplot	No Discriminatory Power	No Discriminatory Power
Relative cover of annuals	No Discriminatory Power	No Discriminatory Power	**FINAL METRIC**	No Discriminatory Power	Narrow range/noisy scatterplot
Mean cover of annuals	No Discriminatory Power	No Discriminatory Power	Narrow range/noisy scatterplot	No Discriminatory Power	Narrow range/noisy scatterplot
% native annuals	No Discriminatory Power	No Discriminatory Power	Weak Correlation to HDI	No Discriminatory Power	No Discriminatory Power
% perennials	No Discriminatory Power	No Discriminatory Power	No Discriminatory Power	No Discriminatory Power	No Discriminatory Power
Relative cover of perennials	No Discriminatory Power	No Discriminatory Power	No Discriminatory Power	No Discriminatory Power	No Discriminatory Power
Mean cover of perennials	No Discriminatory Power	No Discriminatory Power	Redundant	**FINAL METRIC**	No Discriminatory Power
% native perennial	**FINAL METRIC**	No Discriminatory Power	No Discriminatory Power	No Discriminatory Power	No Discriminatory Power
% native perennial graminoid	No Discriminatory Power	No Discriminatory Power	No Discriminatory Power	Weak Correlation to HDI	No Discriminatory Power
% dicot	No Discriminatory Power	No Discriminatory Power	No Discriminatory Power	No Discriminatory Power	No Discriminatory Power
Relative cover of dicots	No Discriminatory Power	No Discriminatory Power	No Discriminatory Power	Weak Correlation to HDI	No Discriminatory Power
Mean cover of dicots	No Discriminatory Power	No Discriminatory Power	No Discriminatory Power	Weak Correlation to HDI	No Discriminatory Power
% native dicot	Weak Correlation to HDI	No Discriminatory Power	No Discriminatory Power	No Discriminatory Power	No Discriminatory Power
% non-native dicot	Narrow range/noisy scatterplot	Narrow range/noisy scatterplot	Narrow range/noisy scatterplot	No Discriminatory Power	Narrow range/noisy scatterplot
% monocot	No Discriminatory Power	No Discriminatory Power	No Discriminatory Power	Weak Correlation to HDI	No Discriminatory Power
Relative cover of monocots	No Discriminatory Power	No Discriminatory Power	No Discriminatory Power	Narrow range/noisy scatterplot	No Discriminatory Power
Mean cover of monocots	No Discriminatory Power	No Discriminatory Power	Redundant	Weak Correlation to HDI	No Discriminatory Power
% native monocot	No Discriminatory Power	No Discriminatory Power	No Discriminatory Power	No Discriminatory Power	No Discriminatory Power
% non-native monocot	Narrow range/noisy scatterplot	No Discriminatory Power	No Discriminatory Power	Weak Correlation to HDI	No Discriminatory Power
Carex richness	Limited Scope of Detection	Weak Correlation to HDI	Weak Correlation to HDI	No Discriminatory Power	No Discriminatory Power
% carex	No Discriminatory Power	Weak Correlation to HDI	Weak Correlation to HDI	No Discriminatory Power	No Discriminatory Power
Relative cover of Carex	No Discriminatory Power	No Discriminatory Power	No Discriminatory Power	No Discriminatory Power	Weak Correlation to HDI

Vegetation Attribute	**Riparian Shrublands**	**Fen**	**Extremely Rich Fens**	**Slope Wet Meadows**	**Riverine Wet Meadows**
Mean cover of Carex	Limited Scope of Detection	No Discriminatory Power	No Discriminatory Power	No Discriminatory Power	Weak Correlation to HDI
Relative cover of bryophytes	No Discriminatory Power	Limited Scope of Detection	Limited Scope of Detection	Weak Correlation to HDI	No Discriminatory Power
Mean cover of bryophytes	No Discriminatory Power	Limited Scope of Detection	Limited Scope of Detection	Weak Correlation to HDI	No Discriminatory Power
Relative cover of shrubs	No Discriminatory Power	No Discriminatory Power	No Discriminatory Power	No Discriminatory Power	No Discriminatory Power
Mean cover of shrubs	No Discriminatory Power	No Discriminatory Power	No Discriminatory Power	No Discriminatory Power	No Discriminatory Power
Mean cover of bare ground	No Discriminatory Power	**FINAL METRIC**	Weak Correlation to HDI	Weak Correlation to HDI	Narrow range/noisy scatterplot
Mean cover of water	No Discriminatory Power	No Discriminatory Power	No Discriminatory Power	Weak Correlation to HDI	Limited Scope of Detection
Mean cover of litter	No Discriminatory Power	**FINAL METRIC**	No Discriminatory Power	No Discriminatory Power	No Discriminatory Power
Annual Richness	No Discriminatory Power	No Discriminatory Power	Weak Correlation to HDI	No Discriminatory Power	Weak Correlation to HDI
Perennial Richness	No Discriminatory Power	No Discriminatory Power	No Discriminatory Power	**FINAL METRIC**	No Discriminatory Power
Invasive Richness	**FINAL METRIC**	Narrow range/noisy scatterplot	Narrow range/noisy scatterplot	No Discriminatory Power	**FINAL METRIC**
Relative cover of invasives	Weak Correlation to HDI	Weak Correlation to HDI	Weak Correlation to HDI	Weak Correlation to HDI	Weak Correlation to HDI
Mean cover of invasives	Narrow range/noisy scatterplot	No Discriminatory Power	No Discriminatory Power	No Discriminatory Power	No Discriminatory Power
Cyperaceae Richness	Limited Scope of Detection	No Discriminatory Power	Weak Correlation to HDI	Weak Correlation to HDI	No Discriminatory Power
Relative cover of Cyperaceae	No Discriminatory Power	No Discriminatory Power	Weak Correlation to HDI	No Discriminatory Power	Weak Correlation to HDI
Mean cover of Cyperaceae	Limited Scope of Detection	No Discriminatory Power	Weak Correlation to HDI	No Discriminatory Power	Weak Correlation to HDI
Asteraceae Richness	No Discriminatory Power	Weak Correlation to HDI	No Discriminatory Power	Weak Correlation to HDI	**FINAL METRIC**
Relative cover of Asteraceae	Weak Correlation to HDI	Weak Correlation to HDI	Weak Correlation to HDI	Weak Correlation to HDI	Weak Correlation to HDI
Mean cover of Asteraceae	Weak Correlation to HDI	Weak Correlation to HDI	Weak Correlation to HDI	Weak Correlation to HDI	Weak Correlation to HDI
Poaceae Richness	No Discriminatory Power	No Discriminatory Power	No Discriminatory Power	Weak Correlation to HDI	No Discriminatory Power
Relative cover of Poaceae	Weak Correlation to HDI	Weak Correlation to HDI	Weak Correlation to HDI	**FINAL METRIC**	**FINAL METRIC**
Mean cover of Poaceae	No Discriminatory Power	No Discriminatory Power	Weak Correlation to HDI	Narrow range/noisy scatterplot	No Discriminatory Power
Brassicaceae Richness	No Discriminatory Power	No Discriminatory Power	Narrow range/noisy scatterplot	No Discriminatory Power	No Discriminatory Power
Relative cover of Brassicaceae	No Discriminatory Power	No Discriminatory Power	No Discriminatory Power	No Discriminatory Power	No Discriminatory Power
Mean cover of Brassicaceae	Weak Correlation to HDI	No Discriminatory Power	Narrow range/noisy scatterplot	No Discriminatory Power	No Discriminatory Power
Gentianaceae Richness	No Discriminatory Power	No Discriminatory Power	No Discriminatory Power	Weak Correlation to HDI	Narrow range/noisy scatterplot
Relative cover of Gentianaceae	No Discriminatory Power	No Discriminatory Power	No Discriminatory Power	No Discriminatory Power	Weak Correlation to HDI
Mean cover of Gentianaceae	No Discriminatory Power	Weak Correlation to HDI	No Discriminatory Power	Limited Scope of Detection	Weak Correlation to HDI
% intolerant species	**FINAL METRIC**	No Discriminatory Power	Limited Scope of Detection	Redundant	No Discriminatory Power
Mean cover of intolerant species	Limited Scope of Detection	Redundant	**FINAL METRIC**	Limited Scope of Detection	No Discriminatory Power

Vegetation Attribute	**Riparian Shrublands**	**Fen**	**Extremely Rich Fens**	**Slope Wet Meadows**	**Riverine Wet Meadows**
Relative cover of intolerant species	Narrow range/noisy scatterplot	No Discriminatory Power	No Discriminatory Power	No Discriminatory Power	No Discriminatory Power
% tolerant species	**FINAL METRIC**	Narrow range/noisy scatterplot	Weak Correlation to HDI	No Discriminatory Power	Narrow range/noisy scatterplot
Mean cover of tolerant species	Narrow range/noisy scatterplot	Narrow range/noisy scatterplot	Weak Correlation to HDI	No Discriminatory Power	Narrow range/noisy scatterplot
Relative cover of tolerant species	Narrow range/noisy scatterplot	Narrow range/noisy scatterplot	Weak Correlation to HDI	Weak Correlation to HDI	Narrow range/noisy scatterplot
Shannon-Diversity Index	No Discriminatory Power	No Discriminatory Power	No Discriminatory Power	No Discriminatory Power	Weak Correlation to HDI
Simpson Diversity Index	No Discriminatory Power	No Discriminatory Power	No Discriminatory Power	No Discriminatory Power	Narrow range/noisy pattern
% native graminoids	No Discriminatory Power	No Discriminatory Power	No Discriminatory Power	Narrow range/noisy scatterplot	No Discriminatory Power
Mean cover of native graminoids	No Discriminatory Power	No Discriminatory Power	Redundant	No Discriminatory Power	No Discriminatory Power
Relative cover of native graminoids	No Discriminatory Power	No Discriminatory Power	No Discriminatory Power	No Discriminatory Power	No Discriminatory Power
Mean cover of native forbs	No Discriminatory Power	No Discriminatory Power	No Discriminatory Power	Redundant	No Discriminatory Power
Relative cover of native forbs	No Discriminatory Power	No Discriminatory Power	No Discriminatory Power	Narrow range/noisy scatterplot	Weak Correlation to HDI
Mean cover of native annuals	No Discriminatory Power	No Discriminatory Power	Narrow range/noisy scatterplot	No Discriminatory Power	No Discriminatory Power
Relative cover of native annuals	No Discriminatory Power	No Discriminatory Power	Narrow range/noisy scatterplot	No Discriminatory Power	No Discriminatory Power
Mean cover of native perennials	Weak Correlation to HDI	No Discriminatory Power	**FINAL METRIC**	Redundant	No Discriminatory Power
Relative cover of native perennials	No Discriminatory Power	No Discriminatory Power	No Discriminatory Power	Weak Correlation to HDI	No Discriminatory Power
Mean cover of native perennial graminoids	No Discriminatory Power	Narrow range/noisy scatterplot	Narrow range/noisy scatterplot	No Discriminatory Power	Weak Correlation to HDI
Relative cover of native perennial graminoids	No Discriminatory Power	No Discriminatory Power	No Discriminatory Power	No Discriminatory Power	No Discriminatory Power
Mean cover of native dicots	No Discriminatory Power	No Discriminatory Power	No Discriminatory Power	Redundant	No Discriminatory Power
Relative cover of native dicots	No Discriminatory Power	No Discriminatory Power	No Discriminatory Power	Narrow range/noisy scatterplot	No Discriminatory Power
Mean cover of non-native dicots	Narrow range/noisy scatterplot	Narrow range/noisy scatterplot	No Discriminatory Power	No Discriminatory Power	No Discriminatory Power
Relative cover of non-native dicots	Narrow range/noisy scatterplot	Narrow range/noisy scatterplot	No Discriminatory Power	No Discriminatory Power	Weak Correlation to HDI
Mean cover of native monocots	No Discriminatory Power	No Discriminatory Power	Redundant	Weak Correlation to HDI	No Discriminatory Power
Relative cover of native monocots	No Discriminatory Power	No Discriminatory Power	No Discriminatory Power	No Discriminatory Power	No Discriminatory Power
Mean cover of non-native monocots	Narrow range/noisy scatterplot	No Discriminatory Power	No Discriminatory Power	No Discriminatory Power	No Discriminatory Power
Relative cover of non-native monocots	Narrow range/noisy scatterplot	No Discriminatory Power	No Discriminatory Power	Weak Correlation to HDI	No Discriminatory Power
Tolerant/Intolerant Ratio	Weak Correlation to HDI	Redundant	Narrow range/noisy scatterplot	Weak Correlation to HDI	No Discriminatory Power
Forb/Graminoid Ratio	No Discriminatory Power	No Discriminatory Power	No Discriminatory Power	Weak Correlation to HDI	No Discriminatory Power
Native Forb/Graminoid Ratio	No Discriminatory Power	No Discriminatory Power	No Discriminatory Power	No Discriminatory Power	No Discriminatory Power

Vegetation Attribute	Riparian Shrublands	Fen	Extremely Rich Fens	Slope Wet Meadows	Riverine Wet Meadows
Annual/Perennial Ratio	Weak Correlation to HDI	No Discriminatory Power	Weak Correlation to HDI	No Discriminatory Power	No Discriminatory Power
Native Annual/Perennial Ratio	No Discriminatory Power	No Discriminatory Power	**FINAL METRIC**	No Discriminatory Power	No Discriminatory Power
Rhizomatous/Nonrhizomatous Ratio	No Discriminatory Power	Narrow range/noisy scatterplot	No Discriminatory Power	Narrow range/noisy scatterplot	**FINAL METRIC**
Mean cover of rhizomatous species	Weak Correlation to HDI	No Discriminatory Power	Weak Correlation to HDI	**FINAL METRIC**	No Discriminatory Power
Relative cover of rhizomatous species	No Discriminatory Power	No Discriminatory Power	Weak Correlation to HDI	No Discriminatory Power	Weak Correlation to HDI
Mean cover of Forb/Graminoid Ratio	No Discriminatory Power	Weak Correlation to HDI	Weak Correlation to HDI	Weak Correlation to HDI	No Discriminatory Power
Relative cover of Forb/Graminoid Ratio	No Discriminatory Power	Weak Correlation to HDI	Weak Correlation to HDI	Weak Correlation to HDI	No Discriminatory Power
Mean cover of native Forb/Graminoid Ratio	No Discriminatory Power	Weak Correlation to HDI	No Discriminatory Power	Weak Correlation to HDI	No Discriminatory Power
Relative cover of native Forb/Graminoid Ratio	No Discriminatory Power	Weak Correlation to HDI	No Discriminatory Power	Weak Correlation to HDI	No Discriminatory Power
Mean cover of Rhizomatous/Nonrhizomatous Ratio	Weak Correlation to HDI	No Discriminatory Power	Weak Correlation to HDI	No Discriminatory Power	Narrow range/noisy scatterplot
Relative cover of Rhizomatous/Nonrhizomatous Ratio	Weak Correlation to HDI	No Discriminatory Power	Weak Correlation to HDI	No Discriminatory Power	Narrow range/noisy scatterplot
Mean cover of native Rhizomatous/Nonrhizomatous Ratio	Weak Correlation to HDI	No Discriminatory Power	Weak Correlation to HDI	No Discriminatory Power	Narrow range/noisy scatterplot
Relative cover of native Rhizomatous/Nonrhizomatous Ratio	Weak Correlation to HDI	No Discriminatory Power	Weak Correlation to HDI	No Discriminatory Power	Narrow range/noisy scatterplot
Mean cover of native rhizomatous species	Weak Correlation to HDI	No Discriminatory Power	Weak Correlation to HDI	Narrow range/noisy scatterplot	Weak Correlation to HDI
Relative cover of native rhizomatous species	No Discriminatory Power	No Discriminatory Power	Weak Correlation to HDI	Weak Correlation to HDI	Weak Correlation to HDI
Mean cover of native stoloniferous species	No Discriminatory Power	No Discriminatory Power	No Discriminatory Power	Weak Correlation to HDI	Weak Correlation to HDI
Relative cover of native stoloniferous species	No Discriminatory Power	No Discriminatory Power	No Discriminatory Power	Weak Correlation to HDI	Weak Correlation to HDI
Relative cover of stoloniferous species	No Discriminatory Power	No Discriminatory Power	No Discriminatory Power	Narrow range/noisy scatterplot	Weak Correlation to HDI
Mean cover of stoloniferous species	No Discriminatory Power	No Discriminatory Power	No Discriminatory Power	Weak Correlation to HDI	Weak Correlation to HDI

Table 6. Metrics Selected for the VIBI Models

Metric	Riparian Shrublands	Fen	Extremely Rich Fens	Slope Wet Meadows	Riverine Wet Meadows
% non-native species	X	X			X
Mean cover of dominant[6] native species		X	X		
Mean C[7] (natives species)	X	X			
Mean cover of FQI[8] (native species)				X	
Wetland indicator status[9] (all species)	X				X
Relative cover of hydrophytes[10]	X				
Mean cover of hydrophytes		X			
Mean cover of native hydrophytes			X		
% native forbs	X				
Relative cover of annuals			X		
Mean cover of perennials				X	
% native perennial	X				
Mean cover of bare ground		X			
Mean cover of litter		X			
Perennial Richness				X	
Invasive Richness[11]	X				X
Asteraceae Richness					X
Relative cover of Poaceae				X	X
% intolerant[12] species	X				
Mean cover of intolerant species			X		
% tolerant[13] species	X				
Mean cover of native perennials			X		
Native Annual/Perennial Ratio			X		
Rhizomatous/Non-rhizomatous Ratio					X
Mean cover of rhizomatous species				X	

---

[6] Dominant species are those with > 5% average cover.

[7] Mean C is the average coefficient of conservatism for each plot. A coefficient of conservatism is a value representing a species fidelity to high-quality natural communities. The coefficient ranges from 0-10 with 0 indicating the plant had no fidelity to high-quality natural communities while a 10 indicates the species is obligate to such communities. See Rocchio (2007) for more information regarding coefficients of conservatism for Colorado's flora.

[8] FQI = Floristic Quality Index (Mean C * sqrt. of species richness)

[9] Wetland indicator status is based on Reed (1988) and were converted to numeric value for calculating this metric (OBL = -5, FACW+ = -4, FACW = -3, FACW- = -2, FAC+ = -1, FAC = 0...UPL = 5)

[10] Hydrophytes are those species with a wetland indicator status of FACW or OBL (Reed 1988).

[11] The degree of invasiveness of each species was ranked (0= not invasive; 4=highly invasive) by the Colorado Floristic Quality Assessment Panel. Species with value ≥ 3 were invasive

[12] Intolerant species are those with a coefficient of conservatism value ≥ 7.

[13] Tolerant species are those with a coefficient of conservatism value ≤ 3.

4.5 Vegetation Index of Biotic Integrity Models

4.5.1 Rocky Mountain Subalpine-Montane Riparian Shrubland VIBI

Nine metrics were selected for inclusion in the riparian shrubland VIBI (Table 7). Three metrics were indicative of community level integrity and were based on richness calculations. The remaining six metrics are indicative of functional groups based on both dominance and richness calculations. All nine metrics were clearly able to distinguish reference and highly impacted sites (Figure 16) and had a very strong correlation to the HDI, with most exhibiting a Spearman's correlation coefficient of 0.70 and above (Table 8; Figure 17). The % non-native metric showed a slight non-linear response with non-native species rapidly increasing abundance in plots with an HDI score of 60 or higher (Figure 17). The remaining eight metrics showed linear responses to the HDI. The weakest correlation (r[s] = -0.53) was found with % native forbs. Mean C (natives) and % intolerant metrics had a negative response to increasing human disturbance while the % tolerant metric had a positive response (Table 7). Four metrics (% non-native, wetland indicator status of all species, % tolerant, and invasive richness) had a positive response and five metrics (% native forbs, % native perennials, mean c natives, % intolerant, and relative cover of hydrophytes) had a negative response to increasing human disturbance (Table 7).

The riparian shrubland VIBI showed a strong response r[s]) = -0.84) to the HDI (Figure 17). Reference plots showed little variability in VIBI scores while impacted plots were much more variable. Although eight plots were assigned to the Impacted class (Figure 7), most of those occurred near the most disturbed end of that class (Figure 17). Consequently, there were only three plots with an HDI score between 21-55, leaving a large data gap near the middle of the disturbance gradient (Figure 17). Metric scores for the HDI for each plot are shown in Table 8.

4.5.2 Rocky Mountain Subalpine-Montane Fen VIBI

Six metrics were selected for inclusion in the fen VIBI (Table 8). One metric (mean C natives) is indicative of community level integrity while the remaining five metrics are indicative of functional groups (Table 9). Two metrics (% non-native and mean C natives) were based on richness calculations while the remaining three were calculated using dominance (e.g. % cover). All metrics were able to distinguish reference from highly impacted sites (Figure 18). Variability of metrics in highly impacted sites was quite high for most metrics, and especially so for mean cover of bare ground (Figure 18). Mean cover of bare ground showed a non-linear response to the HDI, suggesting that in sites with a HDI score > 70 bare ground suddenly increases (Figure 19). 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 (Table 10; Figure 19). Mean cover of litter was quite variable under reference conditions yet was still useful to discern those sites from highly impacted ones. Four of the six metrics had a negative response to the HDI. Mean C (natives) showed the strongest correlation to the HDI (r[s] = -0.71) and mean cover of litter exhibited the weakest (r[s] = -0.55; Table 9, Figure 19). The remaining six metrics had a correlation coefficient (positive or negative) near 0.60.

The fen VIBI showed a strong response to the HDI with (r[s] = -0.85; Figure 20). The sites with lowest VIBI scores had the most severe hydrological alterations (Table 10).

Table 7. Rocky Mountain Subalpine-Montane Riparian Shrubland VIBI Model

Metric	Metric Category (basis of calculation)	Metric Calculation	Correlation to Human Disturbance Index*	Min Value	Max Value	95th /5th Percentile of Data	Score Calculation
% non-native	Functional Group (Dominance)	Number of non-native species/total species richness	0.74	0%	33%	2% (5th percentile)	(Max - observed value)/(Max – 5th percentile)
Mean C (natives)	Community-based (Richness)	Sum of C-value of native species/native species richness	-0.70	4.47	6.77	6.57 (95th percentile)	0bserved value/95th percentile
Wetland indicator status (all species)	Functional Group (Dominance)	Sum of wetland indicator values of all species/total species richness [Wetland indicator status categories are assigned values from -5 (OBL), -4 (FACW-), -3 (FACW), -2 (FACW+), etc. to 5 (UPL)]	0.72	-2.69	0.14	-2.32 (5th percentile)	(Max - observed value)/(Max – 5th percentile)
Relative cover of hydrophytes	Functional Group (Dominance)	Sum of cover of hydrophytes (OBL & FACW)/sum of cover of all plants	-0.66	17%	92%	85% (95th percentile)	0bserved value/95th percentile
% native forbs	Functional Group (Richness)	Number of native forb species/total species richness	-0.53	22%	60%	59% (95th percentile)	0bserved value/95th percentile
% native perennial	Functional Group (Richness)	Number of native perennial species/total species richness	-0.76	48%	88%	85% (95th percentile)	0bserved value/95th percentile
Invasive Richness	Functional Group (Richness)	Number of invasive species (invasiveness was identified in Rocchio 2007)	0.78	0	17	1 (5th percentile)	(Max - observed value)/(Max – 5th percentile)
% intolerant species	Community-based (Richness)	Number of intolerant species (those species with a C-value >= 7)/total species richness	-0.60	4%	38%	30% (95th percentile)	0bserved value/95th percentile
% tolerant species	Community-based (Richness)	Number of tolerant species (those species (all) with a C-value <=3)/total species richness	0.76	0%	14%	1% (5th percentile)	(Max - observed value)/(Max – 5th percentile)
						Riparian Shrubland VIBI Score	**Sum of metric scores/9**

*Spearman's Correlation Coefficient was used

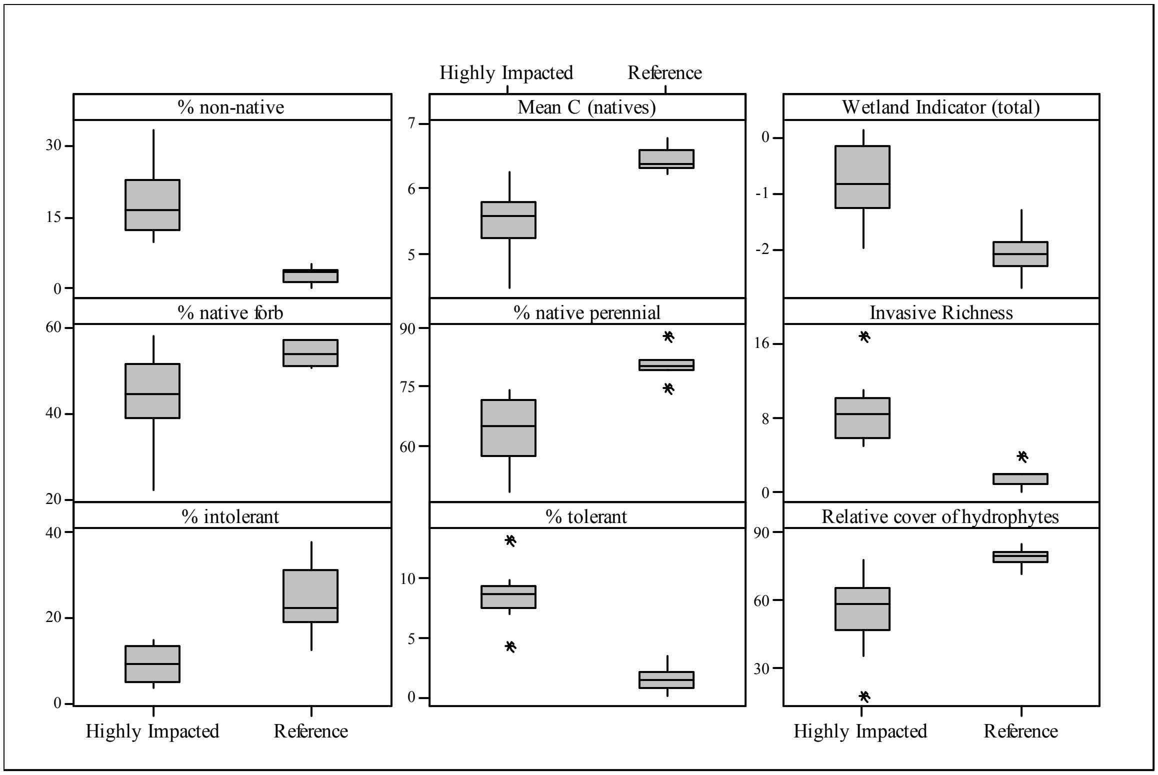


Figure 16. Discriminatory Power of the Riparian Shrubland Metrics (Box represents 75% (top) and 25% (bottom); horizontal line = median; whiskers to upper/lower limit; and asterisks = outliers)

