THESIS

DISTINGUISHING THE HYDROLOGIC REGIMES AND VEGETATION OF FENS AND WET MEADOWS IN THE ROCKY MOUNTAINS

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WE HEREBY RECOMMEND THAT THE THESIS PREPARED UNDER OUR SUPERVISION BY KATHARINE M. DRIVER ENTITLED DISTINGUISHING THE HYDROLOGIC REGIMES AND VEGETATION OF FENS AND WET MEADOWS IN THE ROCKY MOUNTAINS BE ACCEPTED AS FULFILLING IN PART REQUIREMENTS FOR THE DEGREE OF MASTER OF SCIENCE.

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ABSTRACT OF THESIS

DISTINGUISHING THE HYDROLOGIC REGIMES AND VEGETATION OF FENS AND WET MEADOWS IN THE ROCKY MOUNTAINS

Fens and wet meadows in the Rocky Mountains are groundwater fed wetlands that are infrequent on the landscape but critical for the support of biodiversity and ecosystem functions. Organic vs. mineral soil layer classifications, hydrologic regime and vegetation indicators have been used to distinguish fens from wet meadows, but complex interactions between physical and environmental variables can make identifying wetland types challenging. Understanding the differences between wetland types is vital for conservation efforts, increasingly so due to the threat of climate-driven changes to the persistence of wetlands. I compared the soils, hydrologic regime, and vegetation composition of groundwater fed wetlands in Rocky Mountain National Park to examine current soil and hydrology-based criteria for distinguishing fens from wet meadows, and to formulate predictions about impacts to these wetlands from climate changes. A three-stage Generalized Random Tessellation Stratified design paired with hand selection was used to identify 45 fens and 55 wet meadows for sampling and one 16m^2 plot per site was used to collect vegetation species composition and cover data. The plot was centered on a groundwater monitoring well, measured manually or with an automatic data logger, and the water table variations were compared to local precipitation patterns. The soil profile was described and soil samples were collected at 40 cm depth to determine percent organic matter. Four distinct hydrologic regimes were identified that corresponded to differences in peat thicknesses. Precipitation influences between wetlands and a classification of 12 plant communities were correlated with differences in water table depth, peat thickness, organic matter content, and elevation. No evidence was found to support the use of the existing National Resource Conservation Service (NRCS) Soil Taxonomy distinction between organic and mineral soil layers as a criterion for distinguishing fens from wet meadows. Rather the use of ≥20 cm of peat accumulation was useful for identifying sites with fen vegetation and hydrologic regime. Fen water tables remain within 40 cm of the soil surface while for wet meadows a seasonal water table near the soil surface is sufficient. Many fens and wet meadows had multiple water sources, unrelated to wetland type, each of which influenced their hydrologic regime. Wetlands dominated by groundwater or snow melt inputs may be impacted by climate driven changes in total annual snowpack, longer summer season, and increased summer temperatures, while those influenced by seasonal precipitation will also be affected by changes in the timing, duration, and amount of summer precipitation. Most wetlands are expected to exhibit drying, decreases in peat thickness, and loss of wetland vegetation.

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1. INTRODUCTION

Wetlands play a large role in supporting the ecological functioning and biodiversity of mountain ecosystems despite their small total area. In Colorado, wetlands occupy less than 2% of the landscape but contain more than 14% of the state's native plant species (Cooper 1990). The vegetation of mountain wetlands are often species rich and support a large number of rare and endangered plant species (Vitt *et al.* 1995). In addition, these wetlands perform valuable ecosystem services such as water purification, nutrient cycling, ground water recharge, regulation of global levels of greenhouse gases, and are vital to many species of wildlife (Erman and Erman 1975).

Rocky Mountain wetland area is small due to the continental climate characterized by low precipitation and low atmospheric humidity, high solar radiation, and seasonal dry periods (Hauer *et al.* 1997). Steep slopes create excessive drainage and most wetlands occur in confined topographic positions with bedrock close to the ground surface and where glacial and alluvial landforms allow ground water to concentrate (Patterson and Cooper 2007). These wetlands and their watersheds typically have small water storage capacity and yet seasonally high surface-water and ground-water flow rates. Wetland water levels respond rapidly to changes in ground water inflows or precipitation events. Fens and wet meadows are two types of wetlands that are dependent to varying degrees on ground water inputs (Amon *et al.* 2002, Halpern 1986, Halsey *et al.* 1997, Kuramoto and Bliss 1970). They form where ground water from local and regional aquifers creates shallow water tables along aquifer flow paths or where water discharges to the soil surface (Almendinger and Leete 1998, Glaser *et al.* 1997, Hauer *et al.* 1997, Woods *et al.* 2006). Seasonal or perennial saturation over millennia allows the formation of wetland soils, including peat bodies, and characteristic plant communities.

Distinguishing between wetland types is important for continuing wetland research, management of mountain ecosystems, and wetland conservation in a changing climate. The distinctive species assemblages of fens and wet meadows support critical regional biodiversity and ecosystem functions, but historically these ecosystems have been threatened by human activities including ditching and draining for agricultural use, water diversions, peat-mining and ski and housing development projects which have all caused site-level degradation or destruction of fens and wet meadows (Cooper *et al.* 1998). As global temperatures and climate patterns change, significant hydrologic changes may occur throughout the Rocky Mountains (Baron *et al.* 2000). The maintenance of each wetland type depends upon a particular hydrologic regime, and studies predict that inflows to predominantly groundwater fed wetlands could be severely affected by future climate changes (Poff *et al.* 2002, Hauer *et al.* 1997). Reduced ground water recharge and flow due to decreased snowfall, higher temperatures, and earlier spring melt dates could result in lower water tables and reduced soil saturation in ground water dependant wetlands during the summer (Baron *et al.* 2000, Chimner and Cooper 2003). These wetlands may also be affected by changes in the timing, duration, or amount of summer precipitation, which in the Southern Rocky Mountains typically occurs from mid July through August, at the height of the growing season. Climate change may affect each wetland type differently and understanding the hydrologic regime, soil, and vegetation of each will aid in identifying climate-driven changes that could influence them.

Fens and wet meadows may occur in similar landscape positions and support some of the same plant species, but are ecologically distinct wetlands on the ends of moisture and soil gradients. Wet meadows have mineral soil layers while fens have organic soil layers made up of predominately fibric, hemic or sapric organic soil materials. This organic soil material is commonly referred to as peat and is formed by perennially saturated conditions (Amon *et al.* 2002). In waterlogged, anaerobic conditions the long-term rate of organic matter production exceeds the rate of decomposition, leading to organic matter accumulation (Clymo 1983). In mountain ecosystems rates of net primary production (NPP) are low and peat accumulation may be as little as 10% of annual NPP (Chimner *et al.* 2002) causing the formation of organic soil layers to require millennia. The approach used by most scientists and regulators to distinguish fens from wet meadows currently relies on the criteria for identifying organic soil layers according to Soil Taxonomy (NRCS 1999). These criteria identify an organic soil layer as having 40 cm or more of organic soil material in the upper 80 cm of soil. Fens are characterized as having a minimum of 30 cm (Scandinavia: Moen 1995) to 40 cm (North America: NRCS 1999) thickness of the organic layer, adhering to Soil Taxonomy definitions. Once peat has accumulated to this thickness, the availability of oxygen and nutrients necessary for plant growth sharply decreases and plants acquire the majority of their water and mineral nutrients from the waterlogged and anoxic peat body. Fen plants thus are dependent on mineral nutrients from the atmosphere or inflowing water (Almendinger and Leete 1998). According to Soil Taxonomy (NRCS 1999), in addition to a minimum thickness of the organic layer, organic soil layers must have sufficient organic carbon content, ranging from 12 - >18% by dry weight (equivalent to approximately 24 to >36% organic matter by dry weight) depending on clay content, for the soil organic fraction to have a greater influence on soil properties than the mineral fraction. The large water holding capacity per unit volume of organic matter helps maintain saturation and support stable, autogenic conditions (Bedford and Godwin 2003).

Wet meadows have mineral soil layers (Cooper 1990) with organic carbon concentrations <12% and too low to meet these criteria for organic soil layers (NRCS 1999). Mineral soil layers have lower water holding capacity per unit volume than peat and may dry more readily. Mineral soil layers with wetland hydrology are identified in the field using redoximorphic features such as low chroma and gley soil colors, mottling and oxidized rhizospheres (Simonson and Boersma 1972). The lack of perennial saturation results in aerobic organic matter decomposition during dry periods, which may provide greater nutrient availability to wet meadow vegetation (Venterink *et al.* 2002).

Intra-annual and inter-annual water table variation, hereafter referred to as the hydrologic regime, is an important determinant of wetland formation and persistence and has also been used to distinguish fens from wet meadows. Fens are characterized as having water tables near the soil surface with little annual variance and short periods with deeper water tables (Malmer 1986, Thompson *et al.* 2007) while wet meadows have water tables at the soil surface for a shorter portion of the growing season (Dix and Smeins 1967). Hydrologic characterization of ground-fed wetlands is difficult because few long term water table studies or comparisons among fens and wet meadows exist. Cooper (1990) and Chimner and Cooper (2003) demonstrated that a water table within 20-30 cm of the soil surface in mid-July to early August is necessary to maintain the organic soil layer in fens, although the water table may decline during August. Thus, one characteristic of fen hydrologic regime is a high water table during mid to late summer. However, information for other aspects of seasonal hydrologic regime variation is unknown. In meadows of the Olympic Mountains in Washington State and the California Sierra Nevada water levels fall and soils may dry soon after spring snowmelt, however this characterization did not distinguish fens vs. wet or dry meadows (Kuramoto and Bliss 1970, Ratliff 1985). In addition, further information about the importance of ground water vs. precipitation inputs for sustaining water tables in fens and wet meadows is unknown. Although fens and wet meadows are groundwater fed ecosystems precipitation may also play a role in maintaining saturated conditions (Thompson *et al.* 2007).

Differentiating fens and wet meadows using soil characteristics as outlined in Soil Taxonomy (NRCS 1999) is straightforward and frequently used, yet may not adequately reflect ecological differences among wetland types and may be an inappropriate application of Soil Taxonomy and inaccurate for describing mountain wetland ecosystems. Where slow rates of peat accumulation occur perennially saturated areas may have thinner peat horizons than expected. Plant rooting depth also varies between species, plant size and elevation (Chapin and Chapin 1981) therefore peat thicknesses of less than 30 to 40 cm may strongly influence shallowly rooted species such as *Carex aquatilis*. Constant soil saturation and anoxic conditions may also be more important than organic matter content in controlling plant community composition (Nekola 1994). No studies have compared Soil Taxonomy criteria to ecological characteristics such as vegetation composition or water table depth in mountain wetlands.

Fen and wet meadow classification may be based upon regional plant communities or dominant strata paired with variables such as topographic position or seasonal water table levels to create detailed, regionally relevant wetland taxonomies (Allen-Diaz 1991, Malmer 1986, Ruuhijarvi 1983, Ratliff 1982). The vegetation of groundwater-fed wetlands in the Rocky Mountains has been documented and described for Colorado (Carsey *et al.* 2003). Fen habitats support saturation tolerant species including non-vascular plants and rare, threatened and endangered vascular plant species (Carsey et al. 2003). Wet meadows contain some of the same saturation tolerant species as fens in addition to species that flourish in seasonally drier habitats and mineral soil layers (Cooper 1990). Regional studies, while descriptive of a broad range of possible vegetation types in regional fens and wet meadows, often fail to relate variations in species composition across wetlands to specific differences in site-level soil characteristics and hydrologic regimes. Thus, it is not entirely clear how vegetation differences relate to soil or hydrologic regime based classifications of fens and wet meadow and these descriptions remain too provincial for broader application.