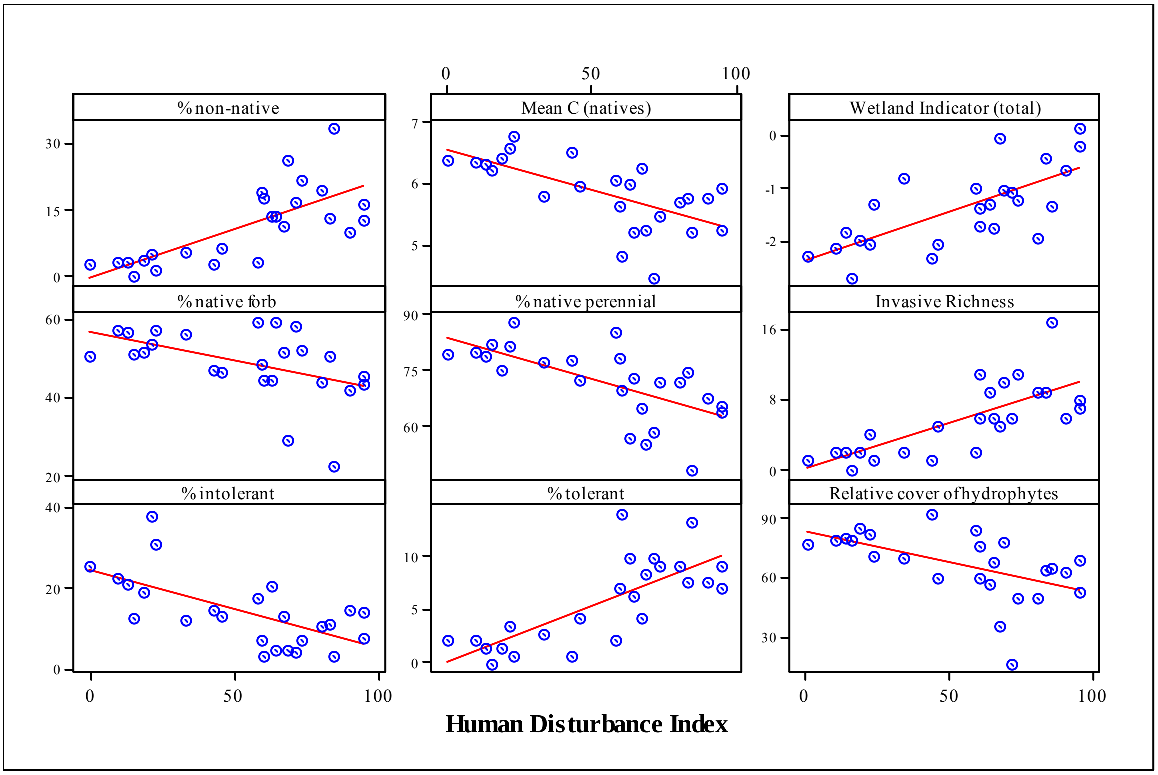


Figure 17. Spearman's Rank Correlation of the Riparian Shrubland Metrics to the Human Disturbance Index

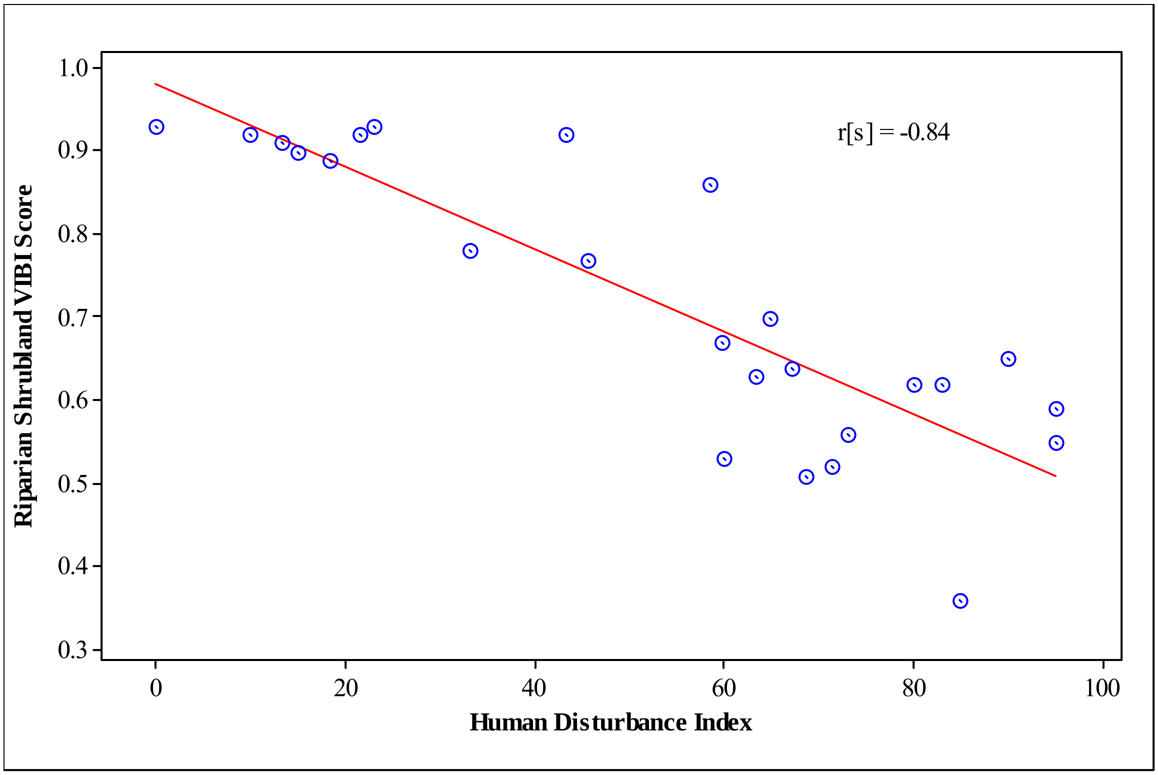


Figure 18. Spearman's Rank Correlation of Riparian Shrubland VIBI to the Human Disturbance Gradient

Table 8. Human Disturbance Index (HDI) Metric Scores for Riparian Shrubland Plots

Plot	VIBI Score	Dominant Stressors	HDI Class*	Human Disturbance Index Score	Buffer and Landscape Alterations Score	Hydrological Alterations Score	Chemical/Physical Alterations Score
Plot 05	0.64	Suburban	Highly Impacted	67	23.1	34	9.9
Plot 06	0.36	Urban	Highly Impacted	84.85	33	23.8	28.05
Plot 09	0.62	Grazing	Highly Impacted	80.05	23.1	28.9	28.05
Plot 10	0.90	Natural	Reference	15	9.9	5.1	0
Plot 11	0.77	Suburban	Impacted	45.52	33	5.1	7.42
Plot 13	0.93	Natural	Reference	23.1	9.9	0	13.2
Plot 18	0.91	Natural	Reference	13.2	13.2	0	0
Plot 19	0.92	Natural	Reference	9.9	9.9	0	0
Plot 23	0.56	Grazing	Highly Impacted	73.1	28.05	17	28.05
Plot 28	0.70	Grazing	Impacted	64.75	23.1	13.6	28.05
Plot 29	0.67	Grazing	Impacted	59.8	23.1	13.6	23.1
Plot 30	0.86	Exurban	Impacted	58.35	28.05	20.4	9.9
Plot 31	0.93	Natural	Reference	0	0	0	0
Plot 33	0.89	Natural	Reference	18.4	9.9	8.5	0
Plot 38	0.78	Suburban	Impacted	33.15	23.1	5.1	4.95
Plot 40	0.92	Recreation	Reference	21.6	16.5	5.1	0

Plot	VIBI Score	Dominant Stressors	HDI Class*	Human Disturbance Index Score	Buffer and Landscape Alterations Score	Hydrological Alterations Score	Chemical/Physical Alterations Score
Plot 41	0.62	Mining	Highly Impacted	83	33	17	33
Plot 43	0.53	Grazing	Impacted	60	16.5	20.4	23.1
Plot 45	0.55	Mining	Highly Impacted	94.9	33	28.9	33
Plot 58	0.92	Mining	Impacted	43.2	16.5	10.2	16.5
Plot 59	0.51	Recreation	Highly Impacted	68.5	23.1	28.9	16.5
Plot 68	0.52	Grazing	Highly Impacted	71.25	28.05	10.2	33
Plot 71	0.59	Suburban	Highly Impacted	94.9	33	28.9	33
Plot 72	0.63	Suburban	Impacted	63.2	23.1	17	23.1
Plot 73	0.65	Suburban	Highly Impacted	89.95	33	28.9	28.05

*HDI class was determined by splitting HDI scores into three equal groups: Reference (≤33), Impacted (34-67), and Highly Impacted (≥68).

4.5.3 Rocky Mountain Subalpine-Montane Extremely Rich Fen VIBI

Six metrics were selected for inclusion in the extremely rich fen VIBI (Table 11). One metric (mean cover of intolerant species) is indicative of community level integrity while the remaining five metrics are indicative of functional groups (Table 11). All but one metric (native annual/perennial ratio) were based on dominance (e.g. % cover) calculations. All metrics were able to distinguish reference from highly impacted sites (Figure 21). Mean cover of native hydrophytes was quite variable for reference but fairly narrow for highly impacted sites (Figure 22). All metrics showed a strong linear response to the HDI (Table 11; Figure 23). Relative cover of annual species showed a strong linear, positive response (r[s] = 0.68) to the HDI (Figure 23) and has strong discriminatory power (Figure 22); however, the range of value for this metric was only 3% (Table 11). Four of the six metrics had a negative response to the HDI. Without consideration of one outlier (Plot 34), mean cover of native hydrophytes showed the strongest correlation (r[s] = -0.69) to the HDI (Table 11; Figure 23). The outlier plot was the only one dominated by shrubs, which occurred on tall hummocks and thus resulted in less hydrophytes cover despite the fact there were no hydrological alterations and the plot was considered a reference site. Since there were no disturbed, shrub dominated extremely rich fen plots in the dataset, its unclear if shrub dominated extremely rich fens would need to be considered separately from herbaceous examples. Mean cover of native perennials exhibited the weakest correlation (r[s] = -0.54) to the HDI (Table 11; Figure 23).

Table 9. Rocky Mountain Subalpine-Montane Fen VIBI Model

Metric	**Metric Category (basis of calculation)**	**Metric Calculation**	**Correlation to HDI***	**Min Value**	**Max Value**	**95th/5th Percentile of Data**	**Score Calculation**
% non-native	Functional Group (Richness)	Number of non-native species/total species richness	0.60	0%	24%	0% (5th Percentile)	(Max - observed value)/(Max – 5th percentile)
Mean cover of dominant native	Functional Group (Dominance)	Sum of cover of dominant native species (cover >= 5%)/number of modules sampled	-0.63	0%	100%	86% (95th Percentile)	0bserved value/95th percentile
Mean C (natives)	Community-based (Richness)	Sum of C-value of native species/native species richness	-0.71	5.0	7.57	7.07 (95th Percentile)	Observed value/95th percentile
Mean cover of hydrophytes	Functional Group (Dominance)	Sum of cover of hydrophytes (OBL & FACW)/number of modules sampled	-0.60	3%	100%	100% (95th Percentile)	0bserved value/95th percentile
Mean cover of bare ground	Functional Group (Dominance)	Sum of cover of bare ground/number of modules sampled	0.62	0%	85%	0% (5th Percentile)	(Max - observed value)/(Max – 5th percentile)
Mean cover of litter	Functional Group (Dominance)	Sum of cover of litter/number of modules sampled	-0.55	1%	85%	79% (95th Percentile)	0bserved value/95th percentile
						Fen VIBI Score	**Sum of metric scores/6**

*Spearman's Correlation Coefficient was used

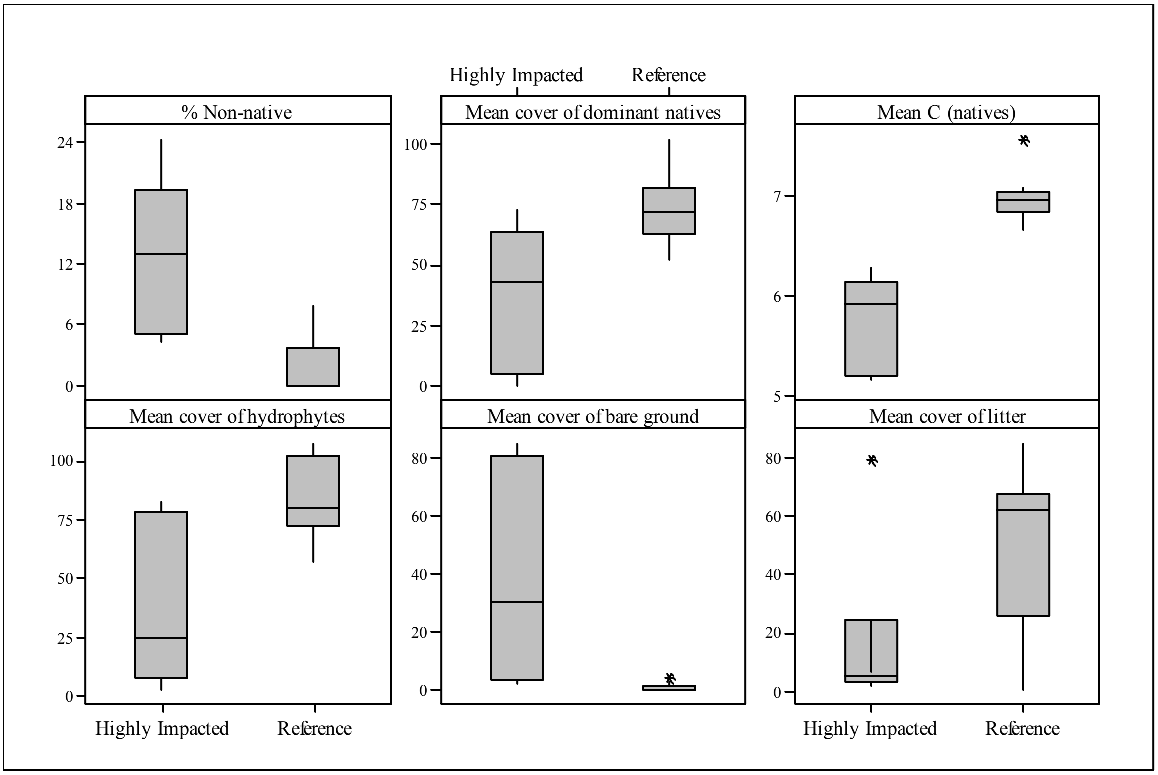


Figure 19. Discriminatory Power of the Fen Metrics (Box represents 75% (top) and 25% (bottom); horizontal line = median; whiskers to upper/lower limit; and asterisks = outliers)

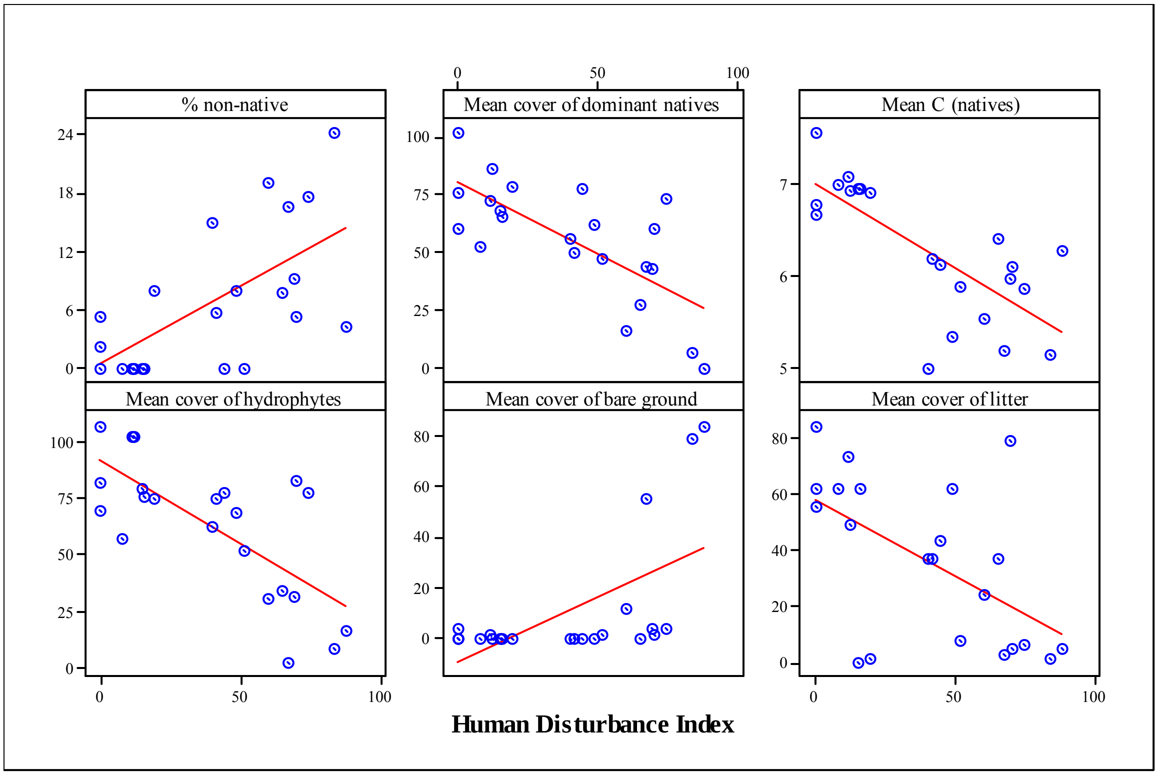


Figure 20. Spearman's Rank Correlation of the Fen Metrics to the Human Disturbance Index

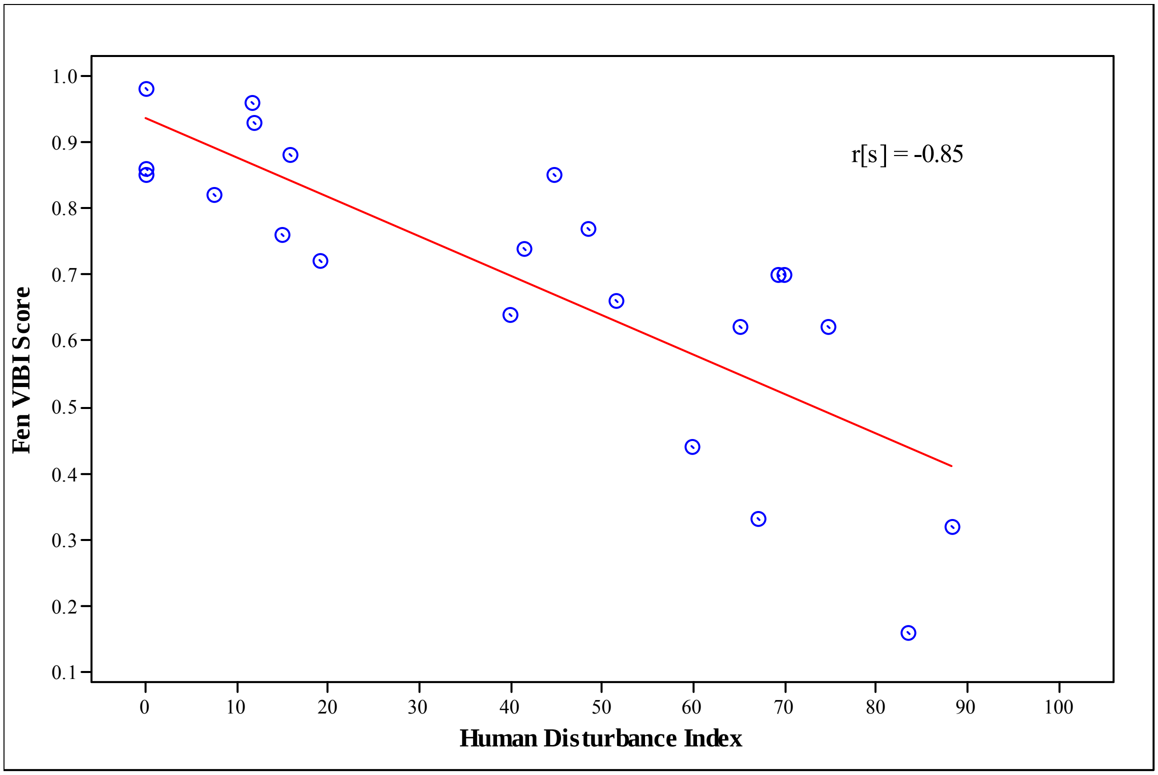


Figure 21. Spearman's Rank Correlation of Fen VIBI to the Human Disturbance Index

Table 10. Human Disturbance Index (HDI) Metric Scores for Fen Plots

Plot	VIBI Score	Dominant Stressors	HDI Class*	Human Disturbance Index Score	Buffer and Landscape Alterations Score	Hydrological Alterations Score	Chemical/Physical Alterations Score
Plot 04	0.72	Natural	Reference	18.97	16.5	0	2.47
Plot 07	0.76	Natural	Reference	14.85	4.95	0	9.9
Plot 17	0.74	Suburban	Impacted	41.35	33	3.4	4.95
Plot 21	0.62	Grazing	Highly Impacted	74.65	33	13.6	28.05
Plot 24	0.44	Grazing	Impacted	59.8	23.1	13.6	23.1
Plot 27	0.88	Natural	Reference	15.75	13.2	2.55	0
Plot 32	0.86	Natural	Reference	0	0	0	0
Plot 37	0.96	Natural	Reference	11.55	11.55	0	0
Plot 46	0.82	Natural	Reference	7.42	7.42	0	0
Plot 48	0.85	Mining	Impacted	44.55	23.1	0	21.45
Plot 50	0.85	Natural	Reference	0	0	0	0
Plot 51	0.98	Natural	Reference	0	0	0	0
Plot 52	0.93	Natural	Reference	11.75	4.95	6.8	0
Plot 54	0.77	Grazing	Impacted	48.45	23.1	20.4	4.95
Plot 56	0.64	Recreation	Impacted	39.8	9.9	6.8	23.1
Plot 61	0.62	Grazing	Impacted	64.95	21.45	20.4	23.1
Plot 70	0.70	Grazing	Highly Impacted	69.9	21.45	20.4	28.05
Plot 74	0.32	Utility Line - site excavated then refilled	Highly Impacted	88.25	28.05	27.2	33

Plot	VIBI Score	Dominant Stressors	HDI Class*	Human Disturbance Index Score	Buffer and Landscape Alterations Score	Hydrological Alterations Score	Chemical/Physical Alterations Score
Plot 75	0.16	Peat Mining	Highly Impacted	83.5	16.5	34	33
Plot 76	0.70	Ditch	Highly Impacted	69.27	16.5	27.2	25.57
Plot 77	0.33	Ditch	Highly Impacted	67	16.5	34	16.5
Plot 78	0.66	Grazing	Impacted	51.35	16.5	6.8	28.05

*HDI class was determined by splitting HDI scores into three equal groups: Reference (≤33), Impacted (34-67), and Highly Impacted (≥68).

The extremely rich fen VIBI showed a strong response (r[s] = -0.69) to the HDI (Figure 24). The two most highly impacted sites were associated with severe hydrological (Plot 26) and physical (Plot 16) alterations (Table 12). As discussed above, the initial sample design focused on three ecological system types (riparian shrublands, fens, and wet meadows) and consequently the additional types (extremely rich fens, slope wet meadows, and riverine wet meadows) identified during the classification analysis did not get sampled with the same intensity as riparian shrublands and fens (Figure 7). Thus, only two highly impacted plots were sampled for extremely rich fens (Figure 24). Although these two plots had similar VIBI scores, the variability associated with highly impacted extremely rich fens can only tentatively be concluded until further data collection occurs and the VIBI is reexamined.

4.5.4 Rocky Mountain Alpine-Montane Slope Wet Meadow VIBI

Five metrics were selected for inclusion in the Slope Wet Meadow VIBI (Table 13). All metrics were clearly able to distinguish reference from highly impacted sites (Figure 25) and showed a linear response to the HDI (Table 13; Figure 26). All but one (relative cover of Poaceae) were negatively correlated to the HDI (Table 13; Figure 26). One metric (mean cover weighted FQI) is indicative of community level integrity and had the strongest correlation (r[s] = -0.87) to the HDI (Table 13). The remaining four metrics are indicative of functional groups (Table 13). All but one metric (perennial richness) were based on dominance (e.g. % cover) calculations. The mean cover of perennials metric is noisy and further data collection from reference quality plots are needed to confirm the usefulness of this metric (Figure 26).

The slope wet meadow VIBI showed a strong response (r[s] = -0.80) to the HDI (Figure 27). Only nine plots were sampled for slope wet meadows and additional data from reference sites are needed to further quantify this VIBI. Grazing was the most common stressor encountered in these wetlands (Table 14).

Table 11. Rocky Mountain Subalpine-Montane Extremely Rich Fen VIBI Model

Metric	Metric Category (basis of calculation)	Metric Calculation	Correlation to HDI*	Min Value	Max Value	95th/5th Percentile of Data	Score Calculation
Mean cover of dominant native	Functional Group (Dominance)	Sum of cover of dominant native species (cover >= 5%)/number of modules sampled	-0.61	10%	70%	65% (95th Percentile)	Observed value/95th percentile
Mean cover of native hydrophytes	Functional Group (Dominance)	Sum of cover of native hydrophytes (OBL & FACW)/number of modules sampled	-0.69 (metric had one outlier which lowered correlation to -0.37; outlier was shrub dominated while other plots were all herbaceous)	24%	81%	76% (95th Percentile)	0bserved value/95th percentile
Relative cover of annuals**	Functional Group (Dominance)	Sum of cover of annual species/sum of cover of all species	0.68	0%	3%	0% (5th Percentile)	(Max - observed value)/(Max – 5th percentile)
Mean cover of intolerant species	Community-based (Dominance)	Sum of cover of intolerant species (those species with a C-value >= 7)/number of modules sampled	-0.60	1%	64%	60% (95th Percentile)	0bserved value/95th percentile
Mean cover of native perennials	Functional Group (Dominance)	Sum of cover native perennials/number of modules sampled	-0.54	28%	75%	73% (95th Percentile)	Observed value/95th percentile
Native Annual/Perennial Ratio	Functional Group (Richness)	Number of annual species/number of perennial species	0.60	0%	13%	0.01 (5th Percentile)	(Max - observed value)/(Max – 5th percentile)
						Extremely Rich Fen VIBI Score	**Sum of metric scores/6**

*Spearman's Correlation Coefficient was used

**Relative cover of annuals metric has a very narrow range. However, because of its strong correlation to the HDI as well as strong discriminatory power, the metric was retained. Repeated sampling needs to occur in order to determine sensitivity of this metric. Thus, it should be used with caution.

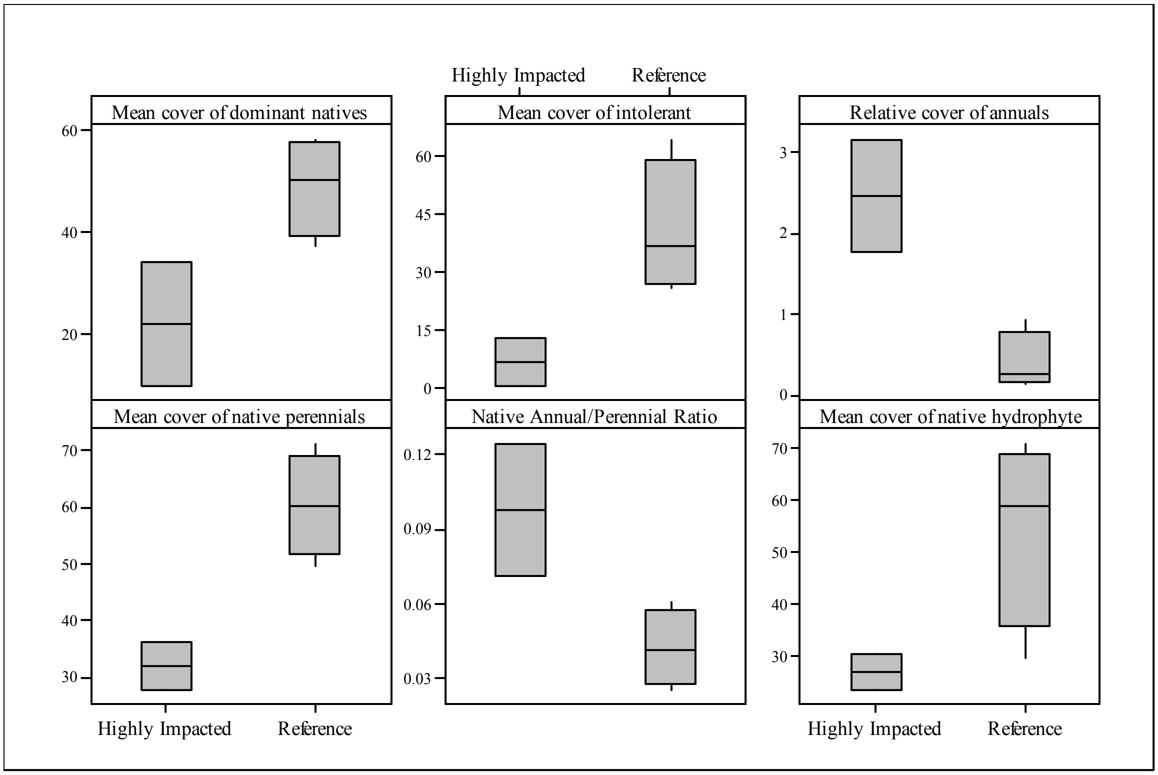


Figure 22. Discriminatory Power of the Extremely Rich Fen Metrics (Box represents 75% (top) and 25% (bottom); horizontal line = median; whiskers to upper/lower limit; and asterisks = outliers)

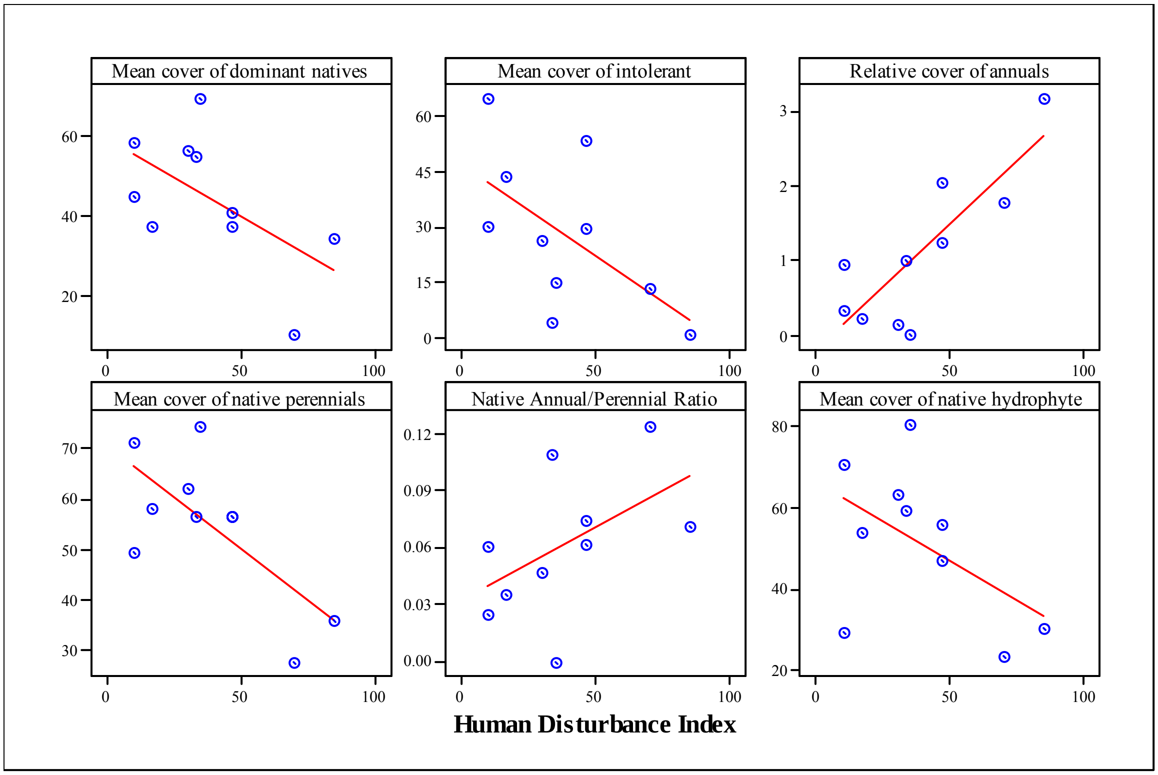


Figure 23. Spearman's Rank Correlation of the Extremely Rich Fen Metrics to the Human Disturbance Index

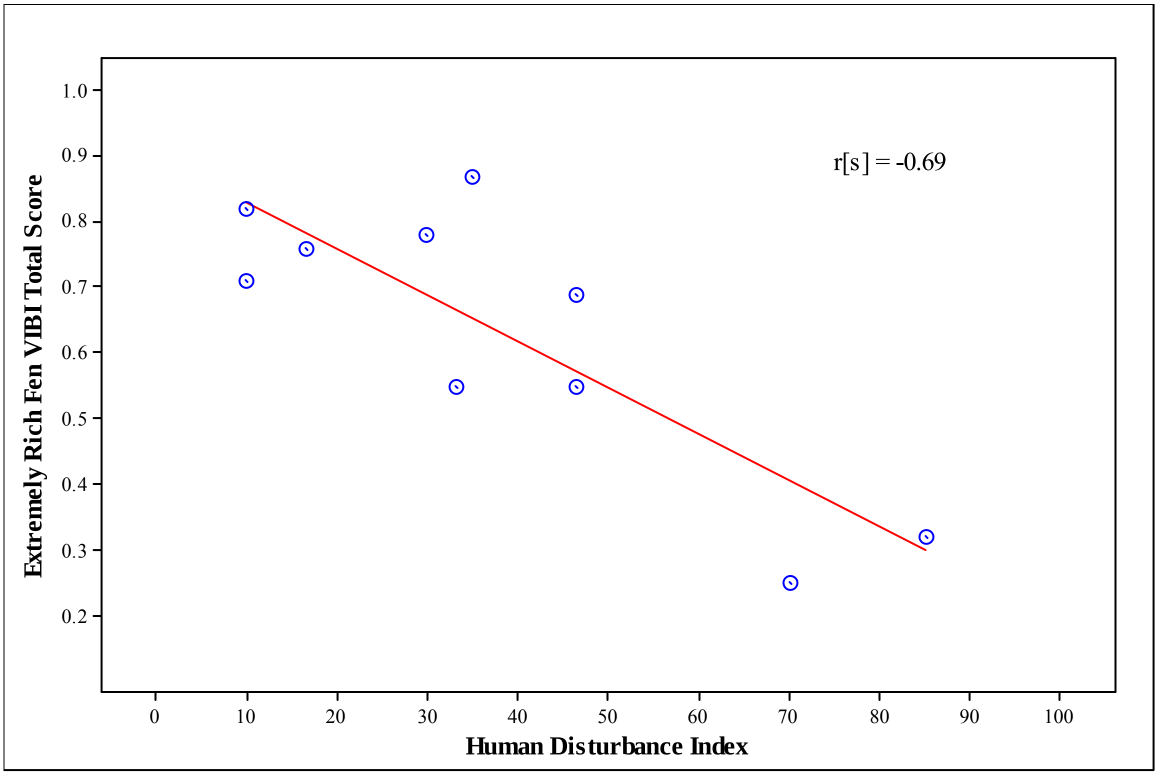


Figure 24. Spearman's Rank Correlation of the Extremely Rich Fen VIBI to the Human Disturbance Index

Table 12. Human Disturbance Index (HDI) Metric Scores for Extremely Rich Fen Plots

Plot	VIBI Score	Dominant Stressors	HDI Class*	Human Disturbance Index Score	Buffer and Landscape Alterations Score	Hydrological Alterations Score	Chemical/Physical Alterations Score
Plot 15	0.82	Natural	Reference	9.9	9.9	0	0
Plot 16	0.25	Peat Mining	Highly Impacted	70.1	9.9	27.2	33
Plot 20	0.76	Natural	Reference	16.5	16.5	0	0
Plot 25	0.78	Grazing	Reference	29.9	13.2	6.8	9.9
Plot 26	0.32	Ditch	Highly Impacted	85.15	28.05	34	23.1
Plot 34	0.71	Natural	Reference	9.9	9.9	0	0
Plot 35	0.87	Grazing	Impacted	34.85	23.1	6.8	4.95
Plot 44	0.69	Grazing	Impacted	46.4	23.1	6.8	16.5
Plot 62	0.55	Grazing	Impacted	46.4	16.5	6.8	23.1
Plot 63	0.55	Grazing	Impacted	33.2	16.5	6.8	9.9

*HDI class was determined by splitting HDI scores into three equal groups: Reference (≤33), Impacted (34-67), and Highly Impacted (≥68).

Table 13. Slope Wet Meadow VIBI Model

Metric	Metric Category (basis of calculation)	Metric Calculation	Correlation to HDI*	Min Value	Max Value	95th/5th Percentile of Data	Score Calculation
Mean cover weighted FQI (native)	Community-based (Dominance)	Cover weighted Mean C-values * SQRT(native species richness) [Cover weighted Mean C = Sum of C-value of each species * its mean cover/total mean cover of all species]	-0.83	4.32	21.39	20.21 (95th Percentile)	Observed value/95th percentile
Mean cover of perennials	Functional Group (Dominance)	Sum of cover of perennial species/number of modules sampled	-0.55	35%	99%	94% (95th Percentile)	Observed value/95th percentile
Perennial Richness	Functional Group (Richness)	Number of perennial species	-0.63	2	43	41 (95th Percentile)	Observed value/95th percentile
Relative cover of Poaceae	Functional Group (Dominance)	Sum of cover of Poaceae species/sum of cover of all plants	0.77	6%	79%	11% (5th Percentile)	(Max - observed value)/(Max – 5th percentile)
Mean cover of rhizomatous species	Functional Group (Dominance)	Sum of cover of rhizomatous species/number of modules sampled	-0.65	5%	62%	61% (95th Percentile)	Observed value/95th percentile
						Slope Wet Meadow VIBI Score	**Sum of metric scores/5**

*Spearman's Correlation Coefficient was used

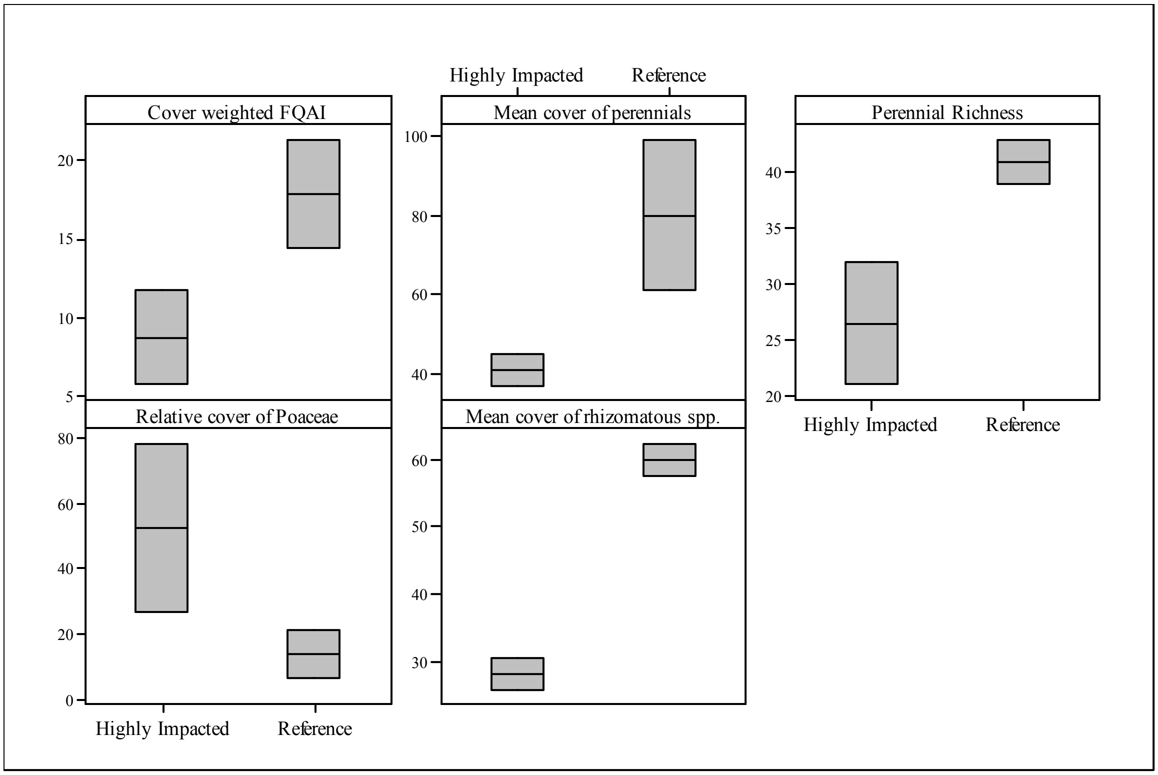


Figure 25. Discriminatory Power of the Slope Wet Meadow Metrics (Box represents 75% (top) and 25% (bottom); horizontal line = median; whiskers to upper/lower limit; and asterisks = outliers)

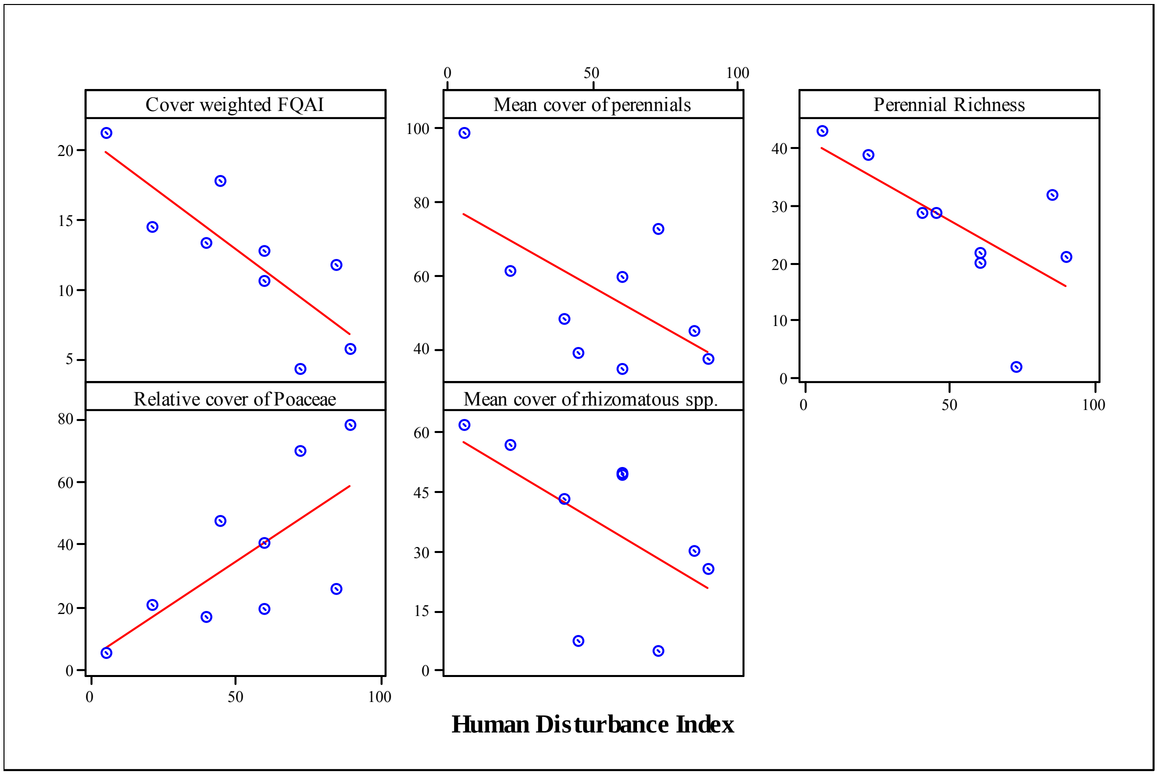


Figure 26. Spearman's Rank Correlation of the Slope Wet Meadow Metrics to the Human Disturbance Index

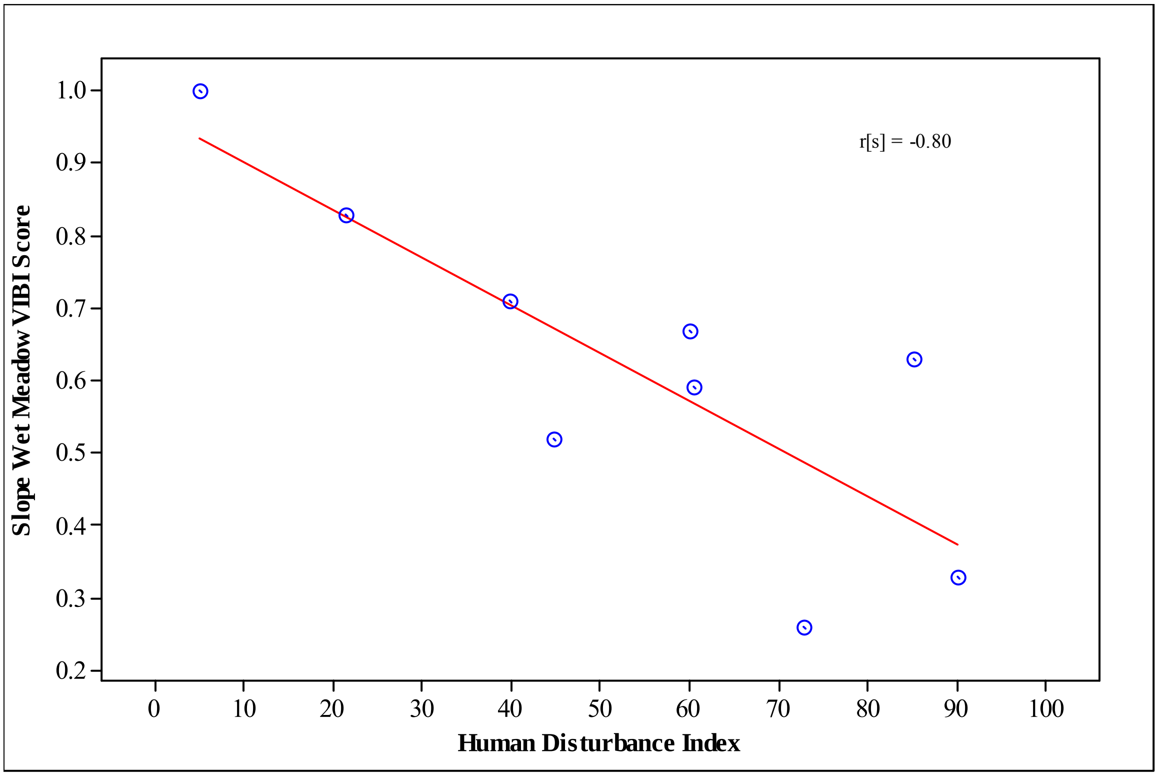


Figure 27. Spearman's Rank Correlation of the Slope Wet Meadow VIBI to the Human Disturbance Index

Table 14. Human Disturbance Index (HDI) Metric Scores for Slope Wet Meadow Plots

Plot	VIBI Score	Dominant Stressors	HDI Class*	Human Disturbance Index Score	Buffer and Landscape Alterations Score	Hydrological Alterations Score	Chemical/Physical Alterations Score
Plot 01	0.71	Recreation	Impacted	39.8	16.5	6.8	16.5
Plot 02	0.67	Grazing	Impacted	60	23.1	20.4	16.5
Plot 22	0.33	Grazing	Highly Impacted	90.1	28.05	34	28.05
Plot 36	0.63	Grazing	Highly Impacted	85.15	23.1	34	28.05
Plot 39	1.00	Natural	Reference	4.95	4.95	0	0
Plot 47	0.26	Mining	Impacted	72.8	33	6.8	33
Plot 53	0.59	Recreation	Impacted	60.4	9.9	34	16.5
Plot 55	0.83	Grazing	Reference	21.45	16.5	0	4.95
Plot 64	0.52	Grazing	Impacted	44.75	16.5	6.8	21.45

*HDI class was determined by splitting HDI scores into three equal groups: Reference (≤33), Impacted (34-67), and Highly Impacted (≥68).

4.5.5 Rocky Mountain Alpine-Montane Riverine Wet Meadow VIBI

Six metrics were selected for inclusion in the riverine wet meadow VIBI (Table 15). All metrics were clearly able to distinguish reference from highly impacted sites (Figure 28). Variability was high in highly impacted sites for all but one metric; wetland indicator status (all species) (Figure 28). All metrics were based on dominance (e.g. % cover) calculations.

All but one (rhizomatous/nonrhizomatous ratio) were positively correlated to the HDI (Table 15; Figure 29). The % non-native, wetland indicator status (total species richness), and relative cover of Poaceae metrics all appear to have a nonlinear response to the HDI although more data is needed to confirm this. Sites with an HDI score of >60 suggest some type of threshold, as metric scores drastically increase as HDI increases (Figure 29).

The riverine wet meadow VIBI showed a strong response (r[s] = -0.80) to the HDI. As with the previous two systems, riverine wet meadows ended up with less plots sampled than for riparian shrublands and fens. The riverine wet meadow VIBI had a narrow range of HDI score relative to the other systems (Figure 29; Table 16). Only nine plots were sampled for riverine wet meadows (Figure 7 & 29) and additional data are needed to further quantify this VIBI. As with slope wet meadows grazing was the most common stressor associated with riverine wet meadows (Table 16).

Table 15. Riverine Wet Meadow VIBI Model

Metric	Metric Category (basis of calculation)	Metric Calculation	Correlation to HDI*	Min Value	Max Value	95th/5th Percentile of Data	Score Calculation
% non-native	Functional Group (Richness)	Number of non-native species/total species richness	0.66	6%	21%	6% (5th Percentile)	(Max - observed value)/ (Max – 5th percentile)
Wetland indicator status (all species)	Functional Group (Richness)	Sum of wetland indicator values of all species/total species richness [Wetland indicator status categories are assigned values from -5 (OBL), -4 (FACW-), -3 (FACW), -2 (FACW+), etc. to 5 (UPL)]	0.58	-3.36	-1.41	-3.36 (5th percentile)	(Max - observed value)/ (Max – 5th percentile)
Invasive Richness	Functional Group (Richness)	Number of invasive species (invasiveness was identified in Rocchio 2007)	0.72	1	8	1.4 (5th Percentile)	(Max - observed value)/ (Max – 5th percentile)
Asteraceae Richness	Functional Group (Richness)	Number of Asteraceae species	0.60	0	13	1.2 (5th Percentile)	(Max - observed value)/ (Max – 5th percentile)
Relative cover of Poaceae	Functional Group (Dominance)	Sum of cover of Poaceae species/sum of cover of all plants	0.59	2%	21%	3% (5th Percentile)	(Max - observed value)/ (Max – 5th percentile)
Rhizomatous/Nonrhizomatous Ratio	Functional Group (Richness)	Number of rhizomatous species/number of nonrhizomatous species	-0.72	0.51	1.2	1.18 (95th Percentile)	Observed value/95th percentile
Riverine Wet Meadow VIBI Score							**Sum of metric scores/6**

*Spearman's Correlation Coefficient was used

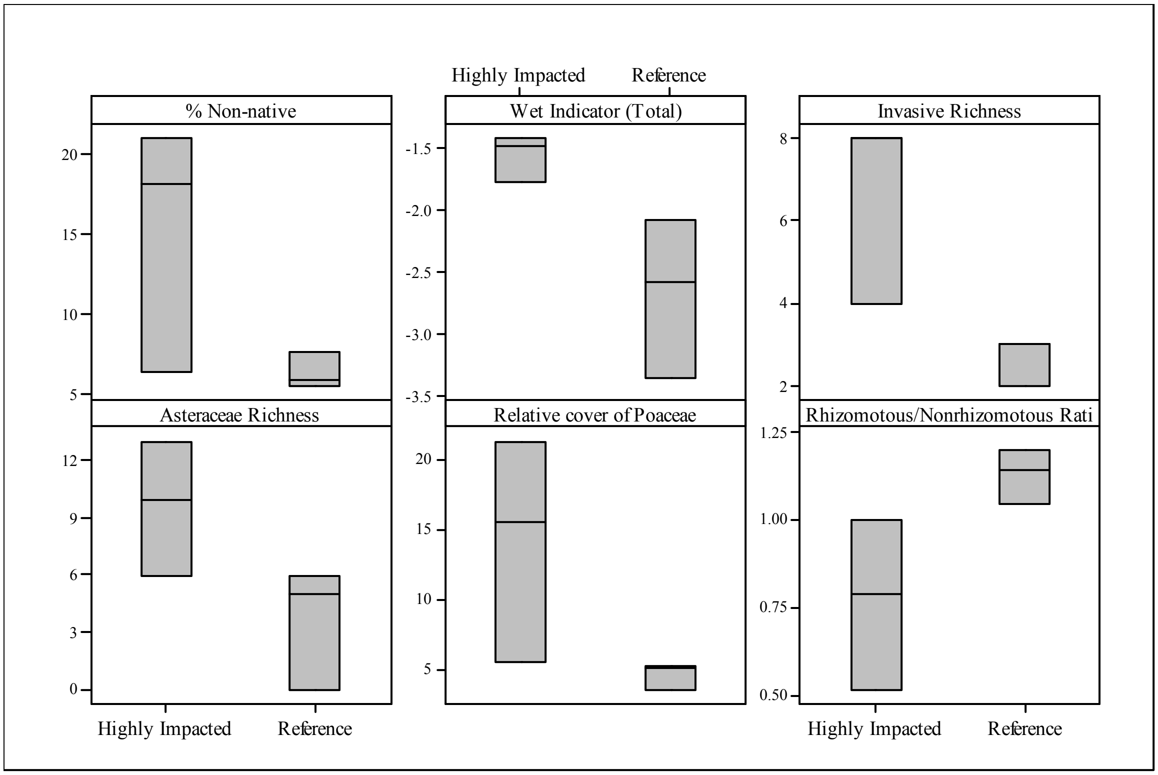


Figure 28. Discriminatory Power of the Riverine Wet Meadow Metrics (Box represents 75% (top) and 25% (bottom); horizontal line = median; whiskers to upper/lower limit; and asterisks = outliers)

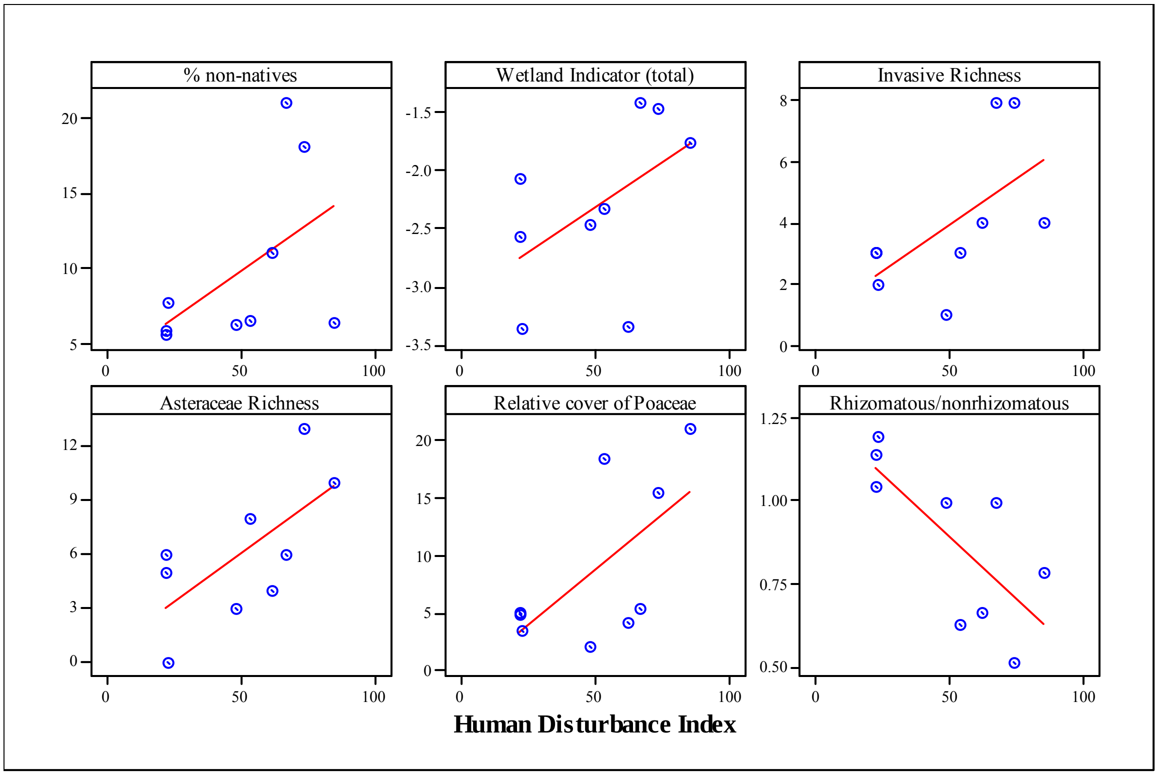


Figure 29. Spearman's Rank Correlation of the Riverine Wet Meadow Metrics to the Human Disturbance Index