The similar visual appearance of some sites with and sites without organic soil layers and the existence of multiple classification criteria make identifying groundwater fed wetlands difficult, and distinguishing between fens vs. wet meadows challenging. Mountain wetland classification is further complicated by the affects of elevation, topography and climate on hydrologic regime, soil formation processes and vegetation composition. Because a changing climate is a large-scale threat to the persistence of groundwater fed wetlands understanding the characteristics and classification of fens vs. wet meadows and the ecological and functional differences between them will help to form inferences about the future of wetlands in the Rocky Mountains. To address these needs, my study has three goals: 1) Compare the soils, hydrologic regime and vegetation across a number of fens and wet meadows and identify correlations between species composition, hydrologic regime and soil characteristics that can be used to distinguish important functional and ecological differences between fens and wet meadows; 2) Use the correlation results to examine *a priori* Soil Taxonomy-based and water table-based classifications of fens vs. wet meadows to re-evaluate classification approaches and if possible establish a more meaningful set of indicators and criteria for identifying fens and wet meadows in the Rocky Mountains; 3) Use established fen and wet meadow indicators to make predictions about how climate-driven changes to the environment may affect fens and wet meadows.

2. SITE DESCRIPTION

This study was conducted in Rocky Mountain National Park (RMNP), where fens and wet meadows are common from 2,440 to 3,990 m elevation (Fig. 1). RMNP is 1075 km^2 in size, its elevation ranges from 2,439 to 4,346 m and includes three ecological zones; montane (1,700 -2,900 m), subalpine (2,750-3500 m) and alpine (above 3350 m which covers more than 1/3 of RMNP)(Marr 1967). Bedrock is primarily Precambrian-aged granitic gneiss and schist while valley floors are covered with glacial till of Pinedale age (Braddock and Cole 1990). The slow weathering of granitic rock limits the mineral content of groundwater and mineral poor fens are common on granite and gneiss (Halsey *et al.* 1997, Cooper and Andrus 1994). Pinedale era glaciers retreated nearly 15,000 years BP and ^{14}C dating of organic material from the base of peat bodies indicates that fen formation was initiated at least 12,000 years BP in many areas (Cooper 1990, Hauer *et al.* 1997). Annual precipitation totals range from 33 to >65 cm snow water equivalent

(SWE), increases with elevation, and approximately 65 to 80% of total annual precipitation is from snow. The western slope of RMNP receives more precipitation, mostly in the form of snow, than the eastern slope. Montane vegetation is dominated by coniferous forest communities of *Pinus ponderosa* and *Pinus contorta*, and subalpine forests by *Abies bifolia* and *Picea engelmanii*. Plant nomenclature follows Weber and Wittman (2001, 2007).

3. MATERIALS AND METHODS

3.1 SITE SELECTION

Sites were selected in collaboration with the National Park Service Inventory and Monitoring Program (NPS I&M) (Britten *et al.* 2007, Fancy *et al.* 2009). Mean annual precipitation, bedrock geology, and stream gradient were identified as dominant large-scale drivers in wetland formation and characterization and 12th level Hydrologic Unit Classification (HUC) watersheds were classified based on the area of each watershed with given characteristics for each parameter (Wohl *et al.* 2007). Annual precipitation was classed as high >40cm, medium 24 - 40cm, or low <24 cm SWE, geology was generalized as granitic, non-granitic (primarily composed of metamorphic rock types), or glacial till and stream gradient by reach was classed as low <2% grade, moderate 2 - 4% grade, or steep >4% grade and watershed area values were calculated using ArcGIS (ESRI 2009). 128 watersheds were classified into 7 clusters using agglomerative cluster analysis in PC-ORD (McCune and Mefford 2006) with Sorenson (Bray-Curtis) distance measure and Group-Average linkage method (McCune and Grace 2002). Watershed type was used as an explicit strata and a subset of watersheds in each cluster were selected using a probabilistic Generalized Random Tessellation Stratified (GRTS) survey design (Stevens and Olsen 2004), creating an initial sampling area of 20 watersheds (Fig. 2). GRTS was chosen for the three stages of site selection to accommodate varying population spatial densities and used a tessellated grid pattern to select a spatially balanced subset of resources from the populations. The selections closely mimicked the spatial density of the resources and were very flexible, allowing for variable inclusion probabilities and errors in the sample frame.

Within the 20 selected watersheds fens and wet meadows were identified and delineated using ArcMap (ESRI 2008), the existing RMNP vegetation map polygons (Salas *et al.* 2005), and stereoscopic imagery (Fig. 2). The second stage of the design selected a subset of delineated wetlands using a second iteration of GRTS with unequal probability among *a priori* wetland types and accessibility classes. Selected wetlands were also ordered by a sampling priority assigned by GRTS and all wetlands were visited following this assignment. The precise sampling location within selected fens and wet meadows was determined by a third iteration of GRTS which assigned a point location within wetlands. An additional 20 sites were subjectively chosen (10 fens and 10 wet meadows) to include sites where previous research occurred, those with instrumentation, and to compensate for possible errors of omission in the sampling design. In 2007 and 2008 a total of 82 wetland complexes were visited and 45 fens and 55 wet meadows were sampled (Fig. 3).

3.2 FIELD METHODS

3.2.1 *Hydrologic Data Collection*

Water table depth was measured in all study sites using ground water monitoring wells installed by hand augering holes that were cased with slotted PVC pipe to a depth adequate for capturing annual water table variation. At sites instrumented with wells during previous research efforts, water table information was collected at existing wells that corresponded with vegetation plot placement. At sites without instrumentation, one well was installed at a pre-determined point within the wetland and used as the source of hydrologic data.

Water table measurements were made both manually and using automated data loggers. Depth to water table was measured manually using an electronic tape that had an accuracy of 1-2 mm. Twelve data loggers were installed in wells within 5 fens and 7 wet meadows during June - September of 2007 and 2008 (Fig. 3). Additionally, barometric pressure recording loggers, used to correct some water table data, were placed at the east entrance, the west entrance and in the center of the park. Water table data from fens and wet meadows in other mountainous areas including the San Juan Mountains in Colorado (Cooper unpublished data), Yosemite National Park (Cooper unpublished data), and Sequoia-Kings National Park (Cooper unpublished data) from the same time intervals was also gathered from other studies for comparison. Precipitation data was obtained from meteorological stations Phantom Valley (2750 m), Willowpark (3260 m), and Lake Irene (3260 m) (National Resource Conservation Service SNOTEL) and Estes Park and Grand Lake (National Climate Data Center) (Fig. 3). All continuously logged data was compared to precipitation at the weather station in closest proximity, accounting for elevation.

3.2.2 *Vegetation Data Collection*

Vegetation was analyzed at each site using a 4m x 4m (16 m^2) plot to meet the minimum area requirements for meadow and fen vegetation (Mueller-Dombois and Ellenberg 1974). Plot axes were stretched in cardinal directions and plots were centered on a previously installed or new groundwater monitoring well (installed after vegetation data was recorded). Plots were marked with small rebar stakes and engraved aluminum caps on each corner. In each plot a floristic survey was conducted to record all vascular and non-vascular species, including ocular estimates of canopy cover by species. Unidentified specimens were collected and verified using the herbarium at University of Colorado, Boulder and expert identification. Bryophytes were identified by Dr. William Weber of University of Colorado, Boulder with the exception of *Sphagnum*, which were identified by Dr. Richard Andrus of Binghamton University in New York. Vouchers of key *Carex* species were identified by Dr. Anton Reznicek of the University of Michigan, Ann Arbor.

3.2.3 *Soil Data Collection*

The soil layers at each study site were analyzed to determine if it met the %OC criteria of Soil Taxonomy organic soil layer. Based on the observed field characteristics of the upper 80 cm of soil, and Soil Taxonomy criteria, each site was classified as a fen (organic soil layer) or wet meadow (mineral soil layer). A soil sample was collected at

~40 cm depth for laboratory analysis of % organic matter content to confirm the *a priori* field classification. The hole dug for well installation was also used to record the soil profile including horizon depth, texture, color, and peat characteristics. At sites of previously installed wells, soil profile was exposed by digging with a long blade shovel. If a site did not exhibit redoximorphic features or organic matter accumulation and failed to meet wetland soil criteria in the upper 80 cm, the site was not sampled.

3.3 LABORATORY ANALYSIS OF SOILS

Soils sampled for % organic matter (OM) analysis were oven dried at 40° C for 24 hours, weighted, burned for12 hours at 650° C in a muffle furnace, and reweighted to determine loss on ignition (Westman *et al.* 2006). The mineral fraction weight was compared to the pre-burn weight to obtain % OM in each sample. Site %OM was then compared to my *a priori* classification of fen and wet meadow to determine if the field classification was accurate. To differentiate between fens and wet meadows the Soil Taxonomy guidelines of ≥12% organic carbon (OC) by weight were used to identify organic soil fens, %OC approximated as ½(%OM) (Mitsch and Gosselink 2006). Clay content was not tested but was presumed low at most sites and all wetlands were assumed to have >30 days saturation per year (NRCS 1999).

3.4 STATISTICAL ANALYSIS

Water table measurements from unvented continuous data loggers were corrected using barometric pressure data and adjusted so depth measurements reference the soil surface. Missing data from mechanism failure or human error was corrected for by averaging across time. If missing data for a site exceeded one week, water table data for that site was not used in the analysis. Daily precipitation measurements from SNOTEL stations were tested and found non-normal (PROC UNIVARIATE: SAS Institute 2008) because the majority of days received no precipitation. A small constant was added and data were log transformed to improve normality. Sample sites were not reweighted in any of the analyses to compensate for the weighting of sample frame based on accessibility and wetland type in the second iteration of GRTS site selection.

3.4.1 *Cluster Analysis*

Cluster analysis was used to analyze site water table data to group sites with similar hydrologic regimes. Hourly depth to water table measurements from the 12 wetlands with loggers for the period July 1 through September 15, 2008 were pooled into weekly averages, which were analyzed using hierarchical agglomerative cluster analysis (Westbrook 2005) with the computer program PC-ORD (McCune and Mefford 2006), using Euclidean distance measure and Ward's linkage method (McCune and Grace 2002). Groups identified using cluster analysis were compared, in pre-determined contrasts, to plot variables of total bryophyte cover, % bare soil, and thickness of the organic layer using ANOVA, $p < 0.05$ (PROC GLM: SAS Institute 2008). One wet meadow site was removed from this analysis due to recent land uses that had disturbed the soil horizons.

The 12 RMNP wetlands were compared in a second cluster analysis with weekly water table means for 2007 and 2008 using data from fens and wet meadows in the San Juan Mountains and Yosemite and Sequoia-Kings Canyon National Parks in California's

Sierra Nevada. Cluster analysis was again performed using Euclidean distance measure and Ward's linkage method.

3.4.2 *Regression Analysis*

Regression analysis was used to determine wetland water table variation that could be explained by summer precipitation events. Hourly measurements from instrumented RMNP wetlands were combined into daily averages for comparison to weather station data. Wetlands were matched to the closest meteorological station, taking into account differences in elevation and position of the Continental Divide. Daily changes in water table position relative to the ground surface in each wetland were calculated for six time periods; same day and 1, 2, 3, 4 and 7 day lags. The change in water table depth in all wetlands for all time lags was regressed against log transformed precipitation data to identify the water retention time lag that provided the best fit for comparing wetland water tables to local precipitation patterns (PROC REG: SAS Institute 2008). Regressions with the highest R^2 value for each wetland were retained and the results were compared between groups generated by cluster analysis using ANOVA (PROC GLM: SAS Institute 2008).

3.4.3 *Species Composition*

Vegetation data were analyzed using hierarchical agglomerative cluster analysis using PC-ORD (McCune and Mefford 2006) to identify vegetation assemblages and dominant species. Cluster analysis was performed using Sorensen distance measure and flexible beta linkage method (β = -0.25) (McCune and Grace 2002). Indicator species analysis was performed to gauge the faithfulness and exclusiveness of species to cluster groups and determine the optimum number of clusters produced by the dendrogram (Dufrene and Legendre 1997, McCune and Grace 2002). Species indicator values were used to determined dominance and sub-dominance of species in cluster groups. Dominant species assemblages were related to existing literature on regional wetland plant communities (Carsey *et al.* 2003).