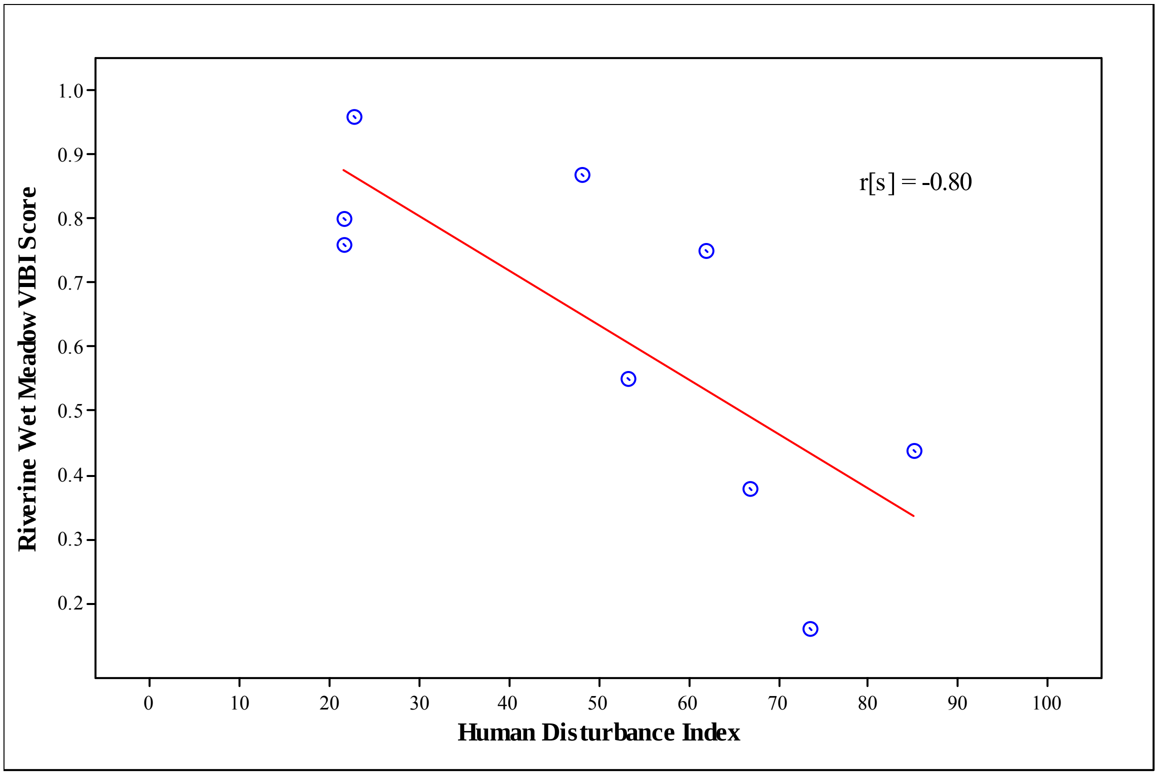


Figure 30. Spearman's Rank Correlation of the Riverine Wet Meadow VIBI to the Human Disturbance Index

Table 16. Human Disturbance Index (HDI) Metric Scores for Riverine Wet Meadow Plots

Plot	VIBI Score	Dominant Stressors	HDI Class*	Human Disturbance Index Score	Buffer and Landscape Alterations Score	Hydrological Alterations Score	Chemical/Physical Alterations Score
Plot 03	0.96	Grazing	Reference	22.5	9.9	7.65	4.95
Plot 08	0.55	Grazing	Impacted	53.2	16.5	13.6	23.1
Plot 14	0.38	Suburban	Highly Impacted	66.7	33	23.8	9.9
Plot 42	0.75	Grazing	Impacted	61.75	21.45	23.8	16.5
Plot 49	0.80	Recreation	Reference	21.45	4.95	0	16.5
Plot 57	0.76	Recreation	Reference	21.45	16.5	0	4.95
Plot 60	0.87	Grazing	Impacted	48	19.8	5.1	23.1
Plot 65	0.44	Grazing/Recreation	Highly Impacted	85	28.05	28.9	28.05
Plot 69	0.16	Grazing	Highly Impacted	73.45	16.5	28.9	28.05

*HDI class was determined by splitting HDI scores into three equal groups: Reference (≤33), Impacted (34-67), and Highly Impacted (≥68).

5.0 DISCUSSION

5.1 Classification

In order to develop a useful VIBI for assessing and monitoring wetland condition, it is necessary to first classify the wetland resource so that natural variability of reference condition sites is minimized. Otherwise, it is very difficult to separate noise (i.e. natural variability) from a useful signal (i.e. vegetation response to human disturbance), the latter being what the VIBI uses to assess and monitor wetland condition.

The nonmetric dimensional scaling ordination and multi-response permutation procedure showed that the reference condition dataset was best classified using NatureServe's ecological system classification (Comer et al. 2003; Rocchio 2006a). Because the ecological system classification utilizes both abiotic and biotic variables as classifying criteria, it essentially incorporates elements of the other classification systems tested (i.e. HGM class/subclass, soil type, and physiognomy). This integrative approach seems to be the reason ecological systems best explained variation in the dataset.

The *a priori* ecological system classification only included three types (wet meadows, fens, and riparian shrublands); however, both classification and metric screening indicated that three additional types (i.e. extremely rich fens, slope and riverine wet meadows) were needed to more clearly explain the dataset. Thus, individual VIBI models were needed for five ecological systems: (1) slope wet meadows; (2) riverine wet meadows; (3) fens; (4) extremely rich fens; and (5) riparian shrublands.

Extremely rich fens, which were distinguished from fens based on their unique geochemistry and resulting floristics, were one of these new types. Although wet meadows did group together in the NMS ordination, metric screening indicated that this type needed to be split, based on HGM class, into slope wet meadows and riverine wet meadows. Since the other ecological system types were essentially associated with one HGM Class (e.g. fens and extremely rich fens (slope) and riparian shrublands (riverine)) it is no surprise that HGM Class would also be an important constraining variable for wet meadows.

Photos of both reference condition and highly impacted examples of each of the five ecological system types are shown in Figures 30-39.

Plot 10
VIBI Score = 0.90
HDI = 15

Plot 18
VIBI Score = 0.91
HDI = 13.2

Figure 31. Examples of Reference Rocky Mountain Subalpine-Montane Riparian Shrublands

Plot 6
VIBI Score = 0.36
HDI = 84.85
This plot was sandwiched
between a parking lot, I-70, and
Hwy. 9

Plot 9
VIBI Score = 0.62
HDI = 80.05
This plot was heavily grazed and has
experienced hydrological alterations
due to upstream ditches/diversions

Figure 32. Examples of Highly Impacted Rocky Mountain Subalpine-Montane Riparian Shrublands

Plot 46
VIBI Score = 0.82
HDI = 7.42

Plot 50
VIBI Score = 0.85
HDI = 0.00

Figure 33. Examples of Reference Rocky Mountain Subalpine-Montane Fens

Plot 75
VIBI Score = 0.16
HDI = 83.5
Peat mining removed most of the peat profile.
Notice exposed cobbles.

Plot 77
VIBI Score = 0.33
HDI = 67
Fen has been dewatered from nearby ditches
(now dominated by *Artemisia frigida*)

Figure 34. Examples of Highly Impacted Rocky Mountain Subalpine-Montane Fens

Plot 15
VIBI Score = 0.82
HDI = 9.9

Plot 20
VIBI Score = 0.76
HDI = 16.5

Figure 35. Examples of Reference Rocky Mountain Subalpine-Montane Extremely Rich Fens

Plot 16
VIBI Score = 0.25
HDI = 70.1
Peat mining has occurred in this extremely rich fen; notice exposed cobbles

Plot 26
VIBI Score = 0.32
HDI = 80.15
This extremely rich fen was bisected by ditch (middle of photo); foreground is dewatered fen; fen in background (Plot 25) was minimally impacted by ditch

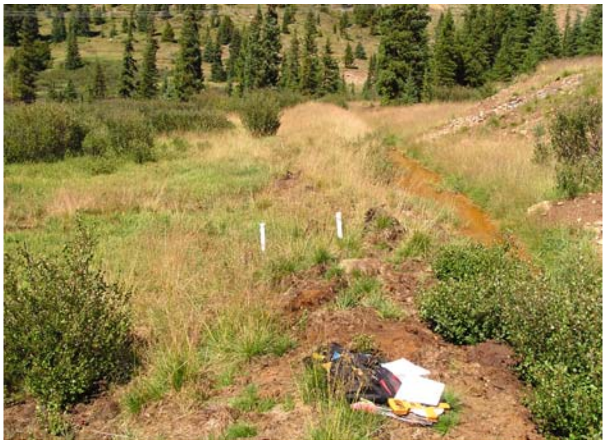
Figure 36. Examples of Highly Impacted Rocky Mountain Subalpine-Montane Extremely Rich Fens

Plot 39
VIBI Score = 1.0
HDI = 4.95

Plot 55
VIBI Score = 0.83
HDI = 21.45

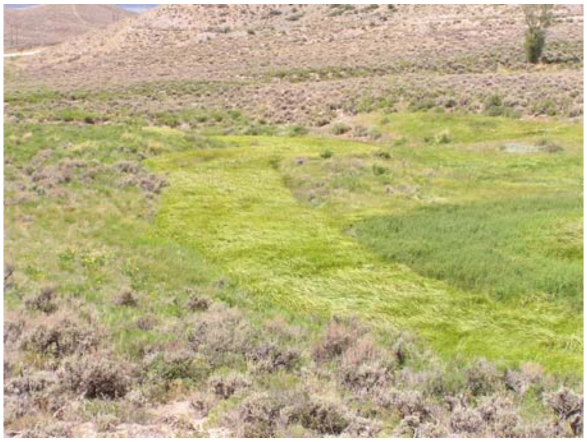
Figure 37. Examples of Reference Rocky Mountain Alpine-Montane Slope Wet Meadows

Plot 22
VIBI Score = 0.33
HDI = 90.1
Upslope ditches have diverted stream flow which contributed to groundwater discharge in this meadow. The site was also heavily grazed.



Plot 47
VIBI Score = 0.26
HDI = 72.8
This meadow was impacted by acid mine drainage (orange flow in ditch on right side of photo) as well as physical disturbances from mining activities

Figure 38. Examples of Highly Impacted Rocky Mountain Alpine-Montane Slope Wet Meadows



Plot 03
VIBI Score = 0.96
HDI = 22.25

Plot 57
VIBI Score = 0.76
HDI = 21.45

Figure 39. Examples of Reference Rocky Mountain Alpine-Montane Riverine Wet Meadows

Plot 14
VIBI Score = 0.38
HDI = 66.7
This riverine wet meadow was surrounded by suburban development and an upstream road crossing was affecting fluvial dynamics.

Plot 69
VIBI Score = 0.16
HDI = 73.45
A large ditch (right side of photo) dewatered much of this meadow; the spoil from the ditch (middle of photo) also affected the site

Figure 40. Examples of Highly Impacted Rocky Mountain Alpine-Montane Riverine Wet Meadows

5.2 Vegetation Metrics

A total of 480 species were identified in the 75 plots sampled (Appendix D), with 354 (mean of 62/plot) species found in riparian shrublands, 246 (mean of 30/plot) in fens, 190 (mean of 46/plot) in slope wet meadows, 171 (mean of 37/plot) in riverine wet meadows, and 130 (mean of 41/plot) in extremely rich fens. The utility of a VIBI is its ability to reduce the information each species conveys regarding ecological condition into much smaller functional groupings (i.e. metrics). Thus, the diversity found in the dataset was able to be reduced into 25 sensitive and ecological meaningful metrics (out of 133 vegetation attributes that were tested) for the five VIBIs.

Classification had a strong affect on the types of metrics that were found useful for VIBI development. Some generalities could be observed among the various wetland types but for the most part, each ecological system resulted in a unique assemblage of metrics. HGM classes showed patterns associated with the kind of data used for metric calculations. For example, riverine systems were dominated by richness-based metrics (67% of riparian shrublands metrics; 83% of riverine wet meadows metrics) while slope systems were dominated by dominance (e.g. % cover)-based metrics (67% of fen metrics; 83% of extremely rich fens metrics; and 80% of slope wet meadow metrics). Since riverine systems are dynamic they are much more diverse (as indicated above by the number of species), then human disturbances might be expected to decrease natural richness but increase non-native richness. It may be that because slope wetlands have less natural disturbances (lack of flooding, scouring, etc.) they tend to be dominated by competitive, clonal species such as beaked sedge (*Carex utriculata*), water sedge (*Carex aquatilis*), and analogue sedge (*Carex simulata*) or aggressive non-clonal species such as tufted hairgrass (*Deschampsia cespitosa*) which could result in lower species diversity. Human disturbance results in a substantial shift in these competitors and may explain why all slope types shared dominance-based metrics.

Floristic Quality Assessment based metrics were found useful for riparian shrublands, fens, and slope wet meadows. Mean C (natives) was found useful for riparian shrublands and fens while mean cover weighted FQI (native) was useful in slope wet meadows. Percent (%) intolerant and % tolerant, which are essentially the extreme ends of the C-value gradient, were also found useful in the riparian shrubland VIBI. It was surprising that FQA-based metrics were not useful for the extremely rich fen and riverine wet meadows VIBI. However, weak correlations between Mean C (native) and mean cover weighted mean C (natives) and the HDI for extremely rich fens may be the result of a lack of data from highly impacted sites. Additional data collection may reveal a stronger correlation with the HDI for this wetland type. Alternatively, the C values assigned to many of the extremely rich fens species may have been inflated due to their occurrence in a rare wetland type as opposed to each species' ability to tolerate disturbance. In other words, when C values were assigned by the Colorado Floristic Quality Assessment Panel the fact that many of the extremely rich fens species are rare may have inadvertently resulted in those species being assigned high C values, when in fact the C values represent fidelity to high quality natural conditions, not rarity. All of the FQA-based metrics for riverine wet meadows showed no discriminatory power or weak correlation to the HDI.

The 25 metrics selected for the five VIBI models are surrogate measures of many different ecological processes, functions, and stressors. For example, the wetland indicator status and mean cover of hydrophytes metrics are indicative of hydrological integrity. Although, not diagnostic of the specific component of the hydrological regime which has been altered, these metrics do indicate that the wetland/riparian has less flooding, lower water tables, or more inundation relative to reference conditions.

The mean cover of litter metric used in the fen VIBI relates to primary production and consequently nutrient cycling. As human disturbance increases, the amount of litter declines, which could be a result of a concurrent decrease in mean cover of dominant natives and/or increased aeration and thus higher decomposition due to pugging by livestock. Grazing and hydrological alterations may be associated with such declines since both can result in lower primary production and shift in competitive species.

Another fen VIBI metric, mean cover of bare ground, has been found to be associated with a shift in carbon dynamics (Cooper et al. 2005). For example, in fens of the southern Sierra Nevada Mountains, a negative carbon balance (i.e. loss of peat) resulted when bare ground increased above 20% (Cooper et al. 2005).

The percentage of non-native species metric could be indicative of many different stressors and shifts in ecological processes such as increased nutrients (Zedler and Kercher 2004), grazing (Jones 2005; Kaufmann et al. 1983), alterations in hydrology (Zedler and Kercher 2004), soil disturbances and sedimentation (Zedler and Kercher 2004), and populations of non-natives in the buffer and/or larger landscape.

The metrics associated with the Floristic Quality Assessment theoretically represent a shift in complexity of abiotic and biotic processes relevant to reference conditions (Swink and Wilhelm 1994). In other words, as ecological relationships are simplified by human disturbance the number of tolerant species increases at a site thereby lowering FQA indices (Wilhelm and Ladd 1988; Wilhelm and Masters 1996).

The native annual/perennial ratio, which increases with human disturbance, likely reflects an increase in physical disturbances, since annuals thrive in such conditions. Similarly, mean cover of perennials and perennial richness are likely responding, negatively, to the same disturbances. These metrics are likely associated with stressors such as grazing, recreation, and other physical disturbances which create disturbed bare ground and allow for increased opportunities for annual species to thrive (Galatowitsch et al. 2000). For example, Grime (2001) notes that many annual species are considered to ruderal (e.g. weedy) species due to their ability to thrive in highly disturbed and productive environments, conditions which are found in disturbed wetlands. Mean cover of rhizomatous species and rhizomatous/non-rhizomatous metrics, which were selected for the two wet meadow VIBIs, may also be responding to similar stressors, as they decrease with increasing human disturbance. The shift in these metrics may also highlight a functional shift from vegetative to sexual reproduction in the wetland.

Another metric shared between the two wet meadow VIBIs is relative cover of Poaceae. Although not correlated with % non-native species, the increase in relative cover of Poaceae species with increased human disturbance is likely due to the dominance of non-native grasses such as redtop (*Agrostis gigantea*) and Kentucky bluegrass (*Poa pratensis*), which thrive under disturbed conditions. It appears that % non-native metric did not show a corresponding response (or, in the case of Slope Wet Meadows, was not chosen as a metric) due to the fact that only a few species account for such a large change in cover. In other words, a relatively small increase in non-native richness was not as correlated with the HDI as the much larger change in mean cover of these species.

Asteraceae richness was found to be a useful metric for riverine wet meadows. This appears to be due to species such as meadow thistle (*Cirsium scariosum*), Canada thistle (*Cirsium arvense*), dandelion (*Taraxacum officinale*), yarrow (*Achillea millefolium var. occidentalis*), various species of pussytoes (*Antennaria* spp.), and daisies (*Erigeron lonchophyllus*) increasing with human disturbance.

5.3 Vegetation Index of Biotic Integrity Models

Vegetation indices of biotic integrity offer a cost-effective means of evaluating the effect of multiple stressors on the ecological condition of wetlands and riparian areas. Because the VIBI models integrate multiple quantitative vegetation metrics, they provide a much more thorough and consistent assessment of vegetation response to human disturbance than traditional measures of species diversity or percentage of native species, etc.

The five VIBI models developed for this project all had strong correlations to an independent measure of human disturbance (Table 17). They clearly were able to differentiate between reference and highly impacted sites and offer an effective method for detecting change in ecological condition for these Southern Rocky Mountain wetland types. However, until the minimum detection level for each VIBI is calculated (to be conducted during Phase 3) it is not known how many different classes of biological condition (Davies and Jackson 2006) they can significantly detect. In addition, although strong correlations were found between VIBI scores and the HDI for extremely rich fens, slope wet meadows, and riverine wet meadows, until more data can be collected from these ecological systems, their VIBI models should be considered tentative since they were all based on approximately ten plots.

Table 17. Summary of Human Disturbance Index and Vegetation Index of Biotic Integrity Scores for All Ecological Systems

Ecological System	**Correlation to HDI***	**Range of Human Disturbance Index** 0 (reference)-100 (highly impacted)		**Range of VIBI Scores** 0.0 (highly impacted)-1.0 (reference)	
		Min	**Max**	**Min**	**Max**
Riparian Shrublands	-0.83	0	94.9	0.36	0.93
Fens	-0.85	0	88.25	0.16	0.98
Extremely Rich Fens	-0.71	9.9	85.15	0.25	0.87
Slope Wet Meadows	-0.80	4.95	90.1	0.26	1.0
Riverine Wet Meadows	-0.80	21.45	85	0.16	0.96

*Spearman's Rank correlation coefficient

Each of the VIBI models, except the slope wet meadow, had a higher Spearman's rank correlation coefficient than any of their component metrics. This suggests that each VIBI effectively integrates the different types of ecological responses to human disturbance. The slope wet meadow VIBI had one metric (mean cover weighted FQI (native)) with a higher correlation coefficient than its' own VIBI. Since each of the VIBIs' component metrics are reflective of underlying ecological processes and/or stressors, the VIBI models also provide a strong surrogate measure of ecological integrity.

Appendix E summarizes the results of each VIBI model in the form of a quick-reference guide as to what vegetation characteristics describe reference and highly impacted examples of each ecological system type.

5.4 Application of the Vegetation Index of Biotic Integrity Models

VIBI models can be used for a variety of assessment and monitoring applications. VIBI scores can be used to conduct ambient monitoring of wetland condition within a targeted area, can be used to prioritize wetlands for protection, restoration, or management efforts, and can be used to monitor the effectiveness of these actions. For example, all of the wetland types targeted in this project are relatively common features in the montane to subalpine zones of the Southern Rocky Mountains. As such, and because of the fairly common presence of stressors in many locations of this ecoregion, these wetland types are subjected to multiple stressors such as hydrological alterations (dams, diversions, impoundment, etc.), grazing, roads, mining, recreation, and increasing human population growth/urbanization. Considering that these wetland types are mostly headwater wetlands and riparian areas, these stressors and their effect on ecological condition could have a disproportionate affect on many ecological functions and services in their respective watersheds. For example, headwater wetlands are cited as having disproportionate impact on a watershed's water quality, water supply, biodiversity, etc. (American Rivers 2003; Day 2003). The VIBI models provide a tool to help prioritize permitting, management, restoration, and protection for these wetlands so that individual wetland and watershed water quality objectives can be effectively attained.

In addition, the VIBI can be used for specific wetland regulatory needs such as defining reference conditions and delineating designated use categories and biocriteria. Once such a framework is established, periodic monitoring of wetland VIBI scores is then possible and would allow an assessment of the status and trends of wetland condition an activity required of each State in Section 305 (b) of the Clean Water Act. It would also allow the identification of impaired wetlands meeting the definition of Waters of the U.S., as required by Section 303(d) of the Clean Water Act. For example, agencies in Minnesota and Wisconsin have developed VIBI model to assist them in developing water quality standards and designated uses, to assess wetland condition, and determine status and trends in wetland water quality (Gernes and Helgen 2002; Lillie et al. 2002). In Ohio, VIBI models have been used to establish wetland tiered aquatic life uses as well as associated biocriteria and have also been used to establish wetland mitigation performance standards (Mack 2004a; Mack et al. 2004). Cuyahoga Valley National Park has adopted this same VIBI for use in their Vital Signs Monitoring Protocol for wetlands (Fraser 2005). The National Park Service has also shown interest in adapting the VIBI models developed in this report into a wetland monitoring protocol for National Parks in the Rocky Mountains (Billy Schweiger, personal communication).

The VIBI and Ecological Integrity Assessments will be used by the Colorado Natural Heritage Program (CNHP) to improve our methodology in prioritizing wetland and riparian conservation targets. CNHP also intends to use the VIBI to calibrate a few other wetland assessment tools currently in development. These include Level 1 (remote-sensing based) and Level 2 (rapid, field assessments) methods which, when calibrated with a quantitative measure such as the VIBI, will provide alternative methods to assess wetland condition depending on the project objectives or the time, money, and level of effort available to the user. CNHP will also seek funding to utilize the VIBI, as well as the Level 1 and Level 2 assessments associated with the Ecological Integrity Assessments (Faber-langendoen et al. 2006; Rocchio 2006a) to conduct probabilistic surveys of wetland condition throughout select watersheds in Colorado. These results will be made available to the Colorado Department of Public Health (CDPHE) so that the data are available for reporting wetland status/trends to the U.S. EPA should CDPHE decide to use them as such.

The VIBI and associated Ecological Integrity Assessments could be used by the Colorado Division of Wildlife to assist in the identification of high-quality wetlands and riparian habitats. Although these assessments are not tailored to specific species habitat needs, high-quality wetlands and riparian areas do serve as excellent habitat for any species that would naturally utilize such ecological systems.

The potential role VIBI and Ecological Integrity Assessment can play in compensatory mitigation is discussed in the next section.

5.5 Integration of Vegetation Index of Biotic Integrity and Functional Assessment

In Section 1.2, the origin, purpose, and applications of condition assessments, such as the VIBI, were discussed. Below, a similar background is given for wetland functional assessments followed by suggestions of why and how the two approaches (condition and functional assessment) should be integrated to provide a more comprehensive approach to maintaining the chemical, physical, and biological integrity of our Nation's wetland resource.

5.5.1 What is a Function Assessment?

The Oxford English dictionary defines function as "an activity that is natural to or the purpose of a person or thing". The application of this definition to wetland assessment has focused on two different scales of assessing "function": within and among wetland ecosystems. Some consider ecological functions as ecological rates or processes which occur within an ecosystem such as plant productivity, hydrodynamics, trophic interactions, disturbance regimes, and biogeochemical cycling as well as evolutionary processes such as gene flow (Noss (1990; Cole 2002; Stevenson and Hauer 2002). Noss (1990) also points out that ecological function, along with composition and structure constitute the three primary attributes of ecosystems. Thus, from this perspective ecological functions are one aspect of ecosystem integrity. Others offer a perspective from a larger scale, in that they consider functions as something an ecosystem provides, i.e. their purpose, to other ecosystems. For example, de Groot (1992) describes ecological functions as "the capacity of natural processes and components to provide goods and services that satisfy human needs", clearly a utilitarian perspective. A National Research Council (1995) report noted that "functions of wetlands often have effects beyond the wetland boundary." The National Research Council's (2001) definition of wetland function states "wetland structure, location in the watershed, and the resulting hydrological, geochemical, and biological processes related to that structure and location give rise to certain wetland functions". Building on the external effects (i.e. functions) of internal, ecological processes, the NRC (2001) report states that wetland functional assessments provide a foundation to assess what consequences out-of-kind mitigation might have on watershed processes as well as providing suggestions on how to best locate and design wetland mitigation to attain the desired functions of a watershed. The Society of Wetland Scientists' definition (SWS 2000) of wetland function is: "The fundamental forces that maintain wetland ecosystems are the hydrology, geomorphic setting, physical processes (e.g., fire, sediment movement), biological processes (e.g., competition, decomposition, predation), and biogeochemical processes (e.g., nutrient cycling). These fundamental forces interact *to perform* the ecological functions and produce the structure that we associate with wetlands." Smith et al. (1995) simplify things by stating that functions are what wetlands do. All of these definitions focus on the ecological *purpose* wetlands play in the landscape.

In other words, functions can be considered at the scale in which they contribute to the ecological condition *of the wetland itself* or those that concern the ecological role or *purpose a wetland serves* in the landscape in which it is embedded. There is no doubt the two scales are correlated, but within the context of an assessment of ecological integrity the two assumptions can result in very different results and may explain much of the confusion behind wetland functional assessments and their association with "values" or ecological services (Karr 1998; Mack et al. 2004) despite their purported purpose of measuring ecological integrity (Brinson 1996; Brinson et al. 1995, Smith et al. 1995).

In summary, condition-based assessments such as the VIBI focus on internal ecological functions or processes while many functional assessments place emphasis on functions that wetlands provide within the context of a larger ecological landscape such as a watershed. The issue is not which definition is correct as they both have merit, rather for what purposes are each considered relevant? In terms, of "maintaining and restoring the chemical, physical, and biological integrity of our Nation's Waters", is it better to assess the internal ecological processes which define the ecological condition of a wetland (i.e. a Water of the U.S.) or the ecological role a wetland serves in a larger context (i.e. the benefits it provides to other Waters of the U.S.)?

5.5.2 Application of Function Assessments

In the regulatory context, wetland functions have mostly been considered in terms of their ecological role or purpose within a landscape. Section 404 of the Clean Water Act (CWA) concerns the permitting of "discharges of dredged or fill material into Waters of the U.S." (Danielson 1998). Although the objective of the CWA is to "maintain and restore chemical, physical, and biological integrity", monitoring and assessment associated with Section 404 activities has mostly focused on the terms "functions" and "values". The assessment of other Waters, such as streams and lakes, do not focus on the "external" concept of ecological functions. For example, as Mack et al. (2004) have poignantly noted, the idea of assessing particular stream functions such as a "fishery" or a "pollutant abatement" function is simply nonexistent in the stream monitoring approach. Why has wetland assessment proceeded down a different path?

Ainslie (1994) provides an overview of the role wetland functional assessment plays in CWA regulatory programs, however there is no discussion as to why "functions", in lieu of other measures of ecological integrity, were chosen as the currency to measure attainment of the CWA objectives. One potential explanation may be that, due to the importance of educating the public regarding the benefits wetlands provide to society (i.e. ecological services), an emphasis on ecological function materialized (Karr 1998; Mack et al. 2004). This may also have created much confusion about what constitutes an ecological function versus an ecological service. Although the difference between the two has been defined, the utilitarian perspectives of many functional assessments remain (Karr 1998). Supreme Court Justice Kennedy appears to agree that a utilitarian rationale is used to legally justify the inclusion of wetlands as a Waters of the U.S. since "wetlands perform critical functions related to the integrity of other Waters-such as pollutant trapping, flood control, and runoff storage" (*Rapanos et ux et al. vs. United States* 547 U.S.___ (2006)). Justice Kennedy appears to be suggesting that a wetland's ecological integrity is only deserving of the Clean Water Act's legislative protection if the wetland's function and ecological role can benefit other Waters of the U.S. In addition, as a result of recent U.S. Supreme Court Decisions (e.g. SWANCC and *Rapanos*), the jurisdictional status of isolated wetlands is now tied to them having a "significant nexus" to other Waters of the U.S. (Downing et al. 2003; Leibowitz 2003). The ecological functions provided by these isolated wetlands may be argued to be that "significant nexus". This would provide some regulatory oversight over further loss of these wetlands, but their importance remains tied to the benefits they provide as opposed to recognizing their importance as a "Waters" themselves.

Compensatory mitigation, a component to the Section 404 regulatory program which entails permitting the destruction or degradation of a wetland if another similar functioning wetland can be enhanced, restored, or created (NRC 2001), follows a similar rationale. To determine success, assessment tools have been developed to estimate the functional capacity of wetlands lost or gained. Some assessments focus on the potential or capacity of a wetland to absorb or buffer the effects of human activities from impacting other water resources such as streams. Other functional assessments have placed emphasis on the maximization of selected functions (i.e. flood attenuation; retention of pollutants) which have societal value (e.g. ecological services) while undervaluing many other components to ecological integrity, such as the integrity of biological communities (Karr 1998).

Considering that many wetlands are legally defined Waters of the U.S., the CWA objective of maintaining and restoring ecological integrity clearly implies that a wetland's internal ecological integrity is of equal importance to the "benefits" it provides to other waters. This is reflected in Section 305(b) of the Clean Water Act which provides protection of wetlands based on their ecological condition as embedded within antidegradation standards (Karr 1998). Biological assessment is increasingly being used to measure attainment of those standards. Since biological endpoints are integrative they should be an integral component to wetland assessment associated with Section 404 activities, since without them there is no way to document loss, protection, or restoration of biological integrity (Karr 1998). The conventional notion, often implied in functional assessments, that wetlands are places that *provide* habitat for plants and animals has deviated from the ideas presented in the CWA, which is that the biota are an essential component to the existence of a wetland and is the reason why biological integrity was included as apart of the CWA's objective to maintain and restore the chemical, physical, and biological integrity of our Nation's waters (Karr 1998). For functional assessments to achieve attainment of the Clean Water Act's goal of protecting ecological integrity, Karr (1998) argues it must include measurable biological endpoints since ecological functions are only one component to ecological integrity (Noss 1990).

5.5.2 Integration of Ecological Integrity and Function Assessments

Consider a wetland located between intense agricultural activity and a navigable river. A functional assessment might conclude that this wetland has a high capacity to perform nutrient and sediment retention which provides an important buffering function for water quality improvement in the river. However, a condition-based assessment might conclude that the same scenario is resulting in the wetland receiving excess inputs of sediment and nutrient and thus degrading its ecological integrity. Assuming both the wetland and river are legal Waters of the U.S., which wetland assessment method answers the question as to whether the objective of "maintaining and restoring the chemical, physical, and biological integrity of the Nation's waters" is being attained?

One could assume that a wetland with ecological integrity is performing all of its expected ecological functions at their expected capacity and that those functions have a more or less negative linear relationship with increasing degradation (Mack et al. 2004). Some argue that making a connection between ecological integrity and ecological function is unnecessary given that measures of biological integrity, which integrate chemical and physical processes, provide a direct measurement pertaining to attainment of the objective of the Clean Water Act (Karr 1998). Nonetheless, there are many valued ecological services provided by wetlands which aren't captured by measurements of ecological integrity. The NRC (2001) compensatory mitigation report found that the goal of "no net loss of wetlands is not being met for wetland functions by the mitigation program" and went on to state that "restoration of community structure (i.e. biological integrity) and wetland functions (i.e. chemical and physical integrity) should be considered in setting goals and assessing outcomes" associated with wetland mitigation, highlighting the need of a more effective approach to achieve and measure functional replacement (Mack et al. 2004). It seems that integrating an assessment of ecological integrity, ecological function, and ecological services would provide a broader perspective concerning the impacts human disturbances have on the "chemical, physical, and biological integrity" of *all Waters of the US.*

Stevenson and Hauer (2002) recommend that HGM and IBI approaches be linked in a national framework to provide a more comprehensive approach for assessing wetlands for both Sections 404 and 305(b) reporting, as well as for other natural resource applications. They note that both approaches have many things in common such as a goal of assessing ecological integrity by evaluating degradation of ecological structure, both rely heavily on classification in order to constrain natural variability, the concept of reference condition plays a key role, and both include measurements of chemical, physical, and biological integrity. Although many measurements are the same, the use of those measurements in the calculation of indicators and the assumptions of what information those indicators provide are very different (Stevenson and Hauer 2002). HGM assumes that if the structural indicators of "function" are intact then a site has the potential to support the biological community that should be present. IBI makes the reverse assumption and assumes if the biological community is intact then the site will perform the various functions expected for its wetland type (Stevenson and Hauer 2002). However, Leibowitz 2003 notes that degradation of wetland ecological integrity does not necessarily result in a linear response of ecological function noting that the type and severity of degradation will result in different degrees of impact to functions. Likewise, functional performance is not necessarily correlated with, and thus is not a useful metric to measure, ecological integrity (Hruby 2001; Fennessy et al. 2004). To compensate for these nonlinear relationships, the integration of both functional and condition-based approaches could provide a more comprehensive assessment, and thus a more accurate approach to ensuring the objective to maintain and restore the chemical, physical, and biological integrity of our Nation's waters is achieved.

5.53 Examples and Potential Opportunities for Integrated Wetland Assessments

One approach to integrating HGM and an IBI would entail incorporating an IBI model, such as the VIBI, as a variable and/or functional capacity index into an HGM assessment. Section 401 of the CWA provides a readily available, but ineffectively used, tool for integrating both functional and condition assessments into wetland permitting programs (Steiner et al. 1994). For example, compensatory mitigation might require that mitigation projects meet or exceed antidegradation criteria in addition to replacement of ecological function. Similarly, designated uses (as defined by biological or ecological criteria) could also be incorporated into compensatory mitigation to ensure replacement of wetland condition.

Since wetlands of the same regional area and HGM type are assumed to share similar functions it would be expected that response of such functions to degradation would be similar (Leibowitz 2003) allowing an inference of which functions are lost for a given HGM type given a specific suite of stressors. However, many functions have a nonlinear response to degradation and are dependent on the type and severity of stressors (Leibowitz 2003). To validate which functions are specifically impacted by degradation and to what degree, a pilot study designed to assess functional performance and ecological condition of a population of similar HGM wetland types across a disturbance gradient, could be conducted. The specific functions which are correlated to degradation and their relationship with specific stressors could be identified. Once these relationships have been identified, , condition-assessments, such as the VIBI, could be used in conjunction with HGM profiling to provide a cumulative effects assessment of wetland functions and condition within a watershed context (Johnson 2005).

The Ohio EPA has integrated elements of functional and condition-based assessments into their wetland permitting program by utilizing an HGM classification to group wetlands according to expected similar functions and then using multimetric indices (e.g. VIBI), unique to each HGM and vegetation type, to assess ecological condition (Mack et al. 2004). This approach assumes that if the size, type, and condition of an impacted wetland are replaced then there is a “very strong assurance” that functional performance has been replaced as well (Mack et al. 2004).

Using rule-based decisions to prioritize permitting and restoration projects based on a wetland’s ecological integrity and functional performance is another integration approach (Brooks et al. 2006). For example, sites possessing ecological integrity would be prioritized for protection. Sites whose ecological integrity has been degraded yet remains feasible to restore would be targeted for restoration with “ecological integrity” as the performance standard. When ecological integrity has been severely degraded or is no longer restorable then desired or targeted ecological functions and services would be the performance standard for any mitigation activities.

In Colorado, there are opportunities to integrate functional assessments such as the Functional Assessment for Colorado Wetlands (FacWet; Johnson *In Progress*) with condition-based assessments such as the VIBI and the Ecological Integrity Assessment (EIA) approach (Faber-Langendoen et al. 2006) to implement a rule-based framework for improving wetland management and restoration decisions.

5.6 Next Steps

The VIBI models presented in this report all showed a strong correlation to human disturbance and thus are able to detect ecological change resulting from human stressors. However, additional analysis needs to occur to determine exactly how many biological condition classes each VIBI can detect. Such information will further enhance the utility of the VIBI models for monitoring and assessing wetland condition both within a regulatory and non-regulatory context. During the next iteration of this project (Phase 3 – 2007/2008), a bootstrap analysis will be conducted to test the statistical precision and power (Fore et al. 1994) of each VIBI. This process will provide an estimate of measurement error and interannual variance which allows for a determination of the number of statistically significant biological condition classes each VIBI can detect (e.g. minimal detection level).

Phase 3 of this project (2007-2008) will also validate the VIBI models presented in this report. Classification and Regression Trees (CART) will be used to assess the accuracy of the ability of the VIBI models presented in this report in predicting membership of data collected in Phase 3 (summer 2007) into the biological condition classes identified during the bootstrapping analysis.

The VIBI models presented here do not apply to all the wetland and riparian types found in the Southern Rocky Mountains. For example, other ecological system types such as the Rocky Mountain Subalpine-Montane Riparian Woodlands, Rocky Mountain Lower Montane Riparian Woodlands and Shrublands, North American Arid Freshwater Marsh, and Intermountain Basin Playas all occur within this ecoregion. The latter three mostly occur in the mountain parks and the large intermountain valleys found in the ecoregion (e.g. North Park, Middle Park, San Luis Valley, Gunnison Basin, etc.) and will be targeted next for VIBI development. Completing these systems would provide a VIBI for most wetland types in the Southern Rocky Mountains, allowing a more comprehensive, large-scale assessment of wetland condition throughout ecoregion.

REFERENCES

Adamus, P.R. 1992. Choices in monitoring wetlands. *In* Ecological Indicators. D.H. McKenzie, D.L. Hyatt, and V.J. McDonald (editors) Elsevier Applied Science, New York, NY. Pp 571-592.

Adamus, P.R., T.J. Danielson, A. Gonyaw. 2001. Indicators for Monitoring Biological Integrity of Inland Freshwater Wetlands: A Survey of North American Technical Literature (1990-2000). EPA843-R-01. Office of Water, Wetlands Division, U.S. Environmental Protection Agency. Washington D.C.

Ainslie, W.B. 1994. Rapid Wetland Functional Assessment: Its Role and Utility in the Regulatory Arena. Water, Air, and Soil Pollution 77:433-444.

American Rivers (and Sierra Club). 2003. Where Rivers Are Born: The Scientific Imperative for Defending Small Streams and Wetlands. Publication by American Rivers and Sierra Club. Online: http://www.americanrivers.org/site/DocServer/WhereRiversAreBorn1.pdf?docID=182

Angermeier, P.L. and J.R. Karr. 1994. Biological integrity versus biological diversity as policy directives. Bioscience 44(10): 690-697.

Arp, C.D. and D.J. Cooper. 2004. Analysis of Sediment Retention in Western Riverine Wetlands: The Yampa River Watershed, Colorado, USA. Environmental Management 33(3): 318-330.

Azous, A.L. and R.R. Horner. 2001. Wetlands and Urbanization: Implications for the Future. CRC Press, LLC. Boca Raton, FL.

Bailey, R.C., R.H. Norris, and T.B. Reynoldson. 2004. Bioassessment of Freshwater Ecosystems: Using the Reference Condition Approach. Kluwer Academic Publishers. Norwell, MA.

Barbour, M.T., J. Gerritsen, G.E. Griffith, R. Frydenborg, E. McCarron, J.S. White, and M.L. Bastian. 1996. A framework for biological criteria for Florida streams using benthic macroinvertebrates. Journal of North American Benthological Society 15(2): 185-211.

Baxter, C.V., K.D. Fausch, and W.C. Saunders. 2005. Tangled webs: reciprocal flows of invertebrate prey link streams and riparian zones. Freshwater Biology 50: 201-220.

Bedford, B.L., M.R. Walbridge, and A. Aldous. 1999. Patterns in Nutrient Availability and Plant Diversity of Temperate North American Wetlands. Ecology 80(7): 2151-2169.

Blocksom, K.A. 2003. A Performance Comparison of Metric Scoring Methods for a Multimetric Index for Mid-Atlantic Highlands Streams. Environmental Management 31(5): 670-682.

Blocksom, K. A., J. P. Kurtenbach, D. J. Klemm, F. A. Fulk, and S. M. Cormier. 2002. Development and Evaluation of the Lake Macroinvertebrate Integrity Index (LMII) for New Jersey Lakes and Reservoirs. Environmental Monitoring and Assessment **77**:311-333.

Brinson, M.M. 1993. A Hydrogeomorphic Classification for Wetlands. Technical Report WRP-DE-4. Washington D.C. U.S. Army Corps of Engineers.

Brinson, M. M. 1996. Assessing wetland functions using HGM. National Wetlands Newsletter. 18:10-16.

Brinson, M. M., F. R. Hauer, L. C. Lee, W. L. Nutter, R. D. Rheinhardt, R. D. Smith, and D. Whigham. 1995. *Guidebook for Application of Hydrogeomorphic Assessments to Riverine Wetlands.* Technical Report WRP-DE-11. US Army Corps of Engineers Waterways Experiment Station, Vicksburg, MS.

Brinson, M. M., L. C. Lee, W. Ainslie, R. D. Rheinhardt, G. G. Hollands, R. D. Smith, D. F. Whigham, and W. B. Nutter. 1997. Common misconceptions of the hydrogeomorphic approach to functional assessment of wetland ecosystems: Scientific and technical issues. *Wetlands Bulletin* June: 16– 21.

Brooks, R.P., D.H. Wardrop, and C.A. Cole. 2006. Inventorying and Monitoring Wetland Condition and Restoration Potential on a Watershed Basis with Examples from Spring Creek Watershed, Pennsylvania, USA. Environmental Management 38:673-687.

Bryce, S.A., R.M. Hughes, and P.R. Kaufmann. 2002. Development of a Bird Integrity Index: Using Bird Assemblages as Indicators of Riparian Condition. Environmental Management 30(2): 294-310.

Bureau of Land Management. 2004. Proper Functioning Condition Data. Kremmling, CO Field Office.

Calow, P. 1992. Can Ecosystems Be Healthy? Critical considerations of concepts. Journal of Aquatic Ecosystem Health 1: 1-5

Campbell, D.E. 2000. Using Energy Systems Theory to Define, Measure, and Interpret Ecological Integrity and Ecosystem Health. Ecosystem Health 6(3): 181-204

Carlisle, B.K., A.L. Hicks, J.P. Smith, S.R. Garcia, and B.G. Largay. 1999. Plants and Aquatic Invertebrates as Indicators of Wetland Biological Integrity in Waquoit Bay Watershed, Cape Cod. Environment Cape Cod 2(2): 30-60

Carsey, K., D. Cooper, K. Decker, and G. Kittel. 2001. Comprehensive Statewide Wetlands Classification and Characterization: Wetland Plant Associations of Colorado. Colorado Natural Heritage Program, Colorado State University, Fort Collins, CO.

Carsey, K., G. Kittel, K. Decker, D. J. Cooper, and D. Culver. 2003. *Field Guide to the Wetland and Riparian Plant Associations of Colorado.* Colorado Natural Heritage Program, Fort Collins, CO.

Chronic, H. 1980. Roadside Geology of Colorado. Mountain Press, Missoula, MT.

Cole, C.A. 2002. The assessment of herbaceous plant cover in wetlands an indicator of function. Ecological Indicators 2: 287-293.

Cole. C.A. 2006. HGM and wetland functional assessment: Six degrees of separation from the data? Ecological Indicators 6(3): 485-493.

Collins, J.N., E. Stein, M. Sutula, R. Clark, A.E. Fletcher, L. Greneir, C. Grosso, and A. Wiskind. 2006. California Rapid Assessment Method (CRAM) for Wetlands and Riparian Habitats v.4.0, User's Manual and Scoring Forms. Online at: http://www.wrmp.org/cram.html

Comer, P., D. Faber-Langendoen, R. Evans, S. Gawler, C. Josse, G. Kittel, S. Menard, M. Pyne, M. Reid, K. Schulz, K. Snow, and J. Teague. 2003. Ecological Systems of the United States: A Working Classification of U.S. Terrestrial Systems. NatureServe, Arlington, VA.

Comer, P., K. Goodin, A. Tomiano, G. Hammerson, G. Kittel, S. Menard, C. Nordman, M. Pyne, M. Reid, L. Sneddon, and K. Snow. 2005. Biodiversity Values of Geographically Isolated Wetlands in the United States. NatureServe, Arlington, VA.

Cooper, D.J. 1990. Ecology of Wetlands in Big Meadows, Rocky Mountain National Park, Colorado. U.S. Fish and Wildlife Service, Biological Report 90(15).

Cooper, D.J. 2005. Analysis of the Strawberry Lake fen complex, Arapaho National Forest, Colorado. Unpublished Report prepared for the U.S. Forest Service, Fort Collins, CO. Dept. of Forest, Rangeland, and Watershed Stewardship, Colorado State University, Fort Collins, CO.

Cooper, D.J. and E. Gage. In progress. Historic Range of Variation Assessment for Wetland and Riparian Ecosystems (Draft), U.S. Forest Service Region 2. Colorado State University, Fort Collins, CO.

Cooper, D.J., R.A. Chimner, and E.C. Wolf. 2005. Livestock Use and Sustainability of Southern Sierra Nevada Fens. Unpublished report prepared for the Inyo National Forest. Colorado State University, Fort Collins, CO.

Costanza, R., B.G. Norton, and B.D. Haskell. 1992. Ecosystem Health: New Goals for Environmental Management. Island Press, Washington D.C.

Cowardin, L. M., V. Carter, F.C. Golet, and E.T. LaRoe. 1979. Classification of Wetlands and Deepwater Habitats of the United States, U. S. Department of the Interior, Fish and Wildlife Services, Office of Biological Services, Washington D.C.

Cronk, J.K. and M.S. Fennessy. 2001. Wetland Plants: Biology and Ecology. CRC Press, LLC. Boca Raton, FL.

Danielson, T.J. 1998. Wetland Bioassessment Fact Sheets. EPA 843-F-001. U.S. Environmental Protection Agency. Office of Wetlands, Oceans, and Watersheds, Wetlands Division, Washington, D.C. 22 pp.

Davies, S.P. and S.K. Jackson. 2006. The Biological Condition Gradient: A Descriptive Model for Interpreting Change in Aquatic Ecosystems. Ecological Applications 16(4): 1251-1266.

Day, F. 2003. Society of Wetland Scientist's Reply to the U.S. Environmental Protection Agency's "Advanced Notice of Proposed Rulemaking on the Clean Water Act Definition of Waters of the United States". Memo published in Society of Wetland Scientist Bulletin, June 2003.

De Groot, R.S. (1992). Functions of Nature. The Netherlands: Wolters-Noordhoff.

DeKeyser, E.S., D.R. Kirby, and M.J. Ell, 2003. An index of plant community integrity: development of the methodology for assessing prairie wetland plant communities. Ecological Indicators 3: 119-133.

Delaware Department of Natural Resources and Environmental Control. 2005. Delaware Rapid Assessment Procedure V. 2.0: User's Manual and Data Sheets. Dover, DE.

Denevan, W.M. 1992. The Pristine Myth: The Landscape of the Americas in 1492. Annals of the Association of American Geographers 82(3): 369-385.

Downing, D.M., C. Winer, and L.D. Wood. 2003. Navigating Through Clean Water Act Jurisdiction: A Legal Review. Wetlands 23(3): 475-493.

Elmore, W. and B. Kauffman. 1994. Riparian and Watershed Systems: Degradation and Restoration. *In*: Ecological implications of livestock herbivory in the west. Society of Range Mgmt. Denver, Colo.

Faber-Langendoen, D., J. Rocchio, M. Shafale, C. Nordman, M. Pyne, J. Teague, and T. Foti. 2006. Ecological Integrity Assessment and Performance Measures for Wetland Mitigation. NatureServe, Arlington VA. Available online at: http://www.natureserve.org/getData/eia_integrity_reports.jsp *Note:* Rocky Mountain Wetland/Riparian Ecological Integrity Assessment Scorecards are also available online at: http://www.cnhp.colostate.edu/reports.html

Fennessy, M.S., A.D. Jacobs, and M.E. Kentula. 2004. Review of Rapid Methods for Assessing Wetland Condition. EPA/620/R-04/009. U.S. Environmental Protection Agency, Washington, D.C.

Ferreira, M.T., P.M. Rodriguez-Gonzalez, F.C. Aguiar, and A. Albuquerque. 2005. Assessing biotic integrity in Iberian rivers: Development of a multimetric plant index. Ecological Indicators 5:137-149.

Flenniken, M., R.R. McEldowney, W.C. Leininger, G.W. Frasier, and M.J. Trlica. Hydrologic responses of a montane riparian ecosystem following cattle use. Journal of Range Management 54: 567-574.

Fore, L.S., J.R. Karr, and L.L. Conquest. 1994. Statistical Properties of an Index of Biological Integrity Used to Evaluate Water Resources. Canadian Journal of Fisheries and Aquatic Science 51: 1077-1087

Fraser, L.H. 2005. Wetland Monitoring Protocol for the Cuyahoga Valley National Park, Ohio. Unpublished report prepared for the U.S. Department of Interior, National Park Service.

Frey, D.G. 1975. Biological integrity of water-An historical approach. Pages 127-140 *In* R.K. Ballentine and L.J. Guarraia (editors). The Integrity of Water: Proceedings of a Symposium. U.S. Environmental Protection Agency, Office of Water and Hazardous Materials. Washington D.C.

Fulton, G.W., J.L. Richardson, and W.T. Baker. 1986. Wetland Soils and Vegetation. North Dakota Research Report, Research Report #106, Fargo, ND.

Galatowitsch, S.M., D.C. Whited, R. Lehtinen, J. Husveth, and K. Schik. 2000. The vegetation of wet meadows in relation to their land use. Environmental Moniotoring and Assessment 60: 121-144.

Gernes, M. C. and J. C. Helgen, 2002. Indexes of biotic integrity (IBI) for Large Depressional Wetlands in Minnesota. Unpublished report prepared for U.S. EPA. Minnesota Pollution Control Agency, Biological Monitoring Program, Environmental Outcomes Division, St. Paul, Minnesota.

Goslee, S.C., R.P. Brooks, and C.A. Cole. 1997. Plants as indicators of wetland water source. Plant Ecology 131:199-206.

Griffith, M.B., B.H. Hill, F.H. McCormick, P.R. Kaufmann, A.T. Herlihy, and A.R. Selle. 2005. Comparative application of application of indices of biotic integrity based on periphyton, macroinvertebrates, and fish to southern Rocky Mountain streams. Ecological Indicators 5: 117-136.

Grime, J.P. 2001. Plant Strategies, Vegetation Processes, and Ecosystem Properties. Second Edition. John Wiley and Sons, LTD. West Sussex, England.

Guntenspergen, G.R., S.A. Peterson, S.G. Liebowitz, and L.M. Cowardin. 2002. Indicators of Wetland Condition for the Prairie Pothole Region of the United States. Environmental Monitoring and Assessment 78:229-252.

Hauer, F.R., B.J. Cook, M.C. Gilbert, E.J. Clairain Jr., and R.D. Smith. 2002. A Regional Guidebook for Applying the Hydrogeomorphic Approach to Assessing Wetland Functions of Riverine Floodplains in the Northern Rocky Mountains. U.S.Army Corps of Engineers, Engineer Research and Development Center, Environmental Laboratory, Vicksburg, MS. ERDC/EL TR-02-21.

Heidel, B. and S. Laursen. 2003. Botanical and ecological inventory of peatlands sites on Shoshone National Forest. Unpublished report prepared for U.S. National Forest Service. Wyoming Natural Diversity Database. Laramie, WY.

Herman, K.D., L.A. Masters, M.R. Penskar, A.A. Rezenick, G.S. Wilhelm, and W.H. Brodowicz. 1997. Floristic Quality Assessment: Development and Application in the State of Michigan (USA). Natural Areas Journal 17(3): 265-279.

Hobbs, R.J. 1997. Can we use plant functional types to describe and predict responses to environmental change? *In* Plant Functional Types: Their Relevance to Ecosystem Properties and Global Change. T.M. Smith, H.H. Shugart, and F.I. Woodward (editors). Cambridge University Press. Cambridge, UK. Pp. 66-90

Hruby, T. 2001. Testing the Basic Assumption of the Hydrogeomorphic Approach to Assessing Wetland Functions. Environmental Management 27(5): 749-761

Jenkins, R.E. 1996. Natural Heritage Data Center Network: Managing Information for Managing Biodiversity. In Biodiversity in Managed Landscapes: Theory and Practice R.C. Szaro and D.W. Johnston (editors). Pp. 176-192. Oxford University Press. New York, NY.

Johnson, J.B. 1996. Environmental Function, Vegetation, and the Effects of Peat Mining on a Calcareous Fen in Park County, Colorado. Unpublished report prepared for the U.S. Environmental Protection Agency, Region VIII and Park County Department of Public Health. Department of Biology, Colorado State University, Fort Collins, CO.

Johnson, J.B. 2005. Hydrogeomorphic Wetland Profiling: An Approach to Landscape and Cumulative Impact Analysis. EPA/620/R-05/001. U.S. Environmental Protection Agency, Washington D.C.

Johnson, A.S. and S.H. Anderson (2003, December 9). Wilson's Warbler (*Wilsonia pusilla pileolata*): a technical conservation assessment. [Online]. USDA Forest Service, Rocky Mountain Region. Available: http://www.fs.fed.us/r2/projects/scp/assessments/wilsonswarbler.pdf

Jones, W.M. 2004. Using Vegetation to Assess Wetland Condition: a multimetric approach for temporarily and seasonally flooded depressional wetlands and herbaceous-dominated intermittent and ephemeral riverine wetlands in the northwestern glaciated plains ecoregion, Montana. Report to the Montana Department of Environmental Quality and the U.S. Environmental Protection Agency. Montana Natural Heritage Program, Helena, MT. 34 pp. plus appendices.

Jones, W. M. 2005. A vegetation index of biotic integrity for small-order streams in southwestern Montana and a floristic quality assessment for western Montana wetlands. Report to the Montana Department of Environmental Quality and U.S. Environmental Protection Agency, Montana Natural Heritage Program, Helena, Montana. 29 pp. plus appendices.

Kantrud, H.A., G.L. Krapu, G.A. Swanson. 1989. Prairie Basin Wetlands of the Dakotas: A Community Profile, U.S. Fish and Wildlife Service Biological Report 85.

Karr, J.R. 1981. Assessment of biotic integrity using fish communities. Fisheries 6(6): 21-27.

Karr, J.R. 1991. Biological integrity: A long neglected aspect of water resource management. Ecological Applications 1(1): 66-84

Karr, J.R. 1994. Landscapes and management for ecological integrity. Pages 229-254 *In* K.C. Kim and R.D. Weaver (editors). Biodiversity and Landscapes: A Paradox of Humanity. Cambridge University Press.

Karr, J.R. 1996. Ecological integrity and ecological health are not the same. Pages 97-110 *In* P.C. Schulze (editor). Engineering within Ecological Constraints. National Academy Press, Washington D.C.