3.4.4 *Ordination*

Indirect gradient analysis was performed using the iterative optimization method Non-metric Multidimensional Scaling (NMS) to analyze the vegetation data and describe relationships between plots based on their floristic composition and to examine correlations with environmental variables. Vegetation data was adjusted by removing species with ≤1% cover to prevent uncommon and low cover species from having a disproportionate influence on the spatial configuration and increasing the stress of the final configuration (McCune and Grace 2002). NMS was run using PC-ORD (McCune and Mefford 2006) with Sorenson (Bray-Curtis) distance measure. Optimal dimensionality was assessed using a step-down procedure. A random starting configuration was used with 50 runs of real data and a Monte Carlo test with 50 runs of randomized data to insure that a similar final stress could not have been obtained by chance and the stability of the solution was examined with a plot of stress vs. iteration number (McCune and Grace 2002). This configuration was then compared to environmental gradients to identify correlations between community composition and soil and hydrology variables. The ordination was also compared to vegetation cluster groups to make inferences concerning unmeasured environmental gradients that may affect floristic composition.

3.4.4 *Wetland Classification*

The *a priori* classification of sites as fen or wet meadow and *post-hoc* classifications based on variables other than organic soil layer thicknesses were examined using multi-response permutation procedures (MRPP) in PC-ORD (McCune and Mefford 2006). MRPP is a nonparametric procedure for testing the hypothesis of no difference between two or more pre-existing groups and describes the effect size of the grouping (McCune and Grace 2002). The significance of differences between classification groups on species composition was verified by MRPP (Rolon *et al.* 2008). *A priori* and *post-hoc* wetland classifications were further examined by comparing classifications using indicator species analysis (McCune and Grace 2002).

4. RESULTS

4.1 SOIL ORGANIC MATTER AND FIELD CLASSIFICATION

Soils from only 3 of 101 wetlands sampled failed to meet the *a priori* assumption of fen vs. wet meadow based upon their organic matter content (NRCS 1999). One site initially identified as a fen had less than 24% OM (12% OC) while two sites identified as wet meadows had greater than 24% OM. These sites changed the sample sizes to 46 fens and 54 wet meadows. Percent soil OM at 40 cm ranged from 24.7 to 99.9% (~12.3 to 50% OC) in fens and 0.6 to 18.1% (~0.3 to 9% OC) in wet meadows.

4.2 HYDROLOGY

4.2.1 *Water Table Comparisons*

The cluster dendrogram of 12 RMNP water tables was cut at 90% similarity and four distinctive hydrologic regimes were identified (Fig. 4). This cut level was chosen to take advantage of natural break points in the dendrogram and to optimize within-group homogeneity (McCune and Grace 2002). The clustering of wetlands based upon hydrologic regime did not follow my *a priori* classification of fens vs. wet meadows. Wetlands with hydrologic regime 1 (HR1) include fens and wet meadows with a water table at or near the ground surface for the entire growing season. Type 2 (HR2) included fens and wet meadows with water tables that were slightly deeper than HR1 sites, more variable throughout the season although the water table never dropped to more than 40 cm below the ground surface. Wetlands in hydrologic regime type 3 (HR3) had considerable water table variation during the summer, frequently falling below 40 cm, and contained only wet meadows. Type 4 hydrologic regimes (HR4) had high water tables in the early summer during the spring snowmelt period with a constantly falling water table thereafter, and also contained only wet meadows. A graphical comparison of daily water tables (depth over time) for all sites shows distinct differences between all four hydrologic regimes. HR1 sites had the highest water tables followed by HR2 within 40 cm of the surface, HR3 within 60 cm of the ground surface and HR4 with mid-summer and fall water tables near or greater than 100 cm beneath the ground surface (Fig. 4).

Thickness of the organic soil layer was significantly related to hydrologic cluster groups in ANOVA contrasts (alpha = 0.10, df = 3). Peat thickness was significantly different between HR1 and HR3 (p = 0.093), HR1 and HR4 (p = 0.079), HR2 and HR3 (p = 0.068) and HR2 and HR4 (p = 0.057) but not significantly different between HR1 and HR2 or HR3 and HR4 (Fig. 5). The average peat thickness was 65.6 cm (range of 24 to 81 cm) for wetlands in group HR1 and 69.0 cm (range of 24 to 108 cm) for HR2. HR3 wetlands averaged 4.7 cm of peat accumulation (range of 0 to 9.3 cm), while HR4 sites averaged 1 cm of peat accumulation (range of 0 to 2 cm) (Table 1) but did not have true organic soil layers. Peat thickness was significantly different between *a priori* fens and wet meadows (p = 0.0002, df = 1). Fens averaged 85 cm peat thickness, and ranged from 40 to >100 cm (beyond the range of measurement) and wet meadows averaged 9.8 cm, and ranged from 24 cm to 0 cm of peat.

The cluster analysis of wetland hydrologic data from RMNP and other western mountain ranges was pruned at a cut level of 75% similarity, dividing the wetlands into 2 groups (Fig. 6). The clusters are interpreted relative to overall water table depth patterns. Wetlands grouped at the top cluster had higher water tables and included fens from all regions and some wet meadows from RMNP, the San Juan Mountains and Sequoia-Kings National Park. Wetlands grouped in the bottom cluster had deeper summer water tables while still retaining hydric soil and vegetation indicators, and include wet meadows from RMNP and Yosemite National Park. The RMNP wet meadows in the upper cluster all had peat accumulation >20cm thick and greater similarity to fen than wet meadow water tables.

4.2.2 *Water Table Variation and Precipitation*

Linear regression analysis comparing daily changes in the water table position to precipitation indicated that significantly different amounts of water table variation could be explained by precipitation for each cluster group. Water retention time lags of one or two days provided the best fit to precipitation in all wetlands. Fens and wet meadows in HR1 with consistent water tables at the ground surface showed little or no variation explained by precipitation ($R^2 \leq 0.162$) (Fig. 7) with two wetlands showing a slight negative but not significant relationship to rain events ($R^2 = 0.018$ and 0.021) while wetlands in HR2 showed a positive and statistically significant response to rain events ($p = 0.0095$). Wetlands in HR2 had 28 to 49% ($R^2 = 0.278 – 0.491$) of water table variation explained by precipitation, water levels rising following rain events. Wet meadows in HR3 were also significantly related to precipitation ($p = 0.0054$) with 33 to 55% ($R^2 = 0.330 - 0.551$) of water table rises explained by rainfall (Fig. 8). Regression results were not significantly different between HR2 and HR3. Precipitation patterns could explain 22 to 26% of water table rises for wet meadows in HR4 ($R^2 = 0.223 - 0.262$) but the results were not significantly different compared to all other hydrologic regimes (Table 1). Regression results were also not significantly different when comparing *a priori* classification of fen vs. wet meadow.

4.3 VEGETATION

4.3.1 *Vegetation types*

The dendrogram of vegetation data was pruned at 45% similarity and 12 plant types were identified, each dominated by individual species or species assemblages.

Vegetation types identified were *Carex aquatilis, Carex utriculata, Eleocharis quinqueflora, Carex illota, Carex nigricans – Juncus drummondii, Carex scopulorum – Carex capillaris, Carex nebrascensis, Carex vesicaria*, *Calamagrostis canadensis*, *Poa pratensis — Phleum pratense, Salix planifolia* – herbaceous understory, and *Picea engelmanni* – shrub. Species that were significantly faithful to particular groups in the indicator species analysis ($p < 0.05$) tended to be relatively abundant and have high cover in that vegetation type (Table 2). Indicator values signified stand dominance or a species with the highest overall abundance. Species with the highest indicator values per group were used to relate vegetation type clusters to previously documented vegetation types (Carsey *et al.* 2003) (Appendix A).

4.3.2 *Indirect Gradient Analysis*

A three dimensional solution was chosen in the NMS analysis, the proportion of variance represented by axes 1, 2, and 3 are $R^2 = 0.221$, 0.214, and 0.199, respectively (Fig. 9). The solution was stable with a stress of 18.99, and found with 200 iterations. Several environmental variables were significantly correlated with axis 1 ($R^2 \geq 0.20$), including peat thickness (0.351), depth to water table (DTW) measured by hand at all sites (0.256), and % soil OM (0.421). Elevation was correlated with axis 2 (0.460) and no environmental variables were significantly correlated with axis 3 (Table 3) which suggests that unmeasured or non-measureable environmental factors may be influencing the ordination.

4.4 WETLAND CLASSIFICATION

Multi-response Permutations Procedures was used to test vegetation differences between a priori classification of fen and wet meadow and additionally test the difference between wetlands with greater than and less than 20 cm of peat thickness, a distinction indicted by the hydrology analysis. Testing of both classifications yielded similar results and together best reflect correlations between peat thickness and vegetation. Vegetation differences between fen and wet meadow groups was highly significant ($p \leq 0.000$) with a test statistic of -12.30. Classifying wetlands based on <20 cm or >20 cm of peat accumulation was also highly significant ($p \leq 0.000$) with a test statistic of -11.70. Indicator species analysis was used on wetlands with >20 cm of peat, 20 - 40 cm of peat, and >40 cm of peat (organic soil layer) (MRPP = -9.3). Wetlands with <20 cm of peat were indicated by the presence of *Deschampsia cespitosa, Juncus arcticus* ssp. *littoris,* and *Carex scopulorum* while wetlands with 20 - 40 cm were indicated by *Carex aquatilis, Carex illota, Pedicularis groenlandica, Senecio triangularis, Swertia perennis, Podagrostis humilis,* and several bryophytes species, and wetlands with >40 cm of peat by *Carex utriculata, Eleocharis quinqueflora,* and bryophytes such as *Sphagnum* spp. (Table 4).

5. DISCUSSION

5.1 SOIL, WATER AND VEGETATION RELATIONSHIPS

Identifying distinct hydrologic regimes that were correlated with peat thickness was critical for understanding the relationship between organic soil layer classifications and water table variation in mountain wetlands. Vegetation types were also correlated with differences in soils and water table depth, but the water table depths and vegetation between sites with organic and mineral soil layers were not as expected. The use of Soil Taxonomy to identify fens based upon organic soil layer classification and wet meadows based upon mineral soil layer classification were not supported by contrast results. Peat accumulation of ≥20 cm and a growing season maximum water table depth of 40 cm were characteristic for identifying fens, while wet meadows typically had <10 cm of peat accumulation and a water table that was only were seasonally or intermittently near the soil surface. Wetlands with <20 cm of peat (often <10 cm) had wet meadow vegetation, indicated by the presence of species such as *Deschampsia cespitosa* and *Juncus arcticus ssp. ater*, while those with true organic soil layers (>40 cm of peat) had common fen wetland species as indicators such as *Eleocharis quinqueflora*. Wetlands with 20-40 cm of peat accumulation contained predominantly fen species but could not clearly be classified by wetland type using only plant species information.