Karr, J.R. 1998. Seeking Suitable Endpoints: Biological Monitoring for Wetland Assessment. Unpublished report prepared for the U.S. Environmental Protection Agency, Region 10. Seattle, WA. University of Washington, Seattle, WA.

Karr J.R. and D.R. Dudley. 1981. Ecological perspective on water quality goals. Environmental Manager 5:55-68.

Karr, J.R., K.D. Fausch, P.L. Angermeier, P.R. Yant, and I.J. Schlosser. 1986. Assessing biological integrity in running waters: a method and its rationale. Special Publication 5. Illinois Natural History Survey, Champaign, IL.

Karr, J. R. and E. W. Chu. 1999. *Restoring Life In Running Waters: Better Biological Monitoring.* Island Press, Washington, DC.

Kauffman, J.B., W.C. Krueger, and M. Vavra. 1983. Effects of late season cattle grazing on riparian plant communities. J. Range Manage. 36:685-691.

Kauffman, J.B. and W.C. Krueger. 1984. Livestock Impacts on Riparian Ecosystems and Streamside Management Implications…A Review. *In*: Ecological implications of livestock herbivory in the west. Society of Range Mgmt. Denver, Colo.

Kauffman, J.B., A.S. Thorpe, and E.N.J. Brookshire. 2004. Livestock exclusion and belowground ecosystem responses in riparian meadows of eastern Oregon. Ecological Applications 14(6): 1671-1679.

Kattelmann, R. and M. Embury. 1996. Riparian Areas and Wetlands. In Sierra Nevada Ecosystem Project: Final Report to Congress, Vol. III, Assessment and Scientific Basis for Management Options. Center for Water and Wildland Resources, University of California, Davis, CA.

Keinath, D. and M. McGee. 2005. Boreal Toad (*Bufo boreas boreas*): a technical conservation assessment. [Online]. USDA Forest Service, Rocky Mountain Region. Available: http://www.fs.fed.us/r2/projects/scp/assessments/borealtoad.pdf

Kost, M.A. 2001. Potential Indicators for Assessing Biological Integrity of Forested, Depressional Wetlands in Southern Michigan. Unpublished report prepared for Michigan Department of Environmental Quality. Michigan Natural Features Inventory, Lansing, MI.

Kruskal, J.B. 1964. Nonmetric Multidimensional Scaling: A Numerical Method. Psychometrika 29: 115-129.

Lane, C.R. 2003. Biological Indicators of Wetland Condition for Isolated Depressional Herbaceous Wetlands in Florida. Phd. Dissertation. University of Florida, Gainesville, FL.

Leibowitz, S.G. 2003. Isolated Wetlands and Their Functions: An Ecological Perspective. Wetlands 23(3): 517-531.

Lemon, J. and L. Westra. 1995. Introduction to Perspectives on Ecological Integrity. *In* Westra and Lemons (editors), Perspectives on Ecological Integrity. Environmental Science and Technology Library, Volume 5. Kluwer Academic Publishers, Dordecht, The Netherlands.

Lillie, R.A., P. Garrison, S.I. Dodson, R.A. Bautz, and G. LaLiberte. 2002. Refinement and Expansion of Wetland Biological Indices for Wisconsin. Unpublished report prepared for U.S. EPA, Region V. Wisconsin Department of Natural Resources. Madison, WI.

Lopez, R.D. and M.S. Fennessy. 2002. Testing the Floristic Quality Assessment Index as an Indicator of Wetland Condition. Ecological Applications 12(2): 487-497.

Mack, J.J., 2001. Ohio rapid assessment method for wetlands v. 5.0, user's Manual and scoring forms. Ohio EPA Technical Report WET/2001-1. Ohio Environmental Protection Agency, Division of Surface Water, Wetland Ecology Group, Columbus, Ohio.

Mack, J. J. 2004a. Integrated Wetland Assessment Program. Part 4: Vegetation Index of Biotic Integrity (VIBI) and Tiered Aquatic Life Uses (TALUs) for Ohio wetlands. Ohio EPA Technical Report WET/2004-4. Ohio Environmental Protection Agency, Wetland Ecology Group, Division of Surface Water, Columbus, Ohio.

Mack, J. J. 2004b. Integrated Wetland Assessment Program. Part 9: Field Manual for the Vegetation Index of Biotic Integrity for Wetlands v. 1.3. Ohio EPA Technical Report W ET/2004-9. Ohio Environmental Protection Agency, Wetland Ecology Group, Division of Surface Water, Columbus, Ohio.

Mack, J.J., M. Siobhan Fennessy, M. Micacchion, and D. Poreg. 2004. Part 6. Standardized Monitoring Protocols, Data Anaylsis, and Reporting Requirements for Mitigation Wetlands in Ohio, v. 1.0. Ohio EPA Technical Report W ET/2004-6. Ohio Environmental Protection Agency, Wetland Ecology Group, Division of Surface Water, Columbus, Ohio.

Magee, T.K. and M.E. Kentula. 2005. Response of wetland plant species to hydrologic conditions. Wetland Ecology and Management 13:163-181.

McCune, B. and J.B. Grace. 2002. Analysis of Ecological Communities. MjM Software, Gleneden Beach, Oregon, U.S.A.

McCune, B. and M. J. Mefford. 1999. PC-ORD. Multivariate Analysis of Ecological Data. Version 4.39. MjM Software, Gleneden Beach, Oregon, U.S.A.

Mebane, C.A., T.R. Maret, and R.M. Hughes. 2003. An Index of Biotic Integrity (IBI) for Pacific Northwest Rivers. Transactions of the American Fisheries Society 132:239-261.

Micacchion, M. 2004. Integrated Wetland Assessment Program. Part9: Amphibian Index of Biotic Integrity (AmphIBI) for Ohio Wetlands. Ohio EPA Technical Report W ET/2004-7. Ohio Environmental Protection Agency, Wetland Ecology Group, Division of Surface Water, Columbus, Ohio.

Miller, J.R., J.A. Wiens, N. T. Hobbs, and D.M. Theobald. 2003. Effects of Human Settlement on Bird Communities in Lowland Riparian Areas of Colorado (USA). Ecological Applications 13(4): 1041-1059.

Miller, S.J., D.H. Wardrop, W.M. Mahaney, and R.P. Brooks. 2006. A plant-based index of biological integrity (IBI) for headwater wetlands in central Pennsylvania. Ecological Indicators 6(2): 290-312.

Mitsch, W.J. and J.G. Gosselink. 2000, Wetlands. 3rd Edition. John Wiley and Sons. New York, NY

Montana Department of Environmental Quality. 2005. Draft Montana Wetland Rapid Assessment Method Guidebook(Version 2.0). Montana Department of Environmental Quality, Helena, MT.

Morgan, P., G.H. Aplet, J.B. Haufler, H.C. Humphries, M.M. Moore, and W.D. Wilson. 1994. Historical Range of Variability: A Useful Tool For Evaluating Ecosystem Change. *In:* N. Sampson and D. L. (editors) Assessing Forest Ecosystem Health in the Inland West. Haworth Press. New York, NY. Pages 87-111.

Muths, E., S. Rittman, J. Irwin, D. Keinath, and R. Scherer. 2005. Wood Frog (*Rana sylvatica*): a technical conservation assessment. [Online]. USDA Forest Service, Rocky Mountain Region. Available: http://www.fs.fed.us/r2/projects/scp/assessments/woodfrog.pdf

National Wetlands Working Group. 1988. Wetlands of Canada. Ecological Land Classification Series, No. 24. Sustainable Development Branch, Environment Canada, Ottawa, Ontario, and Polyscience Publications Inc., Montreal, Quebec. 452 pages.

NatureServe. 2002. Element Occurrence Data Standard. Report prepared in cooperation with the Network of Natural Heritage Programs and Conservation Data Centers. Available online: http://www.natureserve.org/prodServices/eodata.jsp

Nelson, P.W. 2005. The Terrestrial Natural Communities of Missouri. 2nd Edition. Missouri Natural Areas Committee, Missouri Department of Natural Resources. Jefferson City, MO.

Nelson, S.M. In Press. Butterflies (Papilionoidea and Heperioidea) as potential ecological indicators of riparian quality in the semi-arid western United States. Ecological Indicators.

Noson, A.C. and R.L. Hutto. 2005. Using Bird Indices of Biotic Integrity to Assess the Condition of Wetlands in Montana. Unpublished report prepared for the Montana Department of Environmental Quality and the U.S. Environmental Protection Agency Region 8. Avian Science Center, University of Montana, Missoula, MT.

Noss, R.F., 1990. Indicators for monitoring biodiversity: a hierarchical approach. Conservation Biology 4(4): 355–364.

Noss, R.F. 1995. Ecological Integrity and Sustainability: Buzzwords in Conflict? *In* Westra and Lemons (editors), Perspectives on Ecological Integrity. Environmental Science and Technology Library, Volume 5. Kluwer Academic Publishers, Dordecht, The Netherlands.

Noss, R.F., N.C. Slosser, J.R. Strittholt, and C. Carroll. 1999. Metrics of ecological integrity for terrestrial ecosystems and entire landscapes. U.S. Environmental Protection Agency, Washington, DC.

NRC (National Research Council). 1995. Wetlands: Characteristics and Boundaries. National Academy Press, Washington D.C.

NRC (National Research Council). 2001. Compensating for Wetland Losses Under the Clean Water Act. National Academy Press, Washington D.C.

Peet, R.K., T.R. Wentworth and P.S. White. 1998. A flexible, multipurpose method for recording vegetation composition and structure. Castanea 63:262-274

Ohio EPA. 1988. Biological criteria for the protection of aquatic life: Volume 1: the role of biological data in water quality assessment. Ohio Environmental Protection Agency, Ecological Assessment Section, Columbus, Ohio.

Ohio EPA. 2001. Clean Rivers Spring from Their Source: The Importance and Management of Headwater Streams. Fact Sheet. Division of Surface Water, Ohio EPA. Columbus, OH.

Panzer, R. and M.W. Schwartz. 1998. Effectiveness of a Vegetation-Based Approach to Insect Conservation. Conservation Biology 12(3): 693-702.

Poff, N.L., J.D. Allan; M.B. Bain; J.R. Karr; K.L. Prestegaard; B.D. Richter; R.E. Sparks; and J.C. Stromberg. 1997. The natural flow regime. A paradigm for river conservation and restoration. Bioscience 47(11): 769-784.

Quigley, T. M. and S.J. Arbelbide (technical editors). 1997. An Assessment of Ecosystem Components in the Interior Columbia Basin and Portions of the Klamath and Great Basins: Volume 2. Gen. Tech. Rep. PNW-GTR-405. Portland, OR. U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. 4 Volumes. (Quigley, T.M., technical editor; The Interior Columbia Basin Ecosystem Management Project: Scientific Assessment).

Reed, P. Jr. 1988. National List of Plant Species That Occur in Wetlands: National Summary. U.S. Fish and Wildlife Service. Biological Report 88(24). Region 5 and 8 Regional Lists. Online at http://www.fws.gov/nwi/bha/list88.html

Reiss, K.C. 2006. Florida Wetland Condition Index for depressional forested wetlands. Ecological Indicators 6(2): 337-352.

Rocchio, J. 2006a. Ecological Integrity Assessments for North American Arid Freshwater Marsh, Rocky Mountain Montane-Alpine Wet Meadows, Rocky Mountain Upper Montane-Subalpine Fens, Rocky Mountain Upper Montane-Subalpine Riparian Shrublands, Rocky Mountain Upper Montane-Subalpine Riparian Woodlands, Rocky Mountain Lower Montane Riparian Woodland and Shrubland, and Intermoutain Basin Playas. Unpublished report prepared for NatureServe, Arlington, VA. Reports available online at: http://www.cnhp.colostate.edu/reports.html or http://www.natureserve.org/getData/eia_integrity_reports.jsp

Rocchio, J. 2006b. Vegetation Index of Biotic Integrity for Southern Rocky Mountain Fens, Wet Meadows, and Riparian Shrublands: Phase 1 Final Report. Unpublished report prepared for Colorado Department of Natural Resources, and U.S. Environmental Protection Agency, Region VIII. Colorado Natural Heritage Program, Colorado State University, Fort Collins, CO.

Rocchio, J. 2007. Floristic Quality Assessment Indices of Colorado Plant Communities. Unpublished report prepared for Colorado Department of Natural Resources, and U.S. Environmental Protection Agency, Region VIII. Colorado Natural Heritage Program, Colorado State University, Fort Collins, CO.

Rondeau, R. 2001. Ecological System Viability Specifications for Southern Rocky Mountain Ecoregion. 1st Edition. Unpublished report for The Nature Conservancy. Colorado Natural Heritage Program, Colorado State University, Fort Collins, CO.

Rosgen, D. 1996. Applied River Morphology. Wildland Hydrology, Pagosa Springs, CO.

Rueth, H.M., J.S. Baron, and L.A. Joyce. 2002. Natural Resource Extraction: Past, Present, and Future. *In* Rocky Mountain Futures: An Ecological Perspective. J.S. Baron (editor). Island Press. Washington D.C.

SAIC (Science Applications International Corporation). 2000. Summit County Wetland Functional Assessment. Unpublished report prepared for Summit County Community Development Division, Frisco, Colorado.

Sanderson, J. and M. March. 1995. Extreme Rich Fens of South Park, CO: Their Distribution, Identification, and Natural Heritage Significance. Unpublished report prepared for Park County, Colorado Department of Natural Resources, and U.S. Environmental Protection Agency, Region VIII. Colorado Natural Heritage Program, Colorado State University, Fort Collins, CO.

Simon, A. and A.J.C. Collison. 2002. Quantifying the Mechanical and Hydrologic Effects of Riparian Vegetation on Streambank Stability. Earth Surface Processes and Landforms 27: 527-546.

Simon, T.P., P.M. Stewart, and P.E. Rothrock. 2001. Development of multimetric indices of biotic integrity for riverine and palustrine wetland plant communities along Southern Lake Michigan. Aquatic Ecosystem Health and Management 4: 293-309.

Smith, R. D., A. Ammann, C. Bartoldus, and M. Brinson. 1995. *An Approach for Assessing Wetland Functions Using Hydrogeomorphic Classification, Reference Wetlands, and Functional Indices.* Technical Report WRP-DE-9. Wetlands Research Program, US Army Corps of Engineers, Washington, DC.

Smith, B.E. 2003. Conservation Assessment for the Northern Leopard Frog in the Black Hills National Forest, South Dakota and Wyoming. [Online]. USDA Forest Service, Black Hills National Forest, Custer, South Dakota. Available:

Society of Wetland Scientists. 2000. Position Paper on the Definition of Wetland Restoration. Online at: http://www.sws.org/wetlandconcerns/restoration.pdf

Solley, W.B., R.R. Pierce, and H.A. Perlman. 1998. Estimated use of water in the United States in 1995. U.S. Geological Survey Circular 1200. Denver, CO.

Steiner, F. S. Pieart, E. Cook, J. Rich, and V. Coltman. 1994. State wetlands and riparian area protection programs. Environmental Management 18: 183-201

Stevenson, J.A. and F.R. Hauer. 2002. Integrating Hydrogeomorphic and Index of Biotic Integrity approaches for environmental assessment of wetlands. Journal of North American Benthological Society 21(3): 502-513.

Stoddard, J.L., D.P. Larsen, C.P. Hawkins, R.K. Johnson, and R.H. Norris. 2006. Setting Expectation for the Ecological Condition of Streams: The Concept of Reference Condition. Ecological Applications 16(4): 1267-1276.

Summit County 1999. Data collected toward the development of a Special Area Management Plan (SAMP) for Summit County, Colorado.

Suter, G.W. 1993. A Critique of Ecosystem Health Concepts and Indexes. Environmental Toxicology and Chemistry 12: 1533-1539

Swetnam, T.W., C.D. Allen, and J.L. Betancourt. 1999. Applied Historical Ecology: Using the Past to Manage for the Future. Ecological Applications 9(4): 1189-1206.
Tweto, O. 1979. Geological Map of Colorado. Scale 1:500,000, colored. U.S.G.S., Denver, CO.

Swink F. and G. Wilhelm. 1994. Plants of the Chicago Region. 4th Edition. Morton Arboretum, Lisle, IL.

Taft, J.B., G.S. Wilhelm, D.M. Ladd, and L.A. Masters. 1997. Floristic Quality Assessment for Vegetation in Illinois, A Method for Assessing Vegetation Integrity. Erigenia, Number 15, November 1997. The Illinois Native Plant Society Journal.

Tabacchi, E., D.L. Correll, R. Hauer, A. Planty-Tabacchi, and R.C. Wissmar. 1998. Development, maintenance and role of riparian vegetation in the river landscape. Freshwater Biology 40: 497-516.

Teels, B.M., L.E. Mazanti, and C.A Rewa. 2004. Using an IBI to Assess Effectiveness to Mitigation Measures to Replace Loss of a Wetland-Stream Ecosystem. Wetlands 24(2): 375-384.

Tweto, O. 1979. Geologic Map of Colorado. Compiled by the U.S. Geological Survey with technical assistance by the Colorado Geological Survey.

USDA, PLANT Database. http://plants.usda.gov/ Accessed January 2005.

U.S. EPA 1998. Lake and Reservoir Bioassessment and Biocriteria. Techncial Guidance Document. EPA 841-B-98-008. U.S. Environmental Protection Agency, Office of Wetlands, Oceans, and Watersheds. Washington D.C. Available online: http://www.epa.gov/owow/monitoring/tech/lakes.html

U.S. EPA. 2002a. Methods for Evaluating Wetland Condition: #1 Introduction to Wetland Biological Assessment. Office of Water, U.S. Environmental Protection Agency, Washington D.C. EPA-822-R-02-014.

U.S. EPA. 2002b. Methods for Evaluating Wetland Condition: Study Design for Monitoring Wetlands. Office of Water, U.S. Environmental Protection Agency, Washington, DC. EPA-822-R-02-015.

U.S. EPA. 2002c. Methods for Evaluating Wetland Condition: Using Vegetation to Assess Environmental Conditions in Wetlands. Office of Water, U.S. Environmental Protection Agency, Washington D.C. EPA-822-R-02-020.

U.S. EPA. 2003. Elements of a State Water Monitoring and Assessment Program. Assessment and Water Protection Division, Office of Water, U.S. Environmental Protection Agency, Washington D.C. EPA-841-B-03-003.

U.S. EPA. 2006. Application of Elements of a State Water Monitoring and Assessment Program For Wetlands. Wetlands Division, Office of Wetlands, Oceans and Watersheds. U.S. Environmental Protection Agency, Washington D.C.

USGPO. 1972. Report of the Committee on Public Works-United States House of Representatives with Additional and Supplemental View on H.R. 11806 to Amend the Federal

Water Pollution Control Act. House Report 92-9111. 92nd Congress, 2d Session, March 11, 1972. Page 149

Vale, T.R. 1998. The Myth of the Humanized Landscape: An Example from Yosemite National Park. Natural Areas Journal 18: 231-236.

Vierling, L.A. 1998. Palynological Evidence for Late- and Postglacial Environmental Change in Central Colorado. Quaternary Research 49: 222-232.

Vitousek, P.M. 1990. Biological invasions and ecosystem processes: towards an integration of population biology and ecosystem studies. Oikos 57:7-13.

Vitousek, P.M., H.A. Mooney, J. Lubchenko, and J.M. Melillo. 1997. Human domination of Earth's ecosystems. Science 277: 494-499.

Wardrop, D.H. and R.P. Brooks. 1998. The occurrence and impact of sedimentation in central Pennsylvania wetlands. Environmental Monitoring and Assessment 51: 119-130.

Washington State Department of Ecology. 1993. Washington State Wetlands Rating System: Western Washington. Second Edition. Publication #93-74.

Weber, W.A.(1965). Plant Geography in the Southern Rocky Mountains. *In* The Quaternary of the United States (eds. H.E. Wright Jr. and D.G. Frey), pp.453-468. Princeton University Press, Princeton, NJ.

Weber, W.A. 2003. The Middle Asian Element in the Southern Rocky Mountain flora of the Western United States: A Critical Biogeographic Review. Journal of Biogeography 30: 649-685.

Weber, W. and R.C. Wittmann. 2001a. Colorado Flora: Eastern Slope. Third Edition. University Press of Colorado. Boulder, CO.

Weber, W. and R.C. Wittmann. 2001b. Colorado Flora: Western Slope. Third Edition. University Press of Colorado. Boulder, CO.

Weixelman D.A., D.C. Zamudio, K.A. Zumudio, and R.T. Tausch. 1997. Classifying ecological types and evaluating site degradation. Journal of Range Management 50: 315-321.

Western Regional Climate Center. 2006. http:\\ www.wrcc.dri.edu

Westra, L. 1995. Ecosystem Integrity and Sustainability: The Foundational Value of the Wild. *In* Westra and Lemons (editors), Perspectives on Ecological Integrity. Environmental Science and Technology Library, Volume 5. Kluwer Academic Publishers, Dordecht, The Netherlands.

Whitaker, R.H. 1965. Dominance and diversity in land plant communities. Science 147: 250-260.

Whitlock, C., M.A. Reasoner, and C.H. Key. 2002. Paleoenvironmental History of the Rocky Mountain Region During the Past 20,000 Years. *In* Rocky Mountain Futures: An Ecological Perspective. J.S. Baron (editor). Island Press. Washington D.C.

Wicklum, D. and R.W. Davies. 1995. Ecosystem Health and Integrity? Canadian Journal of Botany 73:997-1000

Wilcox, D. A. 1995. Wetland and aquatic macrophytes as indicators of anthropogenic hydrologic disturbance. Natural Areas Journal 15:240-248.

Wilhelm, G. and D. Ladd. 1988. Natural area assessment in the Chicago region. Pp 361-375 in R.E. McCabe, editor, Transactions of the 53rd North American Wildlife and Natural Resources Conference. Wildlife Management Institute, Washington D.C.

Wilhelm, G. and L. Masters. 1996. Floristic Quality Assessment in the Chicago Region. The Morton Arboretum, Lisle, IL.

Williams, D.G., J.P. Brunel, S.M. Schaefer, and K.A. Snyder. 1998. Biotic Controls Over the Functioning of Desert Riparian Ecosystems. American Meteorological Society, Special Symposium on Hydrology, Phoenix, Arizona, 11-16 Jan 1998

Winters, T.C. 2001. The concept of hydrologic landscapes. Journal of the American Water Resources Association 37:335-349.

Winters, D.S., B. Bohn, G. Eaglin, C. Hirsch, C.M. Quimby, D. Scaife, and D.M. Staley. 2004. Anthropogenic Influences used in Conducting Multiple Scale Aquatic, Riparian, and Wetland Ecological Assessments (Version 1). U.S. Department of Agriculture, U.S. Forest Service Region 2. Online: http://www.fs.fed.us/r2/projects/scp/arw/protocols/anthropogenicinfluencesusedinconductingmultiplescale.pdf

Winward, Alma H. 2000. Monitoring the vegetation resources in riparian areas. Gen. Tech. Rep. RMRSGTR- 47. Ogden, UT: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station.

Wohl, E. 2001. Virtual Rivers: Lessons from the Mountain Rivers of the Colorado Front Range. Yale University Press, New Haven, CT.

Zedler, J.B and S. Kercher. 2004. Causes and Consequences of Invasive Plants in Wetlands: Opportunities, Opportunists, and Outcomes. Critical Reviews in Plant Sciences 23(5): 431-452.

APPENIDX A: DESCRIPTIONS AND KEY TO WETLAND ECOLOGICAL SYSTEM TYPES

ECOLOGICAL SYSTEM DESCRIPTIONS

Note: The three "new" ecological system types (riverine wet meadows, slope wet meadows, and extremely rich fens) discussed in this document, are in bold and embedded in the descriptions of the original three ecological systems targeted for this study.

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 **riverine wet meadows**. Wet meadows in the alpine are tightly associated with snowmelt (**slope wet meadows**) and typically not subjected to high disturbance events such as flooding. Wet meadows also occur near the fringes of lakes and ponds as well as near ephemeral groundwater discharge sites (**slope wet meadows**) 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, **extremely rich fens** have distinct soil and water chemistry, with high levels of one or more minerals such as calcium and magnesium and have a high pH (e.g. > 7.0). 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 and presence of organic soils. In fens, ground water maintains a fairly constant water level year-round, with water at or near the surface most of the growing season 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). However, for VIBI development any system with organic soils was classified as a fen.

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.

KEY TO ECOLOGICAL SYSTEM TYPES

1

Mineral soils; sometimes organic soil horizon (histic epipedon) present but <40 cm 2

Organic soils, >40 cm depth present. If < 40 cm then organic soil layer occurs on lithic material 4

2

Shrubs dominate overstory; sometimes with scattered trees, but not densely forested. System usually occurs in riparian landscape but can be found on slopes near seeps/springs

ROCKY MOUNTAIN SUBALPINE-MONTANE RIPARIAN SHRUBLAND

Herbaceous vegetation is predominant; located in riparian landscape, near open water, or associated with groundwater discharge sites...3

3

Wet meadow occurs in riparian landscape; wetland is exposed to fluvial dynamics; supported by overbank flooding, alluvial groundwater

ROCKY MOUNTAIN ALPINE-MONTANE RIVERINE WET MEADOW

Wet meadow occurs on or at base of slope; supported by unidirectional, groundwater discharge;

ROCKY MOUNTAIN ALPINE-MONTANE SLOPE WET MEADOW

4

Wetland occurs on slope or in a basin and/or is supported by groundwater discharge; Generally occurs at elevations above 8000 ft; Shrubs or herbaceous species may dominate. Groundwater pH is circumneutral

ROCKY MOUNTAIN SUBALPINE-MONTANE FEN

Wetland occurs on slope and/or is supported by groundwater discharge; Generally occurs at elevations above 8000 ft; Shrubs or herbaceous species may dominate. Groundwater is calcareous with pH above 7.0 and with high levels of Ca, Mg,; calciphiles are prevalent; marl is often present and may comprise most of substrate. In Colorado, this type is most prevalent in Park County, but examples are also found in Gunnison and Grand counties

ROCKY MOUNTAIN SUBALPINE-MONTANE EXTREMELY RICH FEN

APPENDIX B: 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 wetland. Buffers are natural vegetated areas with no or minimal human-use. Buffer boundaries extend from the wetland 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 wetland 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 amount of unfragmented area in a one km buffer surrounding the wetland 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 wetland 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 wetland 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[14] (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. Have any of soil or substrate disturbances caused or appear to have caused more than trivial alterations to the wetland's natural soils or substrates, or have they occurred so far in the past that current conditions should be considered to be "natural."?	**YES** Assign a score 1, 2 or 3, or an intermediate score, depending on degree of recovery from the disturbance.	**NO** Assign a score of 4 since there are no apparent modifications.	**NOT SURE** 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 surrounding land use(s) occurring in the wetland or riparian 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)	

---

[14] Adapted from Mack 2001

3d. Algae[15] 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 wetland/riparian area.	
10pts POOR Cattails dominate and form a monoculture in the wetland/riparian 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 wetland/riparian area due to human-induced activities (bare ground, row crops, erosion, etc.); Water is not turbid.	
3pts GOOD Slight evidence of excessive sediment in wetland/riparian area due to human-induced activities (bare ground, row crops, erosion, etc.); Water is slightly turbid.	
7pt FAIR Moderate evidence of excessive sediment in wetland/riparian area due to human-induced activities (bare ground, row crops, erosion, etc.); Water is moderately turbid.	
10pts POOR High evidence of excessive sediment in wetland/riparian 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	

---

[15] 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 C: SAMPLE SITE INFORMATION

	Ecological System	HGM Class	Human Disturbance Index	Human Disturbance Category	Dominant Land Use	Sampling Date	Site Name	Watershed	Elevation (ft)	UTM 13 NAD83 Easting	UTM 13 NAD83 Northing	Soil Type	WAA Size (hectare)
Plot 01	Wet Meadow	Slope	39.80	Impacted	Recreation	7/7/2004	Cataract Lake	Blue River	8750	387366	4410496	Mineral	0.18
Plot 02	Wet Meadow	Slope	60.00	Impacted	Grazing	7/8/2004	Cataract Lake-Irrigated Meadow	Blue River	8454	389494	4411631	Mineral	1.89
Plot 03	Wet Meadow	Riverine	22.50	Reference	Grazing	7/9/2004	County Line Meadow	Blue River	7740	386743	4419368	Mineral	0.35
Plot 04	Fen	Slope	18.98	Reference	Natural	7/13/2004	Frisco Boardwalk Fen	Blue River	9120	405649	4380424	Organic	0.58
Plot 05	Riparian Shrubland	Slope	67.00	Highly Impacted	Suburban	7/14/2004	Frisco Bike Path Shrubland	Blue River	9120	405735	4380438	Mineral	1.24
Plot 06	Riparian Shrubland	Riverine	84.85	Highly Impacted	Urban	7/15/2004	Straight Creek - Silverthorne	Blue River	8888	408776	4387160	Mineral	1.51
Plot 07	Fen	Slope	14.85	Reference	Natural	7/20/2004	Lost Park Campground	Upper South Platte River	9960	456222	4348380	Organic	0.24
Plot 08	Wet Meadow	Riverine	53.20	Impacted	Grazing	7/21/2004	BLM 94	South Platte River Headwaters	9600	424978	4350609	Mineral	0.24
Plot 09	Riparian Shrubland	Riverine	80.05	Highly Impacted	Grazing	7/22/2004	Teter SWA Parking Lot	South Platte River Headwaters	9665	426853	4359100	Mineral	1.34
Plot 10	Riparian Shrubland	Riverine	15.00	Reference	Natural	7/23/2004	Michigan Creek Campground	South Platte River Headwaters	10000	424353	4362357	Mineral	6.34
Plot 11	Riparian Shrubland	Riverine	45.53	Impacted	Suburban	7/27/2004	Breckenridge Gold Course	Blue River	9300	411402	4375350	Mineral	1.1
Plot 13	Riparian Shrubland	Riverine	23.10	Reference	Natural	7/29/2004	Deer Creek	Blue River	11000	425236	4377901	Mineral	2.07
Plot 14	Wet Meadow	Riverine	66.70	Highly Impacted	Suburban	7/29/2004	Soda Creek	Blue River	9020	413041	4383563	Mineral	2.21

	Ecological System	HGM Class	Human Disturbance Index	Human Disturbance Category	Dominant Land Use	Sampling Date	Site Name	Watershed	Elevation (ft)	UTM 13 NAD83 Easting	UTM 13 NAD83 Northing	Soil Type	WAA Size (hectare)
Plot 15	Extremely Rich Fen	Slope	9.90	Reference	Natural	8/6/2004	High Creek Fen	South Platte River Headwaters	9290	415981	4328230	Organic	26.32
Plot 16	Extremely Rich Fen	Slope	70.10	Highly Impacted	Mining	8/6/2004	High Creek Fen	South Platte River Headwaters	9290	416069	4328353	Organic	2.72
Plot 17	Fen	Slope	41.35	Impacted	Suburban	8/9/2004	Bemrose Creek	Blue River	10700	409433	4359579	Organic	0.19
Plot 18	Riparian Shrubland	Riverine	13.20	Reference	Natural	8/10/2006	Middle Fork Swan River	Blue River	10000	419389	4372351	Mineral	4.94
Plot 19	Riparian Shrubland	Riverine	9.90	Reference	Natural	8/11/2004	Indiana Creek	Blue River	10600	414071	4364864	Mineral	3.63
Plot 20	Extremely Rich Fen	Slope	16.50	Reference	Natural	8/13/2004	County Line Fen	Blue River	7750	386715	4419389	Organic	0.2
Plot 21	Fen	Slope	74.65	Highly Impacted	Grazing	7/28/2004	Horse Creek Fen 2	Blue River	8000	389963	4416033	Organic	0.53
Plot 22	Wet Meadow	Slope	90.10	Highly Impacted	Grazing	7/7/2005	Horse Creek-irrigated meadow	Blue River	8000	389811	4416186	Mineral	1.29
Plot 23	Riparian Shrubland	Riverine	73.10	Highly Impacted	Grazing	7/7/2005	Horse Creek-Riparian	Blue River	8060	390055	4416443	Mineral	0.88
Plot 24	Fen	Slope	59.80	Impacted	Grazing	7/8/2005	Iron Springs	Blue River	9242	408451	4380581	Organic	1.34
Plot 25	Extremely Rich Fen	Slope	29.90	Reference	Grazing	7/12/2005	Crooked Creek Fen 1	South Platte River Headwaters	10037	415122	4347238	Organic	1.13
Plot 26	Extremely Rich Fen	Slope	85.15	Highly Impacted	Grazing	7/13/2005	Crooked Creek Fen 2	South Platte River Headwaters	10016	415214	4347174	Organic	1.71
Plot 27	Fen	Slope	15.75	Reference	Natural	7/13/2005	Crooked Creek Fen 3	South Platte River Headwaters	10050	415024	4347285	Organic	0.92
Plot 28	Riparian Shrubland	Riverine	64.75	Impacted	Grazing	7/14/2005	Tomahawk SWA	South Platte River Headwaters	9096	425184	4326976	Mineral	0.7
Plot 29	Riparian Shrubland	Riverine	59.80	Impacted	Grazing	7/14/2005	Tomahawk SWA2	South Platte River Headwaters	9088	425166	4327352	Mineral	0.4

	Ecological System	HGM Class	Human Disturbance Index	Human Disturbance Category	Dominant Land Use	Sampling Date	Site Name	Watershed	Elevation (ft)	UTM 13 NAD83 Easting	UTM 13 NAD83 Northing	Soil Type	WAA Size (hectare)
Plot 30	Riparian Shrubland	Riverine	58.35	Impacted	Exurban	7/15/2005	Tarryall Creek	South Platte River Headwaters	10306	418023	4357048	Mineral	7.44
Plot 31	Riparian Shrubland	Riverine	0.00	Reference	Natural	7/19/2005	Trail Creek	Colorado River Headwaters	8984	406499	4459712	Mineral	0.41
Plot 32	Fen	Slope	0.00	Reference	Natural	7/21/2005	Second Creek	Colorado River Headwaters	11268	432956	4408597	Organic	0.26
Plot 33	Riparian Shrubland	Riverine	18.40	Reference	Natural	7/22/2005	St. Louis Creek	Colorado River Headwaters	9388	423068	4414284	Mineral	1.21
Plot 34	Extremely Rich Fen	Slope	9.90	Reference	Natural	7/27/2005	High Creek Fen - Shrubland	South Platte River Headwaters	9276	415702	4327905	Organic	0.25
Plot 35	Extremely Rich Fen	Slope	34.85	Reference	Grazing	7/27/2005	Teter-Michigan Creek SWA	South Platte River Headwaters	9672	426459	4358616	Organic	0.93
Plot 36	Wet Meadow	Slope	85.15	Highly Impacted	Grazing	7/27/2005	Teter-Michigan Creek SWA2	South Platte River Headwaters	9686	426464	4358731	Mineral	0.63
Plot 37	Fen	Slope	11.55	Reference	Natural	7/29/2005	Michigan Creek Headwaters	South Platte River Headwaters	11292	420999	4367487	Organic	0.21
Plot 38	Riparian Shrubland	Riverine	33.15	Reference	Suburban	8/1/2005	Mesa Cortina-Wilderness	Blue River	9600	405626	4386288	Mineral	0.64
Plot 39	Wet Meadow	Slope	4.95	Reference	Natural	8/2/2005	Spruce Creek	Blue River	10757	408443	4364948	Mineral	0.16
Plot 40	Riparian Shrubland	Riverine	21.60	Reference	Recreation	8/3/2005	N. Fork Swan River	Blue River	9850	418977	4374191	Mineral	1.11
Plot 41	Riparian Shrubland	Riverine	83.00	Highly Impacted	Mining	8/4/2005	N. Fork Swan River2	Blue River	9698	417440	4375082	Mineral	0.47
Plot 42	Wet Meadow	Riverine	61.75	Impacted	Grazing	8/15/2005	Tarryall Creek SWA	South Platte River Headwaters	8900	446707	4342923	Mineral	2
Plot 43	Riparian Shrubland	Riverine	60.00	Impacted	Grazing	8/16/2005	Hwy. 9/FR 258	South Platte River Headwaters	9183	443174	4301507	Mineral	0.42

	Ecological System	HGM Class	Human Disturbance Index	Human Disturbance Category	Dominant Land Use	Sampling Date	Site Name	Watershed	Elevation (ft)	UTM 13 NAD83 Easting	UTM 13 NAD83 Northing	Soil Type	WAA Size (hectare)
Plot 44	Extremely Rich Fen	Slope	46.40	Impacted	Grazing	8/16/2005	Badger Creek SWA	South Platte River Headwaters	8955	428314	4321085	Organic	1.27
Plot 45	Riparian Shrubland	Riverine	94.90	Highly Impacted	Mining	8/17/2005	Middle Fork S. Platte River-Fairplay Beach	South Platte River Headwaters	9922	413526	4341839	Mineral	3.17
Plot 46	Fen	Slope	7.43	Reference	Natural	8/18/2005	Montezuma Iron Fen	Blue River	11193	427923	4378064	Organic	0.57
Plot 47	Wet Meadow	Slope	72.80	Impacted	Mining	8/18/2005	Pennsylvania Mine	Blue River	10881	430201	4383761	Mineral	0.17
Plot 48	Fen	Slope	44.55	Impacted	Mining	8/18/2005	Pennsylvania Mine2	Blue River	10982	430164	4383783	Organic	0.68
Plot 49	Wet Meadow	Riverine	21.45	Reference	Recreation	8/19/2005	Ten Mile Creek	Blue River	10000	403054	4381500	Mineral	0.31
Plot 50	Fen	Slope	0.00	Reference	Natural	8/23/2005	Iron Creek	Colorado River Headwaters	10118	421121	4412805	Organic	0.78
Plot 51	Fen	Slope	0.00	Reference	Natural	8/23/2005	Iron Creek	Colorado River Headwaters	10112	421323	4412852	Organic	0.17
Plot 52	Fen	Slope	11.75	Reference	Natural	8/25/2005	Monarch Lake	Colorado River Headwaters	8375	437374	4439314	Organic	0.53
Plot 53	Wet Meadow	Slope	60.40	Impacted	Recreation	6/28/2006	SR 4 Sisters of Charity	Blue River	9200	413834	4384990	Mineral	0.59
Plot 54	Fen	Slope	48.45	Impacted	Grazing	7/9/2006	Blue River Valley	Blue River	8290	401777	4401968	Organic	0.13
Plot 55	Wet Meadow	Slope	21.45	Reference	Grazing	7/10/2006	Blue River Valley	Blue River	8290	401914	4401942	Mineral	0.1
Plot 56	Fen	Slope	39.80	Impacted	Recreation	7/11/2006	Blue River Valley	Blue River	9200	413745	4385011	Organic	0.33
Plot 57	Wet Meadow	Riverine	21.45	Reference	Recreation	7/12/2006	North Fork Snake River	Blue River	10320	423274	4387458	Mineral	0.1
Plot 58	Riparian Shrubland	Riverine	43.20	Impacted	Mining	7/18/2006	Montezuma Wetland	Blue River	10000	425452	4382208	Mineral	0.12
Plot 59	Riparian Shrubland	Riverine	68.50	Highly Impacted	Recreation	7/19/2006	Horse Creek	Blue River	7960	390073	4415505	Mineral	1.26
Plot 60	Wet Meadow	Riverine	48.00	Impacted	Grazing	7/24/2006	East of Fairplay	Upper South Platte River	9688	417389	4341905	Mineral	1.18

	Ecological System	HGM Class	Human Disturbance Index	Human Disturbance Category	Dominant Land Use	Sampling Date	Site Name	Watershed	Elevation (ft)	UTM 13 NAD83 Easting	UTM 13 NAD83 Northing	Soil Type	WAA Size (hectare)
Plot 61	Fen	Slope	64.95	Impacted	Grazing	7/25/2006	Crooked Creek @Coil Ranch	Upper South Platte River	9694	417529	4341059	Organic	4.89
Plot 62	Extremely Rich Fen	Slope	46.40	Impacted	Grazing	7/26/2006	Upper Four Mile Creek1	Upper South Platte River	9852	411690	4337483	Organic	0.29
Plot 63	Extremely Rich Fen	Slope	33.20	Reference	Grazing	8/1/2006	4 mile Creek	Upper South Platte River	9770	412177	4336952	Organic	0.6
Plot 64	Wet Meadow	Slope	44.75	Impacted	Grazing	8/2/2006	Four Mile Creek	Upper South Platte River	9803	412241	4336881	Mineral	0.85
Plot 65	Wet Meadow	Riverine	85.00	Highly Impacted	Grazing/ Recreation	8/3/2006	Ranch 63, S. Fork S. Platte River	Upper South Platte River	8960	416516	4317822	Mineral	1.39
Plot 68	Riparian Shrubland	Riverine	71.25	Impacted	Grazing	8/8/2006	Knight-Imler	Upper South Platte River	9189	415940	4324409	Mineral	1.1
Plot 69	Wet Meadow	Riverine	73.45	Highly Impacted	Grazing	8/9/2006	S.Fork S. Platte River	Upper South Platte River	9000	417674	4317792	Mineral	2.49
Plot 70	Fen	Slope	69.90	Highly Impacted	Grazing	8/11/2006	Platte Ranch	Upper South Platte River	9340	419458	4332415	Organic	5.2
Plot 71	Riparian Shrubland	Riverine	94.90	Highly Impacted	Suburban	8/14/2006	Meadow Creek @ Dillon Reservoir	Blue River	9025	406374	4382617	Mineral	2.41
Plot 72	Riparian Shrubland	Riverine	63.20	Impacted	Suburban	8/15/2006	Willow Creek	Blue River	8960	405713	4389619	Mineral	0.87
Plot 73	Riparian Shrubland	Riverine	89.95	Highly Impacted	Suburban	8/16/2006	Frisco Bay	Blue River	9020	406315	4381492	Mineral	0.67
Plot 74	Fen	Slope	88.25	Highly Impacted	Utility Line	8/22/2006	Sewer Line Fen	Colorado River Headwaters	8855	434448	4416240	Organic	0.15
Plot 75	Fen	Slope	83.50	Highly Impacted	Mining	8/23/2006	Warm Springs	Upper South Platte River	10052	408992	4335304	Organic	1.11
Plot 76	Fen	Slope	69.28	Highly Impacted	Ditch	8/24/2006	Four mile Creek	Upper South Platte River	9240	419534	4328772	Organic	0.6
Plot 77	Fen	Slope	67.00	Highly Impacted	Ditch	8/24/2006	Four mile Creek	Upper South Platte River	9190	420930	4327457	Organic	3.76
Plot 78	Fen	Slope	51.35	Impacted	Grazing	8/25/2006	Elkhorn Road	Upper South Platte River	9640	425957	4351598	Organic	1.9

APPENDIX D: SPECIES FREQUENCY IN EACH ECOLOGICAL SYSTEM AND HUMAN DISTURBANCE CLASS

Values in table = number of plots/category species was present		Extremely Rich Fen			Fen			Riparian Shrubland			Riverine Wet Meadow			Slope Wet Meadow			
Species	**C Value[16]**	Hig Imp[17]	Imp[18]	Ref[19]	Hig Imp	Imp	Ref	Hig Imp	Imp	Ref	Hig Imp	Imp	Ref	Hig Imp	Imp	Ref	**Total # of Plots**
Abies lasiocarpa	5					1	1									1	**3**
Achillea millefolium var. occidentalis	4	1	1	1	5	3	2	7	8	7	3	2	2	2	2	1	**47**
Achnatherum nelsonii	6							4									**4**
Aconitum columbianum	8			1		1		1		5			1			1	**10**
Aconitum columbianum ssp. columbianum	8								1								**1**
Agoseris aurantiaca	6									1							**1**
Agoseris glauca	6		1	2	1			1			1		1	1			**8**
Agoseris glauca var. laciniata	7													1			**1**
Agropyron desertorum	*								1								**1**
Agrostis exarata	*								1								**1**
Agrostis gigantea	*			1	1			1	2				1		1		**7**
Agrostis humilis	10						3		1	2							**6**
Agrostis scabra	4			1	1	3	3	5	5	6	1		2	1		1	**29**
Agrostis stolonifera	*							1									**1**
Allium geyeri	5								2								**2**
Almutaster pauciflorus	4	1	1	2													**4**
Alnus incana ssp. tenuifolia	6		1					1	1								**3**
Alopecurus aequalis	4					1		3	1	3	1	1	1				**11**
Alopecurus alpinus	7								1	3							**4**
Alopecurus pratensis	*							2	3	1	1	1		1			**9**

---

[16] C value = coefficient of conservatism (Rocchio 2007); * = non-native species (defaulted to 0 in metric calculations); NCA = No C value has been assigned yet.
[17] Hig Imp = Highly Impacted sites
[18] Imp = Impacted site
[19] Ref = Reference site

Values in table = number of plots/category species was present		Extremely Rich Fen			Fen			Riparian Shrubland			Riverine Wet Meadow			Slope Wet Meadow			
Species	**C Value[16]**	Hig Imp[17]	Imp[18]	Ref[19]	Hig Imp	Imp	Ref	Hig Imp	Imp	Ref	Hig Imp	Imp	Ref	Hig Imp	Imp	Ref	**Total # of Plots**
Androsace filiformis	8								1	3							**4**
Androsace septentrionalis	6							1									**1**
Anemone cylindrica	5			1					1								**2**
Angelica pinnata	5															1	**1**
Antennaria anaphaloides	5			1										1			**2**
Antennaria can't read	5													1			**1**
Antennaria corymbosa	5		1	1	2	1		1	1	4	1		1		1	1	**15**
Antennaria luzuloides	5										1						**1**
Antennaria rosea	5			2				1	2	1		1					**7**
Antennaria umbrinella	8							1									**1**
Arabis drummondii	5							1	1	2							**4**
Arabis glabra	*					1		5	1	3					1	1	**12**
Arabis hirsuta var. pycnocarpa	3							1	1					1			**3**
Arctostaphylos uva-ursi	6							2									**2**
Arenaria lanuginosa ssp. saxosa	NCA								1								**1**
Argentina anserina	3	2		2	3	2		1	4		3	2			1		**20**
Arnica cordifolia	7					1										1	**2**
Arnica fulgens	6										1						**1**
Arnica mollis	7					1	2			2						1	**6**
Artemisia arbuscula	7														1		**1**
Artemisia biennis	*				1												**1**
Artemisia campestris	7							1	1								**2**
Artemisia campestris ssp. borealis var. borealis	5							1	1								**2**
Artemisia cana ssp. cana	5					1		4	1	1					1		**8**
Artemisia frigida	4	1			2			1	2		1						**7**
Artemisia ludoviciana	4										1						**1**
Artemisia tridentata	4													1			**1**
Astragalus alpinus	6				1	1		2	2	1							**7**
Astragalus bodinii	NCA				1												**1**

Values in table = number of plots/category species was present		Extremely Rich Fen			Fen			Riparian Shrubland			Riverine Wet Meadow			Slope Wet Meadow			
Species	**C Value[16]**	Hig Imp[17]	Imp[18]	Ref[19]	Hig Imp	Imp	Ref	Hig Imp	Imp	Ref	Hig Imp	Imp	Ref	Hig Imp	Imp	Ref	**Total # of Plots**
Astragalus hallii	NCA								1								**1**
Astragalus leptaleus	8				1						1						**2**
Astragalus pubentissimus	NCA							1									**1**
Astragalus spatulatus	6								1								**1**
Axyris amaranthoides	*				2				1		1						**4**
Beckmannia syzigachne	4							2				3					**5**
Betula nana	9			2	1	2	3	4	2	5			1		1		**21**
Botrychium simplex	4									1							**1**
Bromus inermis ssp. inermis var. inermis	*							7	3						2	1	**13**
Bromus inermis ssp. pumpellianus var. pumpellianus	6					1	1	2	3	4			1			1	**13**
Bromus porteri	5							2	1								**3**
Calamagrostis canadensis	6				2	3	5	4	4	8			2	1		1	**30**
Calamagrostis stricta	7	1	1	5	3			2		2	1	1		2	1	1	**20**
Callitriche palustris	5				1								1				**2**
Caltha leptosepala ssp. leptosepala var. leptosepala	7					1	7	1		3				1		1	**14**
Campanula parryi	7			1	2			2	1		1						**7**
Campanula rotundifolia	5		1					3		1						1	**6**
Cardamine cordifolia	8						3	2	4	7			2			1	**19**
Carduus nutans ssp. macrolepis	*								1								**1**
Carex aquatilis	6	2	1	5	3	7	9	3	8	9	3	3	2		2	1	**58**
Carex athrostachya	7							1							1		**2**
Carex aurea	7		1		1	1	1			4	1				1	1	**11**
Carex canescens	8						6		2	4			2				**14**
Carex capillaris	9		1	3		1	1										**6**
Carex disperma	9						2			2						1	**5**
Carex douglasii	5		1									1					**2**

Values in table = number of plots/category species was present		Extremely Rich Fen			Fen			Riparian Shrubland			Riverine Wet Meadow			Slope Wet Meadow			
Species	**C Value[16]**	Hig Imp[17]	Imp[18]	Ref[19]	Hig Imp	Imp	Ref	Hig Imp	Imp	Ref	Hig Imp	Imp	Ref	Hig Imp	Imp	Ref	**Total # of Plots**
Carex ebenea	4					1		1		1							**3**
Carex foenea	6							2									**2**
Carex geyeri	6														1		**1**
Carex gynocrates	10						1										**1**
Carex illota	9						1										**1**
Carex interior	7		1				2		1				1				**5**
Carex lachenalii	10						1										**1**
Carex livida	10			1													**1**
Carex magellanica ssp. irrigua	9						1										**1**
Carex microglochin	9		2	1						1							**4**
Carex microptera	5					1		7	3	8	1		1	1	3		**25**
Carex nebrascensis	5				1	1			1						1		**4**
Carex nelsonii	9					1				3							**4**
Carex nigricans	8						2										**2**
Carex norvegica	8								1								**1**
Carex norvegica ssp. stevenii	8					1	1	3	2	7						1	**15**
Carex nova	10						1										**1**
Carex obtusata	8														1		**1**
Carex occidentalis	7							1									**1**
Carex pachystachya	NCA							1			1				1		**3**
Carex parryana	7		1	1	1										1		**4**
Carex pellita	6					2		2	2	1					1		**8**
Carex phaeocephala	9								1						1	1	**3**
Carex praegracilis	5				1			2	3	1		1			2	2	**12**
Carex praticola	6								1	1							**2**
Carex scirpoidea	9		2	3	1										1		**7**
Carex scopulorum	7						1			1							**2**
Carex simulata	6	1	2	6	2	4	2		3			1	1	2	1		**25**
Carex utriculata	5		1	3	4	7	4	5	6	6	3	2	3	1	4	1	**50**
Carex vesicaria	*					1											**1**

Values in table = number of plots/category species was present		**Extremely Rich Fen**			**Fen**			**Riparian Shrubland**			**Riverine Wet Meadow**			**Slope Wet Meadow**			
Species	**C Value[16]**	Hig Imp[17]	Imp[18]	Ref[19]	Hig Imp	Imp	Ref	Hig Imp	Imp	Ref	Hig Imp	Imp	Ref	Hig Imp	Imp	Ref	**Total # of Plots**
Carex viridula	9			1													**1**
Carum carvi	*							1									**1**
Castilleja rhexiifolia	8						1									1	**2**
Castilleja sulphurea	7					1		4	2	5			1				**13**
Catabrosa aquatica	7					1				1							**2**
Cerastium arvense	*									1							**1**
Cerastium arvense ssp. strictum	5					1		2	1	1							**5**
Cerastium fontanum	*					1		3		1					1		**6**
Ceratophyllum demersum	1		1	1				1									**3**
Chamerion angustifolium ssp. circumvagum	4					1	3	5	4	8			1			1	**23**
Chamerion latifolium	7							2		1							**3**
Chenopodium album	*				1				2		1				1	1	**6**
Chenopodium atrovirens	5					1											**1**
Chenopodium leptophyllum	5				1												**1**
Chenopodium rubrum	2				1												**1**
Chrysothamnus viscidiflorus	5														1		**1**
Cicuta douglasii	3								1				1				**2**
Cirsium arvense	*	1			1	1		6	6		2	1	1	2	2	1	**24**
Cirsium canescens	6				3			2									**5**
Cirsium parryi	5							1		1						1	**3**
Cirsium scariosum	6	2	1	2	2	1		5	4		2	2		1	1		**23**
Coeloglossum viride var. virescens	7						1										**1**
Collomia linearis	4														1		**1**
Comarum palustre	9						1										**1**
Conioselinum scopulorum	7		1	2	3	1	6	4	5	8	2		2			1	**35**
Crepis runcinata ssp. runcinata	6	1	2	2	3				1		2	1			1		**13**

Values in table = number of plots/category species was present		Extremely Rich Fen			Fen			Riparian Shrubland			Riverine Wet Meadow			Slope Wet Meadow			
Species	**C Value**[16]	Hig Imp[17]	Imp[18]	Ref[19]	Hig Imp	Imp	Ref	Hig Imp	Imp	Ref	Hig Imp	Imp	Ref	Hig Imp	Imp	Ref	**Total # of Plots**
Danthonia intermedia	8					1		3		1							**5**
Danthonia parryi	8									1							**1**
Dasiphora floribunda	4	1	2	5	2	3	5	8	6	6	3		2	1	2	1	**47**
Delphinium barbeyi	7						2	1	1								**4**
Deschampsia caespitosa	4	1	2	6	4	6	6	5	8	7	3	3	2	2	3	2	**60**
Descurainia incana	2	1															**1**
Descurainia incana ssp. incisa	2				1					1					1		**3**
Descurainia pinnata	2				1			1			1			1			**4**
Descurainia sophia	*							2	1		1				1		**5**
Dodecatheon pulchellum	8	1	1	3	1	2		1	1	1	1				1		**13**
Draba aurea	7								1								**1**
Eleocharis palustris	4			1	1				1		1	2	1				**7**
Eleocharis quinqueflora	8	1	2	4	2	2	3		1						1		**16**
Elodea bifoliata	NCA					1											**1**
Elymus elymoides ssp. brevifolius	NCA							1									**1**
Elymus repens	*							2	1		1	1					**5**
Elymus trachycaulis	7					1											**1**
Elymus trachycaulus	4	2	1	2		1	2	3	4	2		1	2		1		**21**
Epilobium ciliatum ssp. ciliatum	4			2	4	2		5	2	4		2	1	1	1	2	**26**
Epilobium ciliatum ssp. glandulosum	4			1			1	4	4	5	1	1	1				**18**
Epilobium hornemannii	6					1	1		2	1					1		**6**
Epilobium lactiflorum	7						1			1							**2**
Epilobium leptophyllum	8	1	1	2	3	2	2		1	1	1	1	1				**16**
Epilobium saximontanum	6							1									**1**
Equisetum arvense	4		1	2	3	3	3	6	6	6		1	2		2	2	**37**
Equisetum hyemale var. affine	4				1						2						**3**
Equisetum laevigatum	4				1			1					1				**3**

Values in table = number of plots/category species was present		**Extremely Rich Fen**			**Fen**			**Riparian Shrubland**			**Riverine Wet Meadow**			**Slope Wet Meadow**			
Species	**C Value[16]**	Hig Imp[17]	Imp[18]	Ref[19]	Hig Imp	Imp	Ref	Hig Imp	Imp	Ref	Hig Imp	Imp	Ref	Hig Imp	Imp	Ref	**Total # of Plots**
Equisetum variegatum var. variegatum	5			2	1	1	1										**5**
Ericameria nauseosa ssp. nauseosa var. glabrata	3								1								**1**
Ericameria parryi var. parryi	4							1							1		**2**
Erigeron elatior	7									1							**1**
Erigeron flagellaris	3							1	1								**2**
Erigeron formosissimus	6							1		1							**2**
Erigeron glabellus	6								1						1	1	**3**
Erigeron lonchophyllus	5		1	1	2	2		1	2		2	1		3			**15**
Erigeron peregrinus ssp. callianthemus	7						2	3		2						1	**8**
Erigeron subtrinervis	NCA					1											**1**
Eriogonum lonchophyllum	4														1		**1**
Eriogonum umbellatum	6							2		1						1	**4**
Eriophorum angustifolium	9	1	1	1													**3**
Erysimum cheiranthoides	3					1		1	1								**3**
Erysimum inconspicuum	NCA								1								**1**
Festuca arizonica	6		1						1								**2**
Festuca brachyphylla ssp. coloradensis	7						2	1	2	2							**7**
Festuca idahoensis	7							1									**1**
Festuca rubra	5			1		1		2		1				1			**6**
Festuca saximontana	7							1	1								**2**
Festuca thurberi	8							3	1	2							**6**
Fragaria virginiana ssp. glauca	5			1		1	2	4	3	8			3		1	1	**24**
Galium boreale	6			2				5	3	3							**13**
Galium trifidum ssp. subbiflorum	7				2	2	2		2	6		1	2			1	**18**