5.1.1 *Hydrologic regime and peat thickness*

Depth to water table data for 12 fens and wet meadows revealed that sites with higher seasonal saturation had greater peat thicknesses, as would be expected. Four hydrologic regimes were identified using cluster analysis, but sites with similar depth to water table patterns had significant differences in peat thickness and % OM at 40 cm (Table 1, Fig. 4). HR1 and HR2 sites contained both *a priori* fens and wet meadows, had consistently high water tables within 40 cm of the ground surface and some peat accumulation, but the peat was not thick enough at 3 out of 8 wetlands to meet the Soil Taxonomy criteria of organic soil layer classification. Sites with as little as 24 cm of peat had nearly identical depth to water table patterns as sites with >100 cm of peat, suggesting that a peat horizon of 20 cm may be more useful in predicting fen hydrologic regimes than Soil Taxonomy-based organic soil layer classifications that use the presence of 40 cm of organic material as an indicator. The drastic differences in peat thickness at these sites suggests that multiple factors may affect the formation of organic soil layers such as periodic soil erosion, peat burning, deposition of mineral material, or altered peat accumulation and decomposition rates during wet vs. dry periods (Belyea and Malmer 2004). The ages of the peat forming wetlands may also vary. The oldest sites initiated in the early Holocene soon after the Pinedale glaciers melted (Cooper 1990) and may contain thicker peat and true organic soil layers while younger sites dating to more recent landscape disturbances may have thinner peat (Miner and Ketterling 2003). Sites classified into groups HR3 and HR4 had intermittent soil saturation and deeper summer water levels and supported mineral soil layers, as expected. These sites had <10cm of peat accumulation which likely varies through climate periods, without reaching substantial thickness. Additionally, fen and wet meadow sites classified into group HR2 had water tables that varied from near the soil surface to as deep as 40 cm. This suggests that fen water tables may drop significantly during summer dry periods and still maintain peat formation. Long term water table variation in fens should be investigated on longer time scales. It is possible that these sites experience peat loss when the water table was deep but the maintenance of peat bodies may depend on inter-annual or long-term climate patterns rather than seasonal hydrology (Belyea and Malmer 2004).

5.1.2 *Vegetation correlation to peat thickness*

When site level vegetation was compared to thicknesses of the organic layer using MMRP, thin peat horizons of ≥20 cm were found to be equally significant for predicting vegetation as peat ≥40 cm thick. Sites with 20-40 cm of peat largely supported common fen species including *Carex aquatilis, Carex illota, Podagrostis humilis, Pedicularis groenlandica, Swetia perennis,* and the brown moss *Drepanocladus aduncus*, in addition to *Senecio triangularis,* a species more often found in mineral soils. This is in contrast to sites with <20cm of peat, which supported common wet meadow species such as *Deschampsia cespitosa* and *Juncus arcticus* ssp. *littoralis* and the high elevation wetland species *Carex scopulorum.* Wetlands with little or no peat supported vegetation that I expected in wet meadows while those with >40 cm of peat and organic soil layers were characterized by species such as *Carex utriculata, Eleocharis quinqueflora, Sphagnum* spp. and *Warnstorfia exannulata*, which are common in fens and other perennially saturated wetlands (Table 4). These indicator species can be used to confidently classify wetlands with <20 cm of peat as wet meadows while wetlands with > 40 cm of peat are classified as fens. However, the classification of wetlands with 20-40 cm of peat was more complex. The significance of 20 vs. 40 cm of peat and the mix of species indicated for this group may be related to the small stature and shallow rooting depth of plant species in high elevation wetlands (Chapin and Chapin 1981). Some plant species may be rooted largely in and receive nutrients and water largely from the upper 20 cm of soil, making differences in deeper horizons less important.

When compared in an NMS analysis the differences in vegetation composition between sites corresponded to multiple soil and hydrologic characteristics. Peat thickness, water table depth and % soil OM were correlated with vegetation communities along axis 1 and together represented some redundancy in the amount and type of vegetation differences explained (Fig. 10). Peat thickness was one of several environmental gradients influencing the vegetation composition and species dominance may indicate that a wetland has thick peat, seasonally high water tables, and/or high organic matter content, but not necessarily all three (McCune and Grace 2002) . Fens had similar vegetation composition as wet meadows with perennially saturated mineral soil layers and in the NMS analysis 20-40 cm or ≥40 cm of peat did not produce a meaningful difference in vegetation. Similar vegetation in different soil types may result from the competitive success in wet environments of the indicator species identified in this study (Table 4).

5.1.4 *The influence of precipitation*

The effect of precipitation on wetlands was not predicted *a priori* by wetland type or related to peat thickness. Both fens and wet meadows responded to precipitation events, with some wetland water tables rising after rain events. The response to precipitation events was predictable by hydrologic regime, but not by the fen vs. wet meadow dichotomy (Table 1). Fens and wet meadows with consistent surface saturation (HR1) were little affected by rain events and likely receive a majority of their water inputs from ground water discharge (Fig. 7). Fens and wet meadows in groups HR2 and HR3 had the greatest sensitivity to precipitation, and 28 to 49% of their summer water table increases could be explained by rain events (Fig.8). These wetlands are dependent on summer precipitation inputs in addition to ground water flow to maintain seasonal saturation. Wet meadows in HR4 responded to precipitation in the spring when water tables were high, but the steady summer water table draw down indicated that these wet meadows are depend on snow melt water for early season saturation. Precipitation inputs vary from year to year, and their influence on wetland water tables also varies depending on the volume and consistency of groundwater flows. In years with reduced snow pack and less melt water precipitation events may have a much stronger impact on water table and be of greater importance for maintaining mid-summer water tables.

5.3 THE CLASSIFICATION OF FENS AND WET MEADOWS

Water table data from wetlands in other western mountain ranges supported my findings that wetlands with as little as 20 cm of peat accumulation had similar hydrologic regimes as sites with thick peat bodies and true organic soil layers. On a continental scale wet meadows with 20-40 cm of peat in RMNP clustered with fens. The hydrologic regime of these wet meadows were more similar to fens of the San Juan Mountains, Sequoia-Kings National Park, Yosemite National Park and RMNP than to wet meadows from the same areas with <20cm of peat. Based upon these results, I suggest that wetlands with peat bodies 20-40 cm thick are functionally similar to fens. Therefore, the use of Soil Taxonomy-based classifications of organic soil layers is not always suitable for the identification and classification of mountain fens. Alternative characteristics useful for identifying mountain fen ecosystems are the surficial accumulation of ≥20 cm of peat and the presence of common fen species. Vegetation may consist of both fen and wet meadow species, but characteristic fen species should be used to indicate that a site is potentially functionally similar to fens with ≥20 cm of peat and fen hydrologic regimes.

The maximum mid-summer water table depth was deeper and the effect of summer precipitation greater than expected. Several study fens with peat >40 cm thick had maximum summer water table depths ≥40 cm below the ground surface. Other studies have found maximum mid-summer water table depths approximately 20 cm below ground (Chimner and Cooper 2003, Cooper 1990), but fens in my study periodically or routinely experienced deeper summer draw downs. Finally fens, which are ground-water driven ecosystems, could at times be influenced by summer precipitation driven water table variation. The contribution of precipitation to fen hydrologic regimes should be studied in more detail to quantify the relationship between groundwater, surface water and precipitation inputs to these wetlands.

5.4 CLIMATE CHANGE IMPACTS TO FENS AND WET MEADOWS

Climate-driven changes in precipitation patterns, snowpack depth, snow water equivalent, and melt timing, and temperatures in the Rocky Mountain region are expected to impact groundwater fed wetlands (Poff *et al.* 2002, Hauer *et al.* 1997). However, the mechanism of change will likely depend on hydrologic regime and the source of water inputs to wetlands. Fens and wet meadows receive inputs from precipitation, groundwater inflow, and spring runoff melt water (Brinson 1993) but the importance of each water source is driven by hydrologic regime, not wetland type. The inconsistency of the fen/wet meadow dichotomy response to precipitation events and their multiple sources of hydrologic maintenance make formulation of predictions about future climate changes in wetlands impossible without detailed knowledge of individual wetland hydrologic regimes. Wetlands that receive primarily groundwater inputs, for example fens and wet meadows with continuous surface saturation that are classified in the HR1 group, may be most affected by changes in winter snowpack and increased summer temperatures. The size of this affect will likely be influenced by the size of the contributing watershed and the amount of excess water entering wetlands (Laudon *et al.* 2007), larger catchments and greater amounts of excess water will minimize impacts to wetlands. In wetlands from smaller catchments or with less excess water decreased winter snowpack may result in reduced ground water recharge and reduced groundwater flows during summer months. Higher temperatures would increase evapotranspiration rates and trigger earlier spring snowmelt, increasing spring flows and diminishing residual summer snow fields that contribute to groundwater maintenance (Cooper *et al.* 2006, Baron *et al.* 2000, Hauer *et al.* 1997). Both of these factors may play a part in lowering groundwater levels and discharge into wetlands and cause water tables to drop below current levels. Fens and wet meadows in hydrologic groups HR2 and HR3 receive a significant portion of water from precipitation and may furthermore be affected by changes in the timing, duration, and amount of summer precipitation. Many wetlands in these groups depend on summer rain to raise declining summer water tables and if precipitation is inadequate or occurs outside the historic July-August window, these wetlands may experience unprecedented water table draw downs during the middle to late summer during the height of the growing season. Wetlands with lower water tables and those that are dependent on spring melt-off for early season elevated water tables (HR4 seasonal wet meadows) may be more insulated to climate changes because they do not support species and soils that depend on specific hydrologic regimes. Soils were mineral and vegetation consisted of species which can occur in a wide range of wetland and even upland habitats (Carsey *et al.* 2003) and may possess sufficient tolerance to survive changing conditions. These wetlands may still be affected by higher temperatures and earlier melting spring snow. The temporary soil saturation driven by spring melt water may occur earlier and end too quickly, causing more severe water table draw down (Cooper *et al.* 2006, Hauer *et al.* 1997).

The result of climate-driven changes on hydrologic regimes may appear similar across wetlands due to extreme drying, loss of soil OM, and loss of some wetland plant species. In wetlands with organic soil layers the rate of peat accumulation and decomposition may be altered (Belyea and Malmer 2004), affecting drainage patterns and increasing susceptibility to fire (Rouse 1998, Hauer *et al.* 1997). Experimental studies have shown that CO_2 emissions from peat soils will increase if mid-season water levels fall and peat dries (Chimner and Cooper 2003) or if stable long-term water tables experience sudden changes in hydrologic regime (Belyea and Malmer 2004). Earlier spring or mid-summer drying may also prevent some plant species from completing their life cycle and the reproductive success of wetland vegetation may be affected, resulting in the loss of locally unique species and communities (Poff *et al.* 2002, Hauer *et al.* 1997). Climate-driven changes to wetlands may result in effects scaling up to the ecosystem level (Rouse 1998).

6. CONCLUSION

Fens and wet meadows are distinct wetland types that provide vital services to mountain ecosystems. Current threats to the persistence of mountain wetlands, including climate-driven changes to the physical environment, make understanding the functional differences between these wetlands important for conservation efforts. Field methods to distinguish fens and wet meadows currently rely on soil classifications derived from Soil Taxonomy (NRCS 1999). This study found no evidence that fen vegetation and perennially high water tables were limited to sites with ≥40 cm of peat and true organic soil layers in RMNP wetlands, suggesting that the existing Soil Taxonomy-based approach for identifying groundwater fed wetlands in the field should be modified. I recommend alternative criteria for distinguishing between fens and wet meadows in the field. Peat thickness varied significantly between fens and wet meadows with high water tables and 1) peat accumulation of ≥20 cm is a better indication of fen hydrologic regimes. Vegetation differences between sites suggested that 2) wetlands supporting common fen species typically have fen hydrologic regimes and ≥20 cm of peat, even when there are both fen and wet meadow species present at the site. Include sites that 3) have high water tables but periodically or routinely experience a summer water table draw down to as deep as 40 cm beneath the ground surface, and 4) receive a significant portion of water table maintenance from precipitation in addition to ground water and snow melt inputs. Wetlands that fit these criteria may be more susceptible to the impacts of a changing climate than other wetlands due to the reliance of vegetation and soils on specific hydrologic regimes.

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8. FIGURES AND TABLES

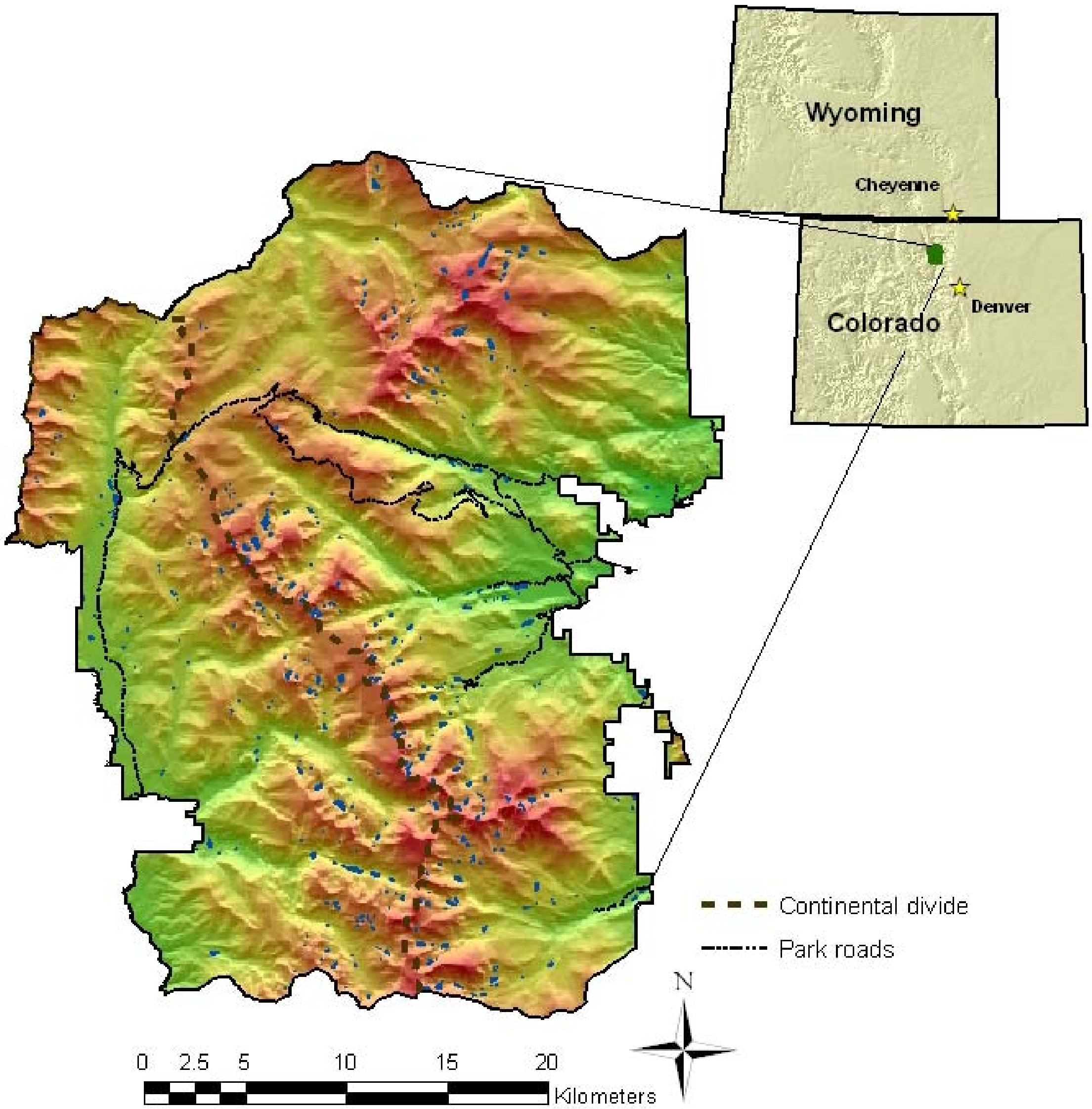

Fig. 1 Map of Rocky Mountain National Park located in northern Colorado. Elevation is indicated by color and ranges from green at low elevations, through yellow, orange and red for high elevations. Lakes are shown in blue.

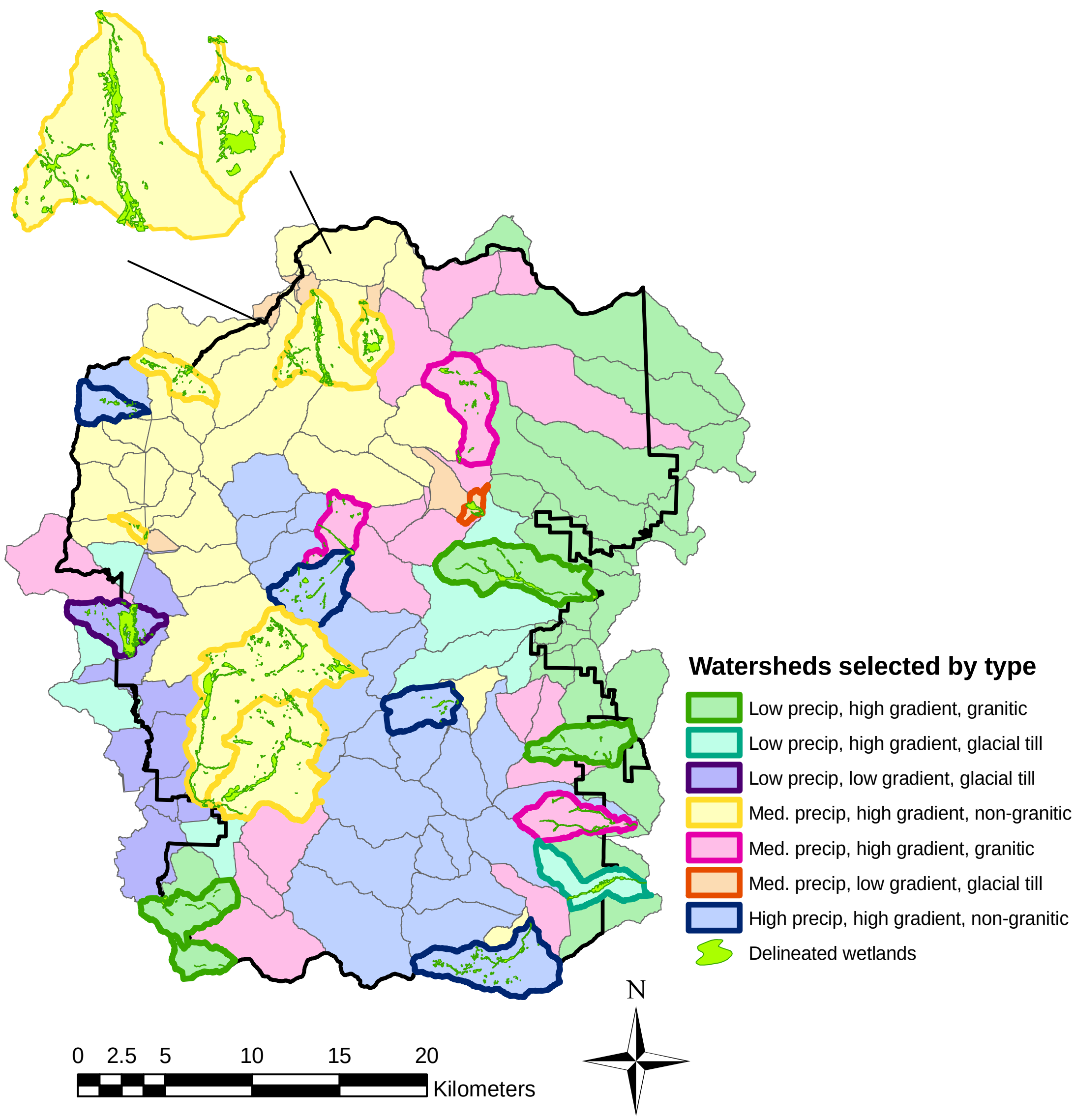

Fig. 2 Map of watersheds selected for sampling and hand-delineated wetland sample frame. Watershed color indicates classification based on environmental gradients affecting wetland formation. Green watersheds are low precipitation and high stream gradient with granitic bedrock geology. Turquoise watersheds are low precipitation and high stream gradient with glacial till bedrock. Purple watersheds are low precipitation and low stream gradient with glacial till bedrock. Yellow watersheds are medium precipitation and high stream gradient with non-granitic bedrock geology. Pink watersheds are medium precipitation with high stream gradient and granitic bedrock geology. Blue watersheds are high precipitation and high stream gradient with non-granitic bedrock geology. Hand delineated wetlands are shown in bright green within selected watersheds. Poudre River and Hague Creek watersheds are enlarged at top to show detail of wetland delineation.

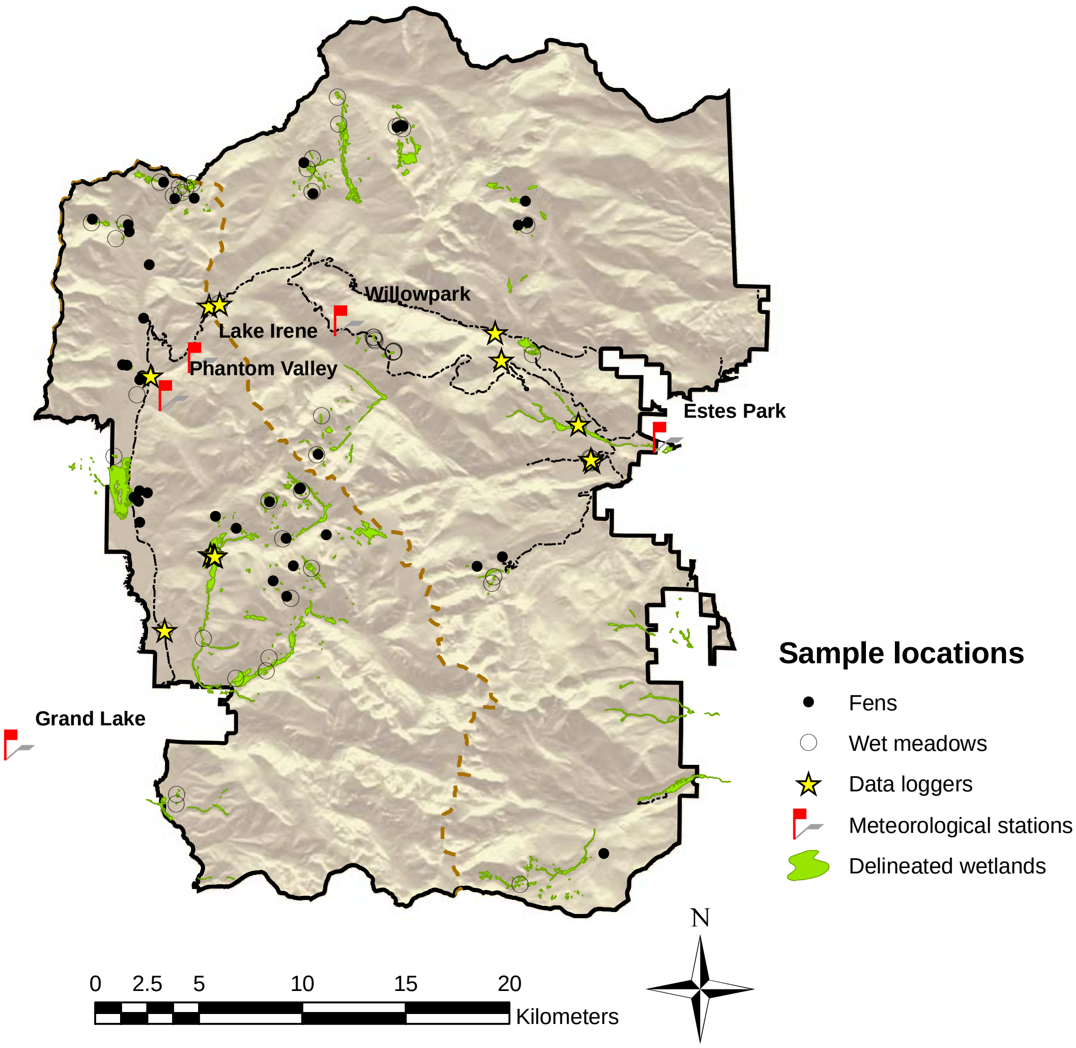

Fig. 3 Locations of sampled wetlands, hydrologic data loggers and meteorological stations

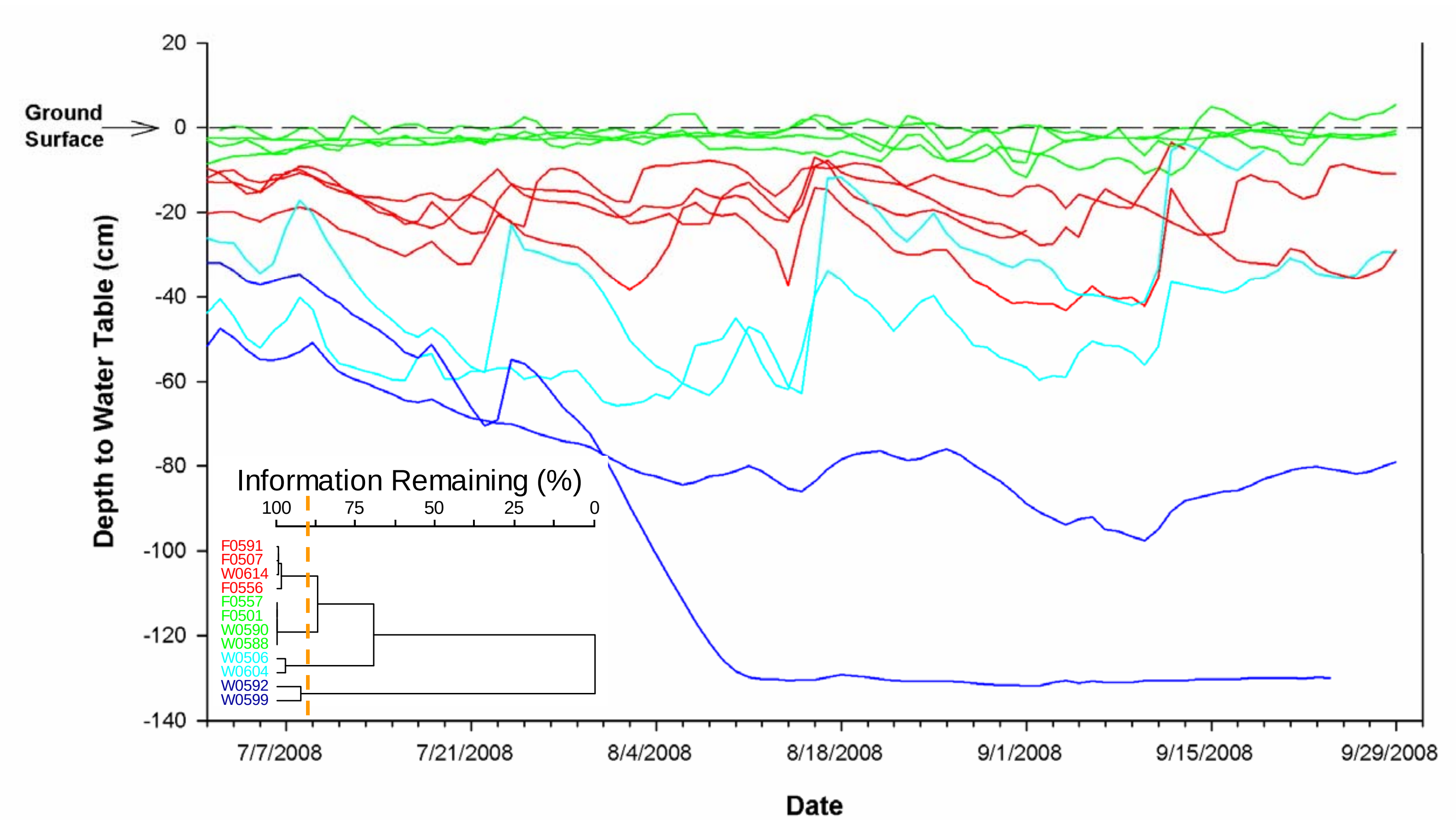

Fig. 4 Hydrograph of daily water table variation (July - Sept) of 12 instrumented RMNP wetlands. Lines show depth of water tables below the ground surface (black dotted line near top). Color coded groups were generated by cluster analysis (shown in inset) using weekly water table averages and cut at approximately 90% similarity (orange line). Plot prefixes 'F' or 'W' indicates a priori grouping of fen and wet meadow. Wetlands with hydrologic regime 1 (HR1) with water tables within 20 cm of the ground surface are shown in green. Wetlands with hydrologic regime 2 (HR2) with water tables with 40 cm of the ground surface are shown in red. Wetlands with hydrologic regime 3 (HR3) with water tables within 60 cm of the ground surface are shown in turquoise. Wetlands with hydrologic regime 4 (HR4) with deep summer water tables are shown in dark blue.

Table 1 Environmental data and regression results for wetlands instrumented with hydrologic data loggers. Table gives wetland type, hydrologic regime generated from cluster analysis of daily water table depths (Fig. 4), peat thickness at site, R^2 value from linear regression giving correlation of precipitation events to rises in water table, and vegetation type generated from cluster analysis and indicator species analysis (Table 2).

Site Name	Wetland type	Hydrologic regime	Peat thickness (cm)	Precipitation regression R^2	Vegetation type
F0591	fen	HR2	108	0.491	*Picea engelmanii/Alnus incana*
F0507	fen	HR2	40	0.322	*Carex aquatilis*
W0614	wet meadow	HR2	24	0.330	*Salix planifolia*
F0556	fen	HR2	104	0.027**	*Calamagrostis canadensis*
F0557	fen	HR1	91	0.278	*Eleocharis quinqueflora*
F0501	fen	HR1	82	0.119	*Carex aquatilis*
W0590*	wet meadow	HR1	2	0.018**	*Carex nebrascensis*
W0588	wet meadow	HR1	24	0.162	*Carex aquatilis*
W0506	wet meadow	HR3	9.3	0.338	*Carex nebrascensis*
W0604	wet meadow	HR3	0	0.552	*Carex aquatilis*
W0592	wet meadow	HR4	0	0.223	*Poa pratensis/Phleum pratense*
W0599	wet meadow	HR4	2	0.262	*Poa pratensis/Phleum pratense*

* identifies plot removed from peat thickness ANOVA comparison due to disturbed soil horizons

** indicates negative relationship to precipitation

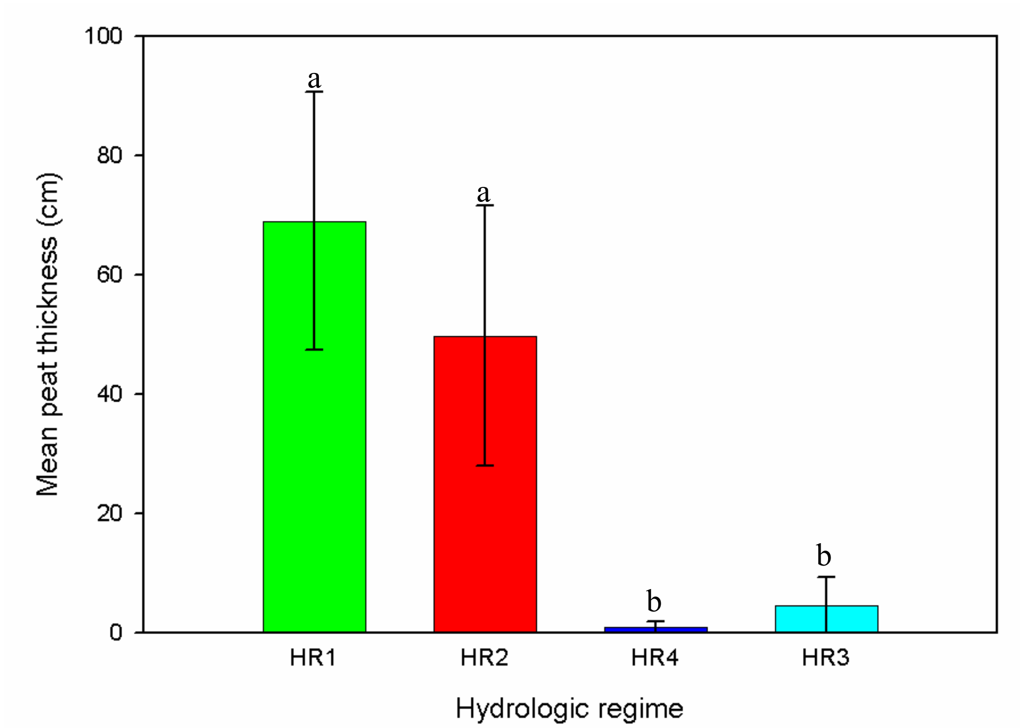

Fig. 5 Mean peat thickness by hydrologic regime. Color coding is consistent with hydrolograph and cluster in Fig. 4.

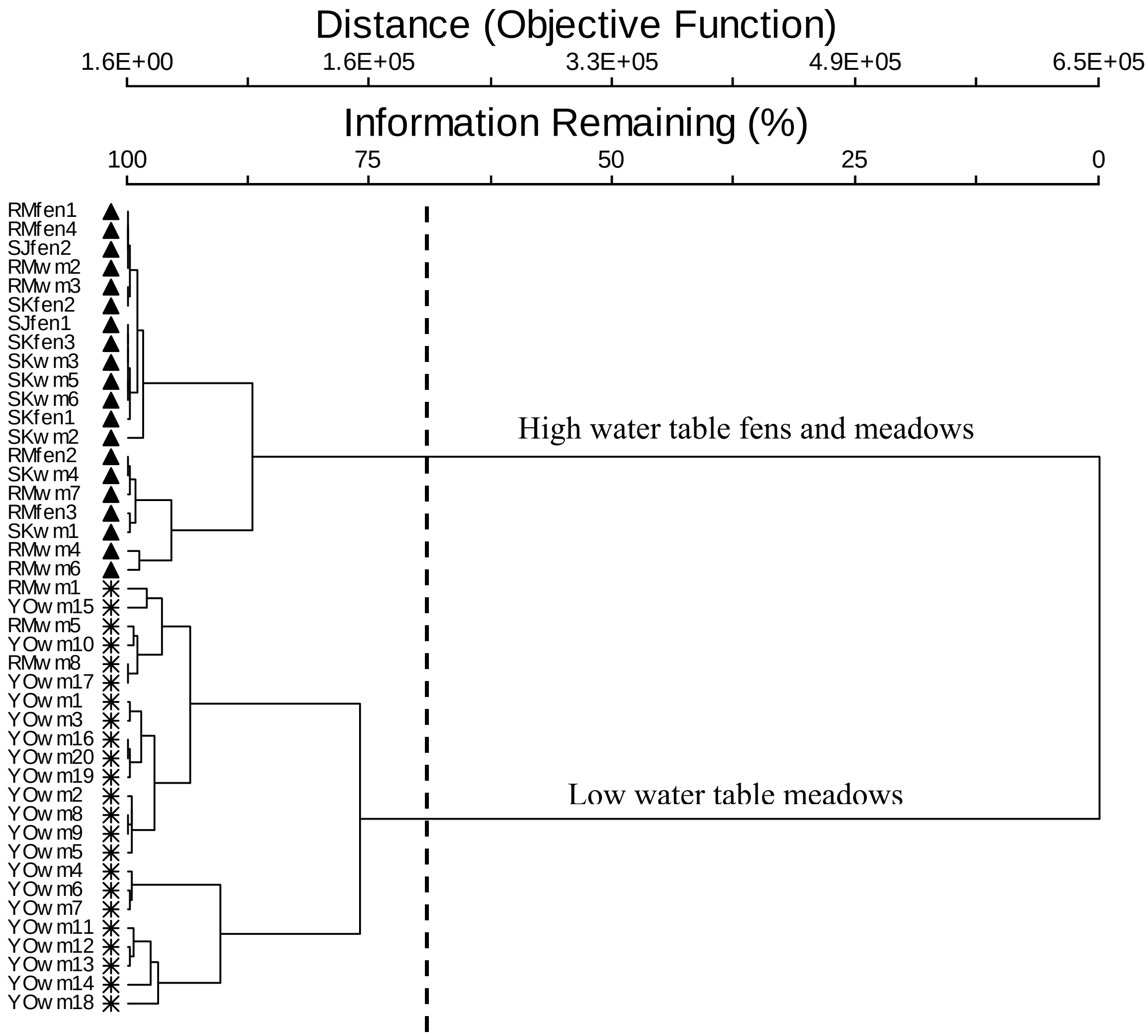

Fig. 6 Dendrogram comparing weekly depth to water table of wetlands in RMNP, Yosemite National Park, Sequoia - Kings Canyon National Park, and the San Juan mountains. Cluster has been pruned at ~75% similarity, dividing the wetlands into 2 groups, the highest water tables at the top and lowest at the bottom. Plot prefixes RM, SK, SJ, and YO indicate location, Rocky Mountain National Park, Sequoia – Kings Canyon National Park, San Juan Mountains and Yosemite respectively. Suffixes "fen" and "wm" followed by a number assignment denote wetland type fen or wet meadow, respectively, based on Soil Taxonomy organic soil criteria of ±40 cm of peat.

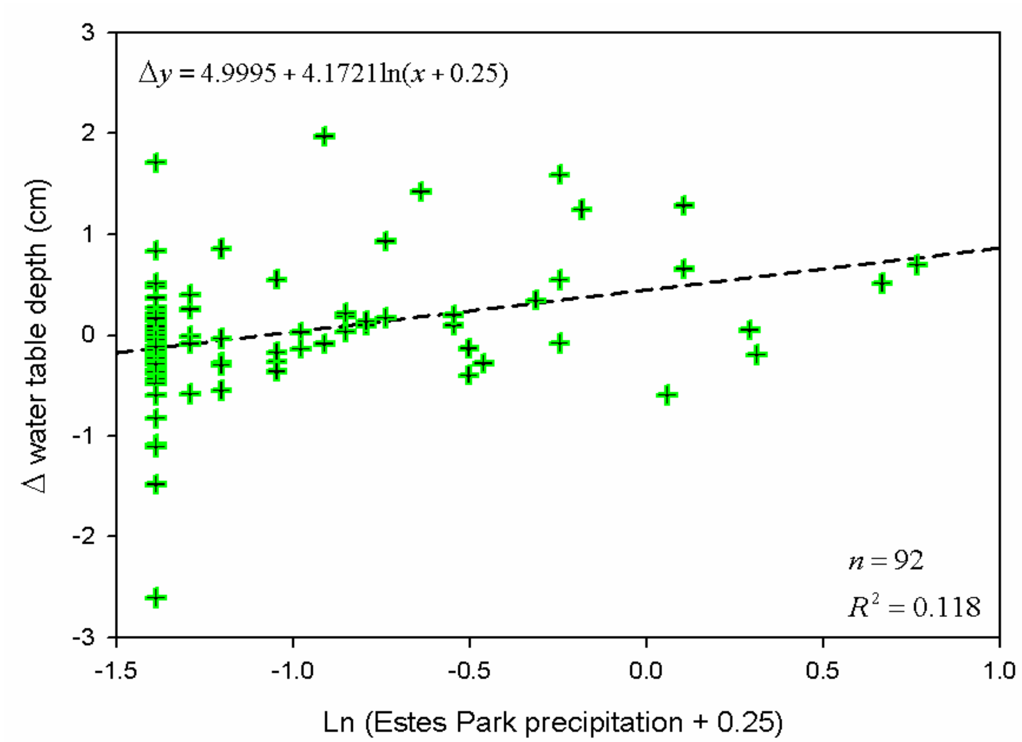

Fig. 7 Example of regression analysis for one example wetland with hydrologic regime 1(HR1) showing a weak relationship to precipitation. Change in daily water table depth with one day time lag is shown in cm on the Y-axis. Transformed daily precipitation amounts for Estes Park SNOTEL weather station are shown on the X-axis. Wetland is located in EndoValley/Horseshoe Park, approximately 5 miles northwest of Estes Park station.

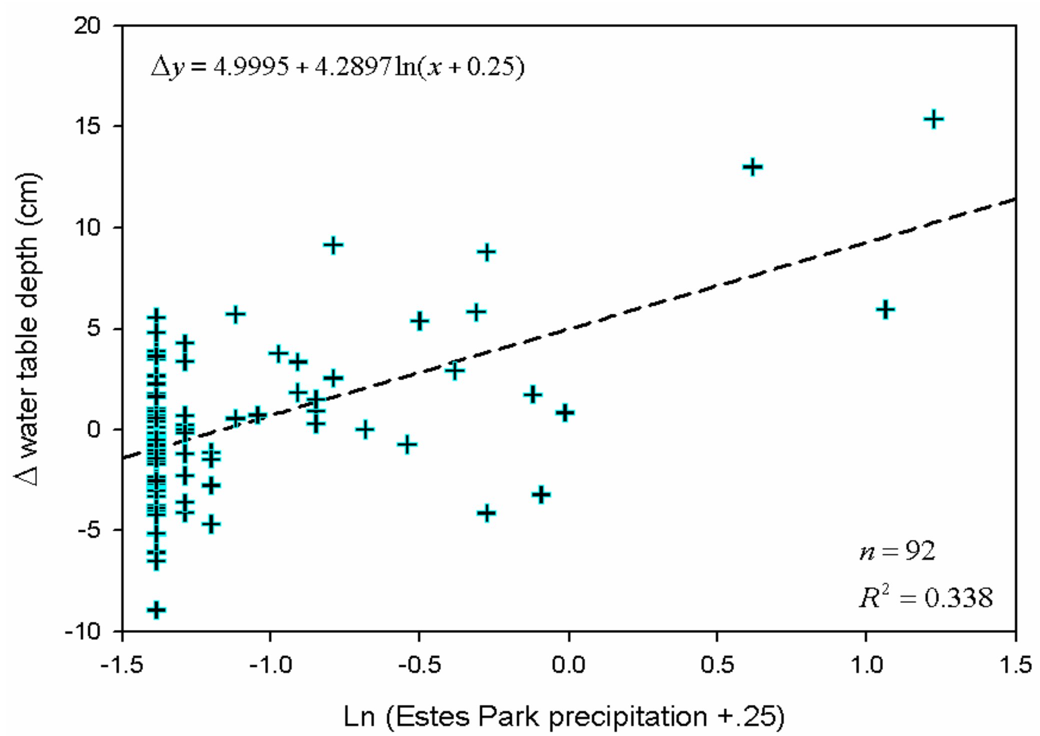

Fig. 8 Example of regression analysis for one example wetland with hydrologic regime 3 (HR3) showing a strong relationship to precipitation. Change in daily water table depth with one day time lag is shown in cm on the Y-axis. Transformed daily precipitation amounts for Estes Park SNOTEL weather station are shown on the X-axis. Wetland is located in Moraine Park, approximately 3 miles west of Estes Park station.

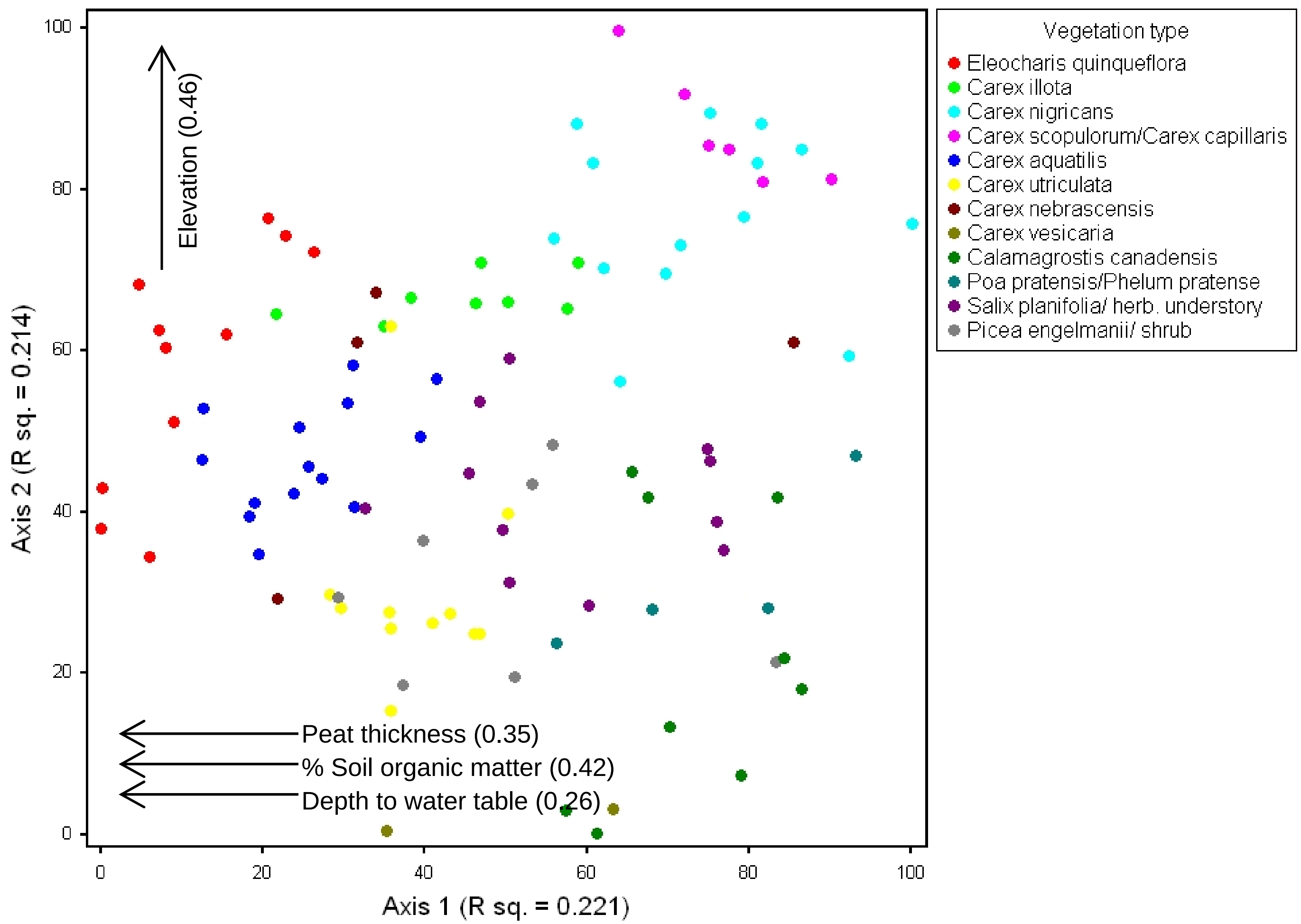

Fig. 9 NMS ordination performed using vegetation data showing correlation to environmental gradients. Plot shows R^2 values for axes 1 and 2. Symbols denote vegetation types derived from indicator species analysis and cluster analysis shown in Table 2. Environmental gradients and Pearson and Kendall values for positive correlation with ordination axes are shown with arrows indicating directionality of effect for each axis. See Table 2 for correlations for all variables and all axes. See Appendix A for descriptions of vegetation types.

Table 2 Vegetation types generated from hieracrchical agglomerative cluster analysis and indicator species analysis**.** Species derived from pruning cluster dendrogram and using species with highest indicator values to designate vegetation type. Table gives indicator values (IV), *p*-values (p<0.05), and number of occurrences (*n*) for each type of stand.

RMNP wetland vegetation types	IV(s)	*p*-value(s)	*n*
Herbaceous types			
Eleocharis quinqueflora	81.5	0.0002	11
Carex illota	36.9	0.0158	8
Carex nigricans – Juncus drummondii	54.9 – 40.9	0.0012 – 0.0106	14
Carex scopulorum – Carex capillaris	86.9 – 16.7	0.0002 – 0.15	6
Carex aquatilis	36.0	0.0002	14
Carex utriculata	30.7	0.0245	11
Carex nebrascensis	50.0	0.0030	4
Carex vesicaria	98.2	0.0004	2
Calamagrostis canadensis	44.6	0.0002	9
Poa pratensis - Phleum pretense	53.8 - 75.0	0.0020 - 0.0004	4
Shrub types			
Salix planifolia – herbaceous understory	62.1	0.0002	11
Forested types			
Picea engelmannii – shrub	44.0	0.0076	7

Table 3 Pearson Kendall values of environmental variable correlation with NMS axes 1, 2 and 3 Values significant at $R^2>0.20$ are shown in bold.

Environmental Variable	***Axis 1*** R^2	***Axis 2*** R^2	***Axis 3*** R^2
Elevation	0.046	**0.460**	0.024
Water Level	**0.256**	0.001	0.002
Peat Thickness	**0.351**	0.001	0.016
% Organic Matter	**0.421**	0.011	0.016
Basal Area	0.007	0.002	0.118
% Bare Substrate	0.015	0.000	0.163

Table 4 Indicator species for wetlands with < 20, 20-40, and > 40 cm of peat accumulation. Table gives size (*n*) of groups, species name, p-value and indicator value (IV) from indicator species analysis. Values significant at p <0.05 are shown in bold.

Wetlands with <20 cm of peat			**Wetlands with 20 - 40 cm of peat**			**Wetlands with >40 cm of peat**		
n=45			*n*=16			*n*=40		
Species	***P***	**IV**	**Species**	***P***	**IV**	**Species**	***P***	**IV**
Carex scopulorum	**0.0204**	18.9	*Carex aquatilis*	**0.0328**	37.3	*Carex utriculata*	**0.0370**	25.0
Deschampsia cespitosa	**0.0194**	31.7	*Carex illota*	**0.0454**	19.2	*Eleocharis quinqueflora*	**0.0004**	35.3
Juncus arcticus ssp. *ater*	0.0554	11.1	*Podagrostis humilis*	**0.0286**	18.8	*Sphagnum* spp.	**0.0330**	19.2
			Senecio triangularis	0.0530	17.7	*Warnstorfia exannulata*	**0.0206**	19.8
			Swertia perennis	**0.0044**	20.8			
			Pedicularis groenlandica	**0.0072**	28.4			
			Drepanocladus aduncus	**0.0418**	10.0			

APPENDIX A: Vegetation Type Descriptions and Comparisons

Appendix A: Descriptions of vegetation types generated from hierarchical cluster analysis and comparison to wetland vegetation associations described and documented by the Colorado Natural Heritage Program (CNHP). (Carsey *et al.* 2003*).* Nomenclature follows Weber and Wittman (2001, 2007).

Note: Vegetation types described in this document are not meant to represent the full range of plant communities or diversity present in the vegetation of fens and wet meadows in Rocky Mountain National Park or to serve as a guide or key to wetland vegetation. Rather, these vegetation types are meant to identify stand-dominating species and common vegetation types and aid in the interpretation of species data and correlation with environmental variables.

A. Herbaceous Vegetation types

Eleocharis quinqueflora

Wetlands dominated by *Eleocharis quinqueflora* typically occur in the subalpine and upper subalpine on slopes or in kettle ponds and are characterized by thick peat soils, low ground cover, often with exposed substrate or standing water and low to moderate cover of brown moss bryophyte species. Typically wetlands were perennially saturated with water near the ground surface, and shallow flooding, sheet flow and/or spring-fed ponds were commonly observed in association with this vegetation type (See photos 6 and 15, Appendix C). *Carex angustior, Pedicularis groenlandica* and brown moss species *Hamatocaulis vernicosus, Straminergon stramineum, Dicranum muehlenbeckii,* and *Warnstorfia exannulata* are associated with this vegetation type.

Equivalent CNHP wetland plant association (Carsey *et al.* 2003, pages 380-381):

Plant Association	Scientific name	State rank
Few-flower spike rush erbaceous Vegetation	*Eleocharis quinqueflora*	S3S4

Carex illota

Wetlands dominated by *Carex illota* typically occur in the upper subalpine to lower alpine and are characterized by thin peat horizons of ~20 - 40 cm, low stature vegetation, and diverse forb communities. Hydrology was variable but wetlands were typically saturated for at least a portion of the growing season and were often found on gentle slopes above natural water impoundments such as deadfall trees or soil banks (See photo 4, Appendix C). Associated species include *Psychrophila leptosepala, Pedicularis groenlandica, Kalmia microphylla, Clemensia rhodantha,* and *Carex praeceptorum. Carex illota* was commonly observed co-dominating stands with *Carex nigricans*, but *Carex illota – Carex nigricans* was not identified as a dominant vegetation type in the cluster analysis.

Equivalent CNHP wetland plant association (Carsey *et al.* 2003, pages 342-343):

Plant Association	Scientific name	State rank
Small-head sedge Herbaceous Vegetation	*Carex illota*	S2

Carex nigricans - Juncus drummondii

Wetlands with *Carex nigricans- Juncus drummondii* vegetation typically occurs in the subalpine to alpine and are common in the alpine tundra along Trail Ridge Road. *Carex nigricans* is often found growing in dense stands often forming hummocks in peaty soils of the subalpine or along alpine seep/springs with intermittent patches of *Juncus drummondii* (See photo 7, Appendix C). Soils are typically saturated for most of the growing season but peat thicknesses varied from >40 cm to very thin or non-existent. Associated species include *Arnica mollis, Packera crocata, Bistorta bistortoides, Trollius laxus* ssp. *albiflorus,* and *Philinotis fontana.*

Equivalent CNHP wetland plant association (Carsey *et al.* 2003, pages 348-349):

Plant Association	**Scientific name**	**State rank**
Black alpine sedge - Drummond rush Herbaceous Vegetation	*Carex nigricans - Juncus drummondii*	S2

Carex scopulorum - Carex capillaris

Wetlands dominated by *Carex scopulorum- Carex capillaris* typically occur in the alpine but *Carex scopulorum* was also found present in stands at subalpine elevations. This vegetation type is found in saturated areas below snow-melt basins and channels and often had thin peat horizons overlaying mineral substrates. Wetlands were commonly saturated for most of the growing season and often had small pools of standing water (See photo 8, Appendix C). Associated species include *Deschampsia cespitosa, Kobresia myosuroides, Bistorta vivipara,* and *Carex nelsonii* and in some stands the alpine willows *Salix nivalis* and *Salix petrophila* were present.

Similar CNHP wetland plant association (Carsey *et al.* 2003, pages 356-357):

Plant Association	**Scientific name**	**State rank**
Mountain sedge - Marsh-marigold Herbaceous Vegetation	*Carex scopulorum - Psychrophila leptosepala (=Caltha leptosepala)*	S4

Carex aquatilis

Wetlands dominated by *Carex aquatilis* are extremely common and occur in the montane to the alpine in low-gradient valleys, slopes, kettle ponds, snow-melt basins, and lake fringes. This vegetation type is characterized by a uniform lawn of *Carex aquatilis* with moderate to thick peat horizons (with the exception of thinner peat in alpine sites) and perennially saturated soils (See photos 2 and 5, Appendix C). Associated species include gramnoids such as *Carex utriculata* and *Calamagrostis canadensis* and bryophytes *Aulacomnium palustre, Climacium dendroides, Campylium stellatum,* and *Ptychostomum pseudotriquetrum.* Some sites had low cover of shrub species *Salix planifolia, Salix wolfii* and *Betula glandulosa.*

Equivalent CNHP wetland plant association (Carsey *et al.* 2003, pages 334-335):

Plant Association	**Scientific name**	**State rank**
Water sedge Herbaceous Vegetation	*Carex aquatilis*	S4

Carex utriculata

Wetlands dominated by *Carex utriculata* are common in the montane and are found in broad, low gradient floodplains, lake fringes and saturated depressions. This vegetation type is characterized by uniform lawns, perennially saturated soils, and thin to moderately thick peat horizons (See photo 13, Appendix C). *Carex utriculata* is also commonly found in marshes and along riparian zones in oxbows, drained beaver ponds, and overflow channels. Associated species include *Carex aquatilis, Calamagrostis canadensis, Carex festivella, Juncus filiformis,* and *Polemonium caeruleum.*

Equivalent CNHP wetland plant association (Carsey *et al.* 2003, pages 360-361):

Plant Association	**Scientific name**	**State rank**
Beaked sedge Herbaceous Vegetation	*Carex utriculata*	S5

Carex nebrascensis

Wetlands dominated by *Carex nebrascensis* occur in the montane and upper montane and due to elevation restrictions this vegetation type is uncommon in Rocky Mountain National Park. *Carex nebrascensis* is typically found in low gradient valleys and floodplains in seasonally saturated soils with very little or no peat accumulation (See photo 14, Appendix C). In this study the *Carex nebrascensis* vegetation type includes several lower elevation species including *Carex simulata, Carex praegracilis,* and *Carex lasiandra* that may be present or co-dominate with *C. nebrascensis.* Other associated species include *Hierochloe hirta* ssp. *arctica, Cicuta douglasii,* and *Conioselinum scopulorum.*

Equivalent CNHP wetland plant association (Carsey *et al.* 2003, pages 346-347):

Plant Association	**Scientific name**	**State rank**
Nebraska sedge Herbaceous Vegetation	*Carex nebrascensis*	S3

Carex vesicaria

Wetlands dominated by *Carex vesicaria* occur in the montane to upper montane and only 2 wetlands of this type were sampled, both on the western slope. One site was seasonally saturated with mineral soils, low vegetation cover, and significant cover of *Carex utriculata.* The other site occurred in seasonally saturated low gradient floodplain and had high cover of *Salix boothii* and *Salix geyeriana* (See photo 3, Appendix C). Other associated species included *Glyceria striata, Petasites sagittatus,* and *Poa palustris.* This species is difficult to distinguish from *Carex utriculata* and this vegetation type is not well documented in the state of Colorado. The CNHP description of a similar *Carex vesicaria* plant association differs slightly from was found in this study but was also based on only 2 sample locations. More data is needed on this vegetation type.

Similar CNHP wetland plant association (Carsey *et al.* 2003, pages 364-365):

Plant Association	**Scientific name**	**State rank**
Blister sedge Herbaceous Vegetation	*Carex vesicaria*	S1

Calamagrostis canadensis

Wetlands dominated by *Calamagrostis canadensis* occur in the upper motane to subalpine in wet forest openings and broad valleys and floodplains. This vegetation type is characterized by dense, hummocked herbaceous vegetation, sporadic low shrub cover, seasonally to perennially high water tables and moderately thick (~40 cm) peat horizons (See photo 12, Appendix C). *Calamagrostis candensis* is also common along riparian areas and in old beaver ponds. Associated species include *Carex neurophora, Carex pachystacha, Senecio triangularis* and the shrub species *Betula glandulosa, Salix planifolia,* and *Salix geyeriana.*

Equivalent CNHP wetland plant association (Carsey *et al.* 2003, pages 328-329):

Plant Association	**Scientific name**	**State rank**
Bluejoint reedgrass Herbaceous Vegetation	*Calamagrostis canadensis*	S4

Poa pratensis – Phleum pratense

Wetlands dominated by the invasive pasture grasses