Values in table = number of plots/category species was present		Extremely Rich Fen			Fen			Riparian Shrubland			Riverine Wet Meadow			Slope Wet Meadow			
Species	**C Value[16]**	Hig Imp[17]	Imp[18]	Ref[19]	Hig Imp	Imp	Ref	Hig Imp	Imp	Ref	Hig Imp	Imp	Ref	Hig Imp	Imp	Ref	**Total # of Plots**
Galium triflorum	7								1								**1**
Gaultheria humifusa	8						2										**2**
Gentiana affinis	8		1	1		1		2	2		3						**10**
Gentiana fremontii	9	1	2	2	1	1				1	1				1		**10**
Gentiana parryi	9				1												**1**
Gentiana prostrata	9			1													**1**
Gentianella amarella ssp. acuta	8	1	1	1	1	1			1	1	1						**8**
Gentianella amarella ssp. heterosepala	8							1		1							**2**
Gentianopsis thermalis	8	1	1	1	2	2	1			2	2				1		**13**
Geranium caespitosum var. caespitosum	4							1									**1**
Geranium richardsonii	6							2		3					1	1	**7**
Geranium viscosissimum var. incisum	5								1								**1**
Geum aleppicum	6															1	**1**
Geum macrophyllum var. perincisum	6				1	3	2	5	4	7	1		2		1	1	**27**
Geum rivale	5												1				**1**
Geum triflorum var. triflorum	7					1	1	4	1	4	1						**12**
Gilia ophthalmoides	6								1								**1**
Glaux maritima	7											1					**1**
Glyceria borealis	8								1				1				**2**
Glyceria grandis	6											1					**1**
Glyceria striata	6				1	1		4	1	2	1		2		2	1	**15**
Grindelia inornata	3								1								**1**
Gutierrezia sarothrae	3								2								**2**
Hackelia floribunda	3	1				1		3	2					1	1	1	**10**
Helenium autumnale var. montanum	5									1							**1**

Values in table = number of plots/category species was present		**Extremely Rich Fen**			**Fen**			**Riparian Shrubland**			**Riverine Wet Meadow**			**Slope Wet Meadow**			
Species	**C Value[16]**	Hig Imp[17]	Imp[18]	Ref[19]	Hig Imp	Imp	Ref	Hig Imp	Imp	Ref	Hig Imp	Imp	Ref	Hig Imp	Imp	Ref	**Total # of Plots**
Helianthella parryi	5								1								**1**
Heracleum maximum	6						1	3	1	2			1				**8**
Hesperostipa comata	6														1		**1**
Hippuris vulgaris	6				1	1			1			1					**4**
Hordeum brachyantherum ssp. brachyantherum	*	1	1		2	3		4	6		2	2	1	2	2		**26**
Hordeum jubatum ssp. jubatum	2			1	2			1	1		1	2					**8**
Hymenopappus filifolius var. parvulus	NCA								1								**1**
Hymenoxys hoopesii	5				1			1									**2**
Hymenoxys richardsonii var. richardsonii	4							1	1								**2**
Iris missouriensis	4			1				3	4		1	1			1		**11**
Juncus alpinoarticulatus	9	1	1	2													**4**
Juncus articulatus	*				2												**2**
Juncus balticus var. montanus	4	2	2	4	5	6	1	7	7	4	3	1	3	2	4	1	**52**
Juncus bufonius	3							1									**1**
Juncus compressus	*						2	1								1	**4**
Juncus confusus	5								1	1							**2**
Juncus drummondii	6									1							**1**
Juncus hallii	NCA								1								**1**
Juncus longistylis	6			2	1	2		2	1	1			1	1		2	**13**
Juncus mertensianus	7						1			2						1	**4**
Juncus saximontanus	6									1							**1**
Juncus tracyi	6					3	2	4	1	2			1			1	**14**
Juncus triglumis	10									1							**1**
Juncus vaseyi	NCA									1							**1**
Juniperus communis var. montana	6							2								1	**3**
Kalmia microphylla	9						1										**1**

Values in table = number of plots/category species was present		**Extremely Rich Fen**			**Fen**			**Riparian Shrubland**			**Riverine Wet Meadow**			**Slope Wet Meadow**			
Species	**C Value[16]**	Hig Imp[17]	Imp[18]	Ref[19]	Hig Imp	Imp	Ref	Hig Imp	Imp	Ref	Hig Imp	Imp	Ref	Hig Imp	Imp	Ref	**Total # of Plots**
Kobresia myosuroides	9		1	3	1										1		**6**
Kobresia simpliciuscula	10	1	2	2													**5**
Koeleria macrantha	6	1	1	1	1	2		2		2	2			1	1		**14**
Lactuca serriola	*							1									**1**
Lappula occidentalis var. occidentalis	2								1								**1**
Lemna minor	2					1											**1**
Lepidium campestre	*							1							1		**2**
Lepidium densiflorum	*				2						1				1		**4**
Lepidium ramosissimum	2								1		1	1					**3**
Leucanthemum vulgare	*							1							1		**2**
Ligusticum tenuifolium	8								1	1						1	**3**
Linaria vulgaris	*							1									**1**
Linum lewisii var. lewisii	4								1		1	1					**3**
Listera borealis	9										1						**1**
Lolium pratense	*								2					1	1		**4**
Lomatium dissectum var. multifidum	7														1		**1**
Lomatogonium rotatum	9				2	1				1		1					**5**
Lonicera involucrata var. involucrata	7					2	3	4	3	3			2		1	2	**20**
Lupinus argenteus	5							1	1	1							**3**
Lupinus caespitosus	NCA							1									**1**
Luzula comosa	7									2							**2**
Luzula parviflora	7					2	4		3	7			1			1	**18**
Luzula subcapitata	8						1										**1**
Maianthemum racemosum ssp. amplexicaule	7						3		1	2						1	**7**
Maianthemum stellatum	7						1	4	3	2							**10**
Melilotus officinalis	*							2	1								**3**
Mentha arvensis	4							1	2			1					**4**
Mertensia ciliata	7			1		1		5	4	7	1		2			1	**22**

Values in table = number of plots/category species was present		Extremely Rich Fen			Fen			Riparian Shrubland			Riverine Wet Meadow			Slope Wet Meadow			
Species	**C Value[16]**	Hig Imp[17]	Imp[18]	Ref[19]	Hig Imp	Imp	Ref	Hig Imp	Imp	Ref	Hig Imp	Imp	Ref	Hig Imp	Imp	Ref	**Total # of Plots**
Mimulus guttatus	8			1		1	1		3	3							**9**
Mitella pentandra	9						2		1								**3**
Moehringia lateriflora	8								2	1							**3**
Monarda pectinata	5									1							**1**
Moneses uniflora	9															1	**1**
Monolepis nuttalliana	4				1				1								**2**
Montia chamissoi	8				1		3	1	1	5			1				**12**
Muhlenbergia filiculmis	4								1								**1**
Muhlenbergia filiformis	8		1		1			1	1		2				1		**7**
Muhlenbergia richardsonis	8		1	3	3	2		1				1			1		**12**
Nassella viridula	4														1		**1**
Orthilia secunda	8						2										**2**
Orthocarpus luteus	6			1													**1**
Osmorhiza depauperata	7															1	**1**
Oxypolis fendleri	7						3			6			1			1	**11**
Oxytropis deflexa var. sericea	NCA							1									**1**
Oxytropis sericea	5				1			1									**2**
Oxytropis splendens	NCA								1								**1**
Packera crocata	6							2									**2**
Packera dimorphophylla	6							1									**1**
Packera pauciflora	9	1	2	2	1						2				1		**9**
Packera pseudaurea	7		1		1	1	2		2	2		1		1			**11**
Packera pseudaurea var. pseudaurea	7							1									**1**
Packera streptanthifolia	8							1									**1**
Parnassia fimbriata	8						1			1							**2**
Parnassia palustris var. parviflora	7	1	2	5	2		1		2								**13**
Pascopyrum smithii	5	1							1								**2**
Pedicularis crenulata	7			2	2	1					1						**6**
Pedicularis groenlandica	8	1	1	3	2	2	7	3	3	6							**28**

Values in table = number of plots/category species was present		Extremely Rich Fen			Fen			Riparian Shrubland			Riverine Wet Meadow			Slope Wet Meadow			
Species	**C Value[16]**	Hig Imp[17]	Imp[18]	Ref[19]	Hig Imp	Imp	Ref	Hig Imp	Imp	Ref	Hig Imp	Imp	Ref	Hig Imp	Imp	Ref	**Total # of Plots**
Pedicularis parryi	9									1						1	**2**
Penstemon auriberbis	7											1					**1**
Penstemon procerus var. procerus	6							1	2								**3**
Penstemon rydbergii	7							1		3							**4**
Penstemon unilateralis	NCA							1	1								**2**
Phalaris arundinacea	*							1									**1**
Phleum alpinum	6			1		1	2	3	2	8	1		1				**19**
Phleum pratense	*				3	2		6	2	1	1		1	2	2		**20**
Phlox longifolia	6										1						**1**
Picea engelmannii	5				1	1	4		1	1					1	1	**10**
Picea pungens	6			2		1	4	1	1	5					1		**15**
Pinus contorta var. latifolia	5				1	1	1	4	3	5							**15**
Plantago eriopoda	5	1			1				1		1						**4**
Plantago major	*							1			2		1				**4**
Plantago tweedyi	5								1								**1**
Platanthera dilatata var. albiflora	8						3			1						1	**5**
Platanthera hyperborea var. hyperborea	7		1	3	1	3	2	1					1			1	**13**
Platanthera stricta	8			1			1	1	3								**6**
Poa alpina	7							3		3							**6**
Poa arctica	7										1				1		**2**
Poa arida	5	1															**1**
Poa cusickii ssp. pallida	6			1			1	1	2			1		1			**7**
Poa fendleriana	7				1					1							**2**
Poa glauca ssp. rupicola	7			1		1				1							**3**
Poa leptocoma	8						2	1		5						1	**9**
Poa nemoralis ssp. interior	6				1												**1**
Poa palustris	6				1		1	5	2	3		1	1	1			**15**

Values in table = number of plots/category species was present		Extremely Rich Fen			Fen			Riparian Shrubland			Riverine Wet Meadow			Slope Wet Meadow			
Species	**C Value[16]**	Hig Imp[17]	Imp[18]	Ref[19]	Hig Imp	Imp	Ref	Hig Imp	Imp	Ref	Hig Imp	Imp	Ref	Hig Imp	Imp	Ref	**Total # of Plots**
Poa pratensis	*	1	1		2	4	1	8	8	3	3		1	2	2	1	**37**
Poa pratensis ssp. pratensis	4							1		2					1		**4**
Poa reflexa	8								1				1			1	**3**
Poa secunda	6				3			1	1		1						**6**
Polemonium	6						1										**1**
Polemonium foliosissimum	7				1		1	1	1	3							**7**
Polemonium occidentale ssp. occidentale	8					1	2	1	1	1			2				**8**
Polemonium pulcherrimum ssp. delicatum	8								1								**1**
Polygonum achoreum	*										1						**1**
Polygonum amphibium var. emersum	4											1					**1**
Polygonum bistortoides	7						1		1	4						1	**7**
Polygonum douglasii	3				1			2	1	2							**6**
Polygonum viviparum	8		1	4	2	2	4	3	3	6	1		2	1		1	**30**
Populus angustifolia	5															1	**1**
Populus tremuloides	5		1							1						1	**3**
Potamogeton epihydrus	5			1	1	1											**3**
Potentilla biennis	4												1		1		**2**
Potentilla diversifolia	6		1			3				1	2						**7**
Potentilla gracilis var. glabrata	NCA														1		**1**
Potentilla hippiana	5	1			1			1			1			1			**5**
Potentilla norvegica	*							4	1						1		**6**
Potentilla pensylvanica	6		1	2	1	1			1			1			1		**8**
Potentilla plattensis	7			1	2				2		1						**6**
Potentilla pulcherrima	5						1	5	2	3	1			1	2		**15**
Potentilla rivalis	5							2									**2**

Values in table = number of plots/category species was present		Extremely Rich Fen			Fen			Riparian Shrubland			Riverine Wet Meadow			Slope Wet Meadow			
Species	**C Value[16]**	Hig Imp[17]	Imp[18]	Ref[19]	Hig Imp	Imp	Ref	Hig Imp	Imp	Ref	Hig Imp	Imp	Ref	Hig Imp	Imp	Ref	**Total # of Plots**
Potentilla subjuga	8				1			1									**2**
Primula egaliksensis	10		1	3	1												**5**
Primula incana	9			1											1		**2**
Primula parryi	8									1							**1**
Prunella vulgaris	4														1		**1**
Pseudocymopterus montanus	6					1		1									**2**
Pseudoroegneria spicata ssp. inermis	7														1		**1**
Pseudoroegneria spicata ssp. spicata	7		1		2	1		3	2		2				1		**12**
Ptilagrostis porteri	10						1										**1**
Puccinellia nuttalliana	6				1						1						**2**
Pyrola asarifolia ssp. asarifolia	8						2										**2**
Pyrola minor	8								2							1	**3**
Pyrrocoma clementis	6		1														**1**
Pyrrocoma lanceolata	NCA					1					1	1					**3**
Ranunculus cymbalaria	4		1	1	3	3			2			2		1	1		**14**
Ranunculus gmelinii	6				1				2								**3**
Ranunculus hyperboreus	8				2	1	1			2							**6**
Ranunculus macounii	7					1		2							1		**4**
Ranunculus pedatifidus	7							1									**1**
Ranunculus repens	*							1									**1**
Ranunculus trichophyllus var. trichophyllus	10								1								**1**
Rhodiola integrifolia	8									1			1				**2**
Rhodiola rhodantha	8			1	1	1	6			6			1	1		1	**18**
Ribes cereum	6								1								**1**
Ribes inerme	5				1			1	2								**4**
Ribes lacustre	7			1				1		1				1			**4**
Ribes montigenum	6			1				1	1	1			1	1			**6**

Values in table = number of plots/category species was present		Extremely Rich Fen			Fen			Riparian Shrubland			Riverine Wet Meadow			Slope Wet Meadow			
Species	**C Value[16]**	Hig Imp[17]	Imp[18]	Ref[19]	Hig Imp	Imp	Ref	Hig Imp	Imp	Ref	Hig Imp	Imp	Ref	Hig Imp	Imp	Ref	**Total # of Plots**
Rorippa curvipes	5				1												**1**
Rorippa nasturtium-aquaticum	*								1								**1**
Rorippa palustris	NCA					1			2		1		1			1	**6**
Rorippa palustris ssp. hispida	NCA									1							**1**
Rorippa sinuata	4							2	1		1				1		**5**
Rorippa sphaerocarpa	4											1	1				**2**
Rosa woodsii	5							3	1	1			1				**6**
Rubus idaeus ssp. strigosus	5							1	1								**2**
Rumex acetosella	*							1									**1**
Rumex aquaticus var. fenestratus	5			1	1	2					1	1			1		**7**
Rumex crispus	*							3	1		1						**5**
Rumex densiflorus	5							1	2	1			1	1			**6**
Rumex obtusifolius	*							1									**1**
Rumex salicifolius var. denticulatus	4									1							**1**
Rumex salicifolius var. mexicanus	4							1	2						1		**4**
S.monticola x S. planifolia	NCA			1													**1**
Sagina saginoides	7								1	4							**5**
Salix boothii	7														1		**1**
Salix brachycarpa	8	1	2	5	3	1	1	2	2	1	3			1	1		**23**
Salix candida	9	1	1	4	1		1										**8**
Salix drummondiana	6				1	1		4	2	4			2				**14**
Salix eriocephala	6				1			2	2	1			1				**7**
Salix exigua	3							1	2							1	**4**
Salix geyeriana	6			1	1	3	2	6	2	4	1		2		2	1	**25**
Salix lucida ssp. lasiandra	6					1											**1**
Salix monticola	6	1		3	2	2	1	8	7	6		1	3	1	1	1	**37**
Salix myrtillifolia	6		1	4			1				1				1		**8**

Values in table = number of plots/category species was present		Extremely Rich Fen			Fen			Riparian Shrubland			Riverine Wet Meadow			Slope Wet Meadow			
Species	**C Value[16]**	Hig Imp[17]	Imp[18]	Ref[19]	Hig Imp	Imp	Ref	Hig Imp	Imp	Ref	Hig Imp	Imp	Ref	Hig Imp	Imp	Ref	**Total # of Plots**
Salix planifolia	7	1	1	5	3	4	9	2	4	7	1		2	1	2	2	**44**
Salix planifolia	7				1												**1**
Salix wolfii	8				1	2	5	4	2	4			1				**19**
Salsola tragus	*				1												**1**
Saxifraga hirculus	9			1			1										**2**
Saxifraga odontoloma	8					1	3			5			1			1	**11**
Saxifraga oregana	8						2									1	**3**
Schoenoplectus pungens	4			1													**1**
Scutellaria galericulata	7															2	**2**
Senecio bigelovii var. hallii	7					1				2							**3**
Senecio eremophilus var. kingii	4							2				1					**3**
Senecio hydrophilus	6							1	1					1			**3**
Senecio integerrimus	5			1					1								**2**
Senecio serra var. admirabilis	7												1				**1**
Senecio triangularis	7					1	4		2	7			1			1	**16**
Sidalcea neomexicana	5							1									**1**
Sisyrinchium montanum	6			1							1	1			1	1	**5**
Sisyrinchium pallidum	7			1							1	1					**3**
Sium suave	6				1			1						1			**3**
Solanum triflorum	2								1								**1**
Solidago canadensis	5							1			1				1		**3**
Solidago multiradiata var. scopulorum	5							3	1	3							**7**
Sparganium angustifolium	7								1	1							**2**
Spartina gracilis	7										1						**1**
Sphagnum sp.	*						1										**1**
Spiranthes romanzoffiana	7		1	1	1												**3**
Stellaria calycantha	8						1		1	2			1				**5**
Stellaria crassifolia	7					1	2		3	5							**11**

Values in table = number of plots/category species was present		Extremely Rich Fen			Fen			Riparian Shrubland			Riverine Wet Meadow			Slope Wet Meadow			
Species	**C Value[16]**	Hig Imp[17]	Imp[18]	Ref[19]	Hig Imp	Imp	Ref	Hig Imp	Imp	Ref	Hig Imp	Imp	Ref	Hig Imp	Imp	Ref	**Total # of Plots**
Stellaria graminea	*													1			**1**
Stellaria longifolia	7				1	2	4	5	2	4			2		2		**22**
Stellaria longipes	8			1		1		1		1	2	1					**7**
Stuckenia pectinatus	3	1	1	1		1			1								**5**
Swertia perennis	8					2	8		2	4			1			1	**18**
Symphyotrichum ascendens	5							2						1			**3**
Symphyotrichum boreale	7				1												**1**
Symphyotrichum campestre var. campestre	NCA											1					**1**
Symphyotrichum foliaceum var. foliaceum	5	2				2	2	5	1	2			1				**15**
Symphyotrichum laeve var. geyeri	6			1													**1**
Symphyotrichum lanceolatum ssp. hesperium var. hesperium	5				1			4	3	4	2		1				**15**
Symphyotrichum spathulatum var. spathulatum	6		2		4			4	1	1	2	1			1		**16**
Taraxacum officinale	*	1	1		4	4	2	9	8	7	3	2	2	1	4	1	**49**
Thalictrum alpinum	8	1	2	4	2	1	3	4	2	4	2			1	1		**27**
Thalictrum fendleri	6							3	1	1							**5**
Thalictrum sparsiflorum	5								1								**1**
Thelypodium integrifolium	6					1		1							1		**3**
Thelypodium wrightii ssp. oklahomense	7										1						**1**
Thermopsis montana	6							1	2								**3**
Thlaspi arvense	*					1		3	2		1	1		1	1	1	**11**
Thlaspi montanum var. montanum	5								1	1							**2**

Values in table = number of plots/category species was present		**Extremely Rich Fen**			**Fen**			**Riparian Shrubland**			**Riverine Wet Meadow**			**Slope Wet Meadow**			
Species	**C Value[16]**	Hig Imp[17]	Imp[18]	Ref[19]	Hig Imp	Imp	Ref	Hig Imp	Imp	Ref	Hig Imp	Imp	Ref	Hig Imp	Imp	Ref	**Total # of Plots**
Tragopogon dubius	*					1		1							1	1	**4**
Tragopogon pratensis	*				1						1						**2**
Trichophorum pumilum	10			2													**2**
Trifolium parryi	8									1							**1**
Trifolium pratense	*							2	1					1		1	**5**
Trifolium repens	*				3	2	1	4	2	1					1		**14**
Triglochin maritimum	6	1	2	4	2	1			2		2						**14**
Triglochin palustre	7	1	2	6	3	1		3	1			2			1		**20**
Tripleurospermum perforata	*							4									**4**
Trisetum spicatum	7					1		4	1	3							**9**
Trisetum wolfii	7						3	1		2	1					1	**8**
Trollius laxus ssp. albiflorus	8						2									1	**3**
Typha angustifolia	*					1											**1**
Urtica dioica ssp. holosericea	3							1									**1**
Urtica gracilis Aiton subsp. gracilis	3								1							1	**2**
Utricularia macrorhiza	7		1	1	1		1		1								**5**
Utricularia ochroleuca	10		1	1													**2**
Vaccinium caespitosum	7						3		1	2			1			1	**8**
Vaccinium myrtillus var. oreophilum	6						3			1							**4**
Vaccinium scoparium	7						2									1	**3**
Valeriana acutiloba var. acutiloba	8							1	1				1				**3**
Valeriana edulis	7			1			1	4	2		3				1		**12**
Valeriana occidentalis	7							1		4							**5**
Veratrum tenuipetalum	4									1						1	**2**
Verbascum thapsus	*							1									**1**
Veronica americana	6				1	1		1	4	5	1		2			1	**16**

Values in table = number of plots/category species was present		**Extremely Rich Fen**			**Fen**			**Riparian Shrubland**			**Riverine Wet Meadow**			**Slope Wet Meadow**			
Species	**C Value[16]**	Hig Imp[17]	Imp[18]	Ref[19]	Hig Imp	Imp	Ref	Hig Imp	Imp	Ref	Hig Imp	Imp	Ref	Hig Imp	Imp	Ref	**Total # of Plots**
Veronica anagallis-aquatica	*								1								**1**
Veronica serpyllifolia ssp. humifusa	6									3							**3**
Veronica wormskjoldii	7					1	3		1	6			1			1	**13**
Vicia americana	6							6	1	3					1	1	**12**
Vicia ludoviciana ssp. ludoviciana	7							1	1								**2**
Viola macloskeyi ssp. pallens	NCA				1												**1**
Viola renifolia	7					1		1	1				1				**4**
Viola sororia	8						3			1			1		1		**6**
Zigadenus elegans ssp. elegans	6		1	2												1	**4**
	Grand Total	**52**	**97**	**233**	**227**	**234**	**295**	**546**	**468**	**537**	**154**	**85**	**134**	**70**	**146**	**115**	**3393**

APPENDIX E: GUIDE TO VEGETATION CHARACTERISTICS OF REFERENCE AND HIGHLY IMPACTED EXAMPLES OF EACH WETLAND SYSTEM

Ecological System	**Ecological Condition**	
	Reference[20]	**Highly Impacted**[21]
Riparian Shrublands	▪ Percentage of non-native species is ≤ 1.5% ▪ Mean coefficient of conservatism is ≥ 6.25 ▪ Average wetland indicator status (of all species) is ≤ -1.4 ▪ Relative cover of hydrophytes is ≥ 73% ▪ Percentage of native forbs present is ≥ 51% ▪ Percentage of native perennials present is ≥ 78% ▪ Number of invasive species is ≤ 2 ▪ Percentage of intolerant species is ≥ 14% ▪ Percentage of tolerant species is ≤ 3%	▪ Percentage of non-native species is ≥ 12% ▪ Mean coefficient of conservatism is ≤ 5.8 ▪ Average wetland indicator status (of all species) is ≥ -1.3 ▪ Relative cover of hydrophytes is ≤ 67% ▪ Percentage of native forbs present is ≤ 51% ▪ Percentage of native perennials present is ≤ 72% ▪ Number of invasive species is ≥ 6 ▪ Percentage of intolerant species is ≥ 14% ▪ Percentage of tolerant species is ≥ 7%
Fens	▪ Percentage of non-native species is ≤ 4% ▪ Average cover of dominant native species is ≥ 63% ▪ Mean coefficient of conservatism is ≥ 6.84 ▪ Average cover of hydrophytes is ≥ 80% ▪ Average cover of bare ground is ≤ 1% ▪ Average cover of litter ≥ 26%	▪ Percentage of non-native species is ≤ 4% ▪ Average cover of dominant native species is ≤ 63% ▪ Mean coefficient of conservatism is ≤ 6.14 ▪ Average cover of hydrophytes is ≤ 79% ▪ Average cover of bare ground is ≥ 4% ▪ Average cover of litter is ≤ 25%
Extremely Rich Fens	▪ Average cover of dominant native species is ≥ 43% ▪ Average cover of hydrophytes is ≥ 48% ▪ Relative cover of annuals is ≤ 1% ▪ Average cover of intolerant species is ≥ 12% ▪ Average cover of native perennials is ≥ 55% ▪ Native Annual/Perennial Ratio is ≤ 0.07	▪ Average cover of dominant native species is ≤ 35% ▪ Average cover of hydrophytes is ≤ 30% ▪ Relative cover of annuals is ≥ 2% ▪ Average cover of intolerant species is ≤ 12% ▪ Average cover of native perennials is ≤ 36% ▪ Native Annual/Perennial Ratio is ≥ 0.07

---

[20] Values represent upper quartile for metrics which decrease with human disturbance and lower quartile for metrics which increase with human disturbance.
[21] Values represent lower quartile for metrics which decrease with human disturbance and upper quartile for metrics which increase with human disturbance.

Ecological System	**Ecological Condition**	
	Reference[20]	**Highly Impacted[21]**
Slope Wet Meadows	▪ Average cover weighted FQI ≥ 18.43 ▪ Average cover of perennials is ≥ 86% ▪ Number of perennial species is ≥ 39 ▪ Relative cover of Poaceae species is ≤ 16% ▪ Average cover of rhizomatous species is ≥ 58%	▪ Average cover weighted FQI ≤ 11.74 ▪ Average cover of perennials is ≤ 45% ▪ Number of perennial species is ≤ 32 ▪ Relative cover of Poaceae species is ≥ 27% ▪ Average cover of rhizomatous species is ≤ 31%
Riverine Wet Meadows	▪ Percentage of non-native species is ≤ 8% ▪ Average wetland indicator status (of all species) is ≤ -2.1 ▪ Number of invasive species is ≤ 3 ▪ Number of Asteraceae species is ≤ 6 ▪ Relative cover of Poaceae species is ≤ 5% ▪ Rhizomatous/Nonrhizomatous Ratio is ≥ 1.05	▪ Percentage of non-native species is ≥ 8% ▪ Average wetland indicator status (of all species) is ≥ -1.8 ▪ Number of invasive species is ≥ 4 ▪ Number of Asteraceae species is ≥ 6 ▪ Relative cover of Poaceae species is ≥ 6% ▪ Rhizomatous/Nonrhizomatous Ratio is ≤ 1.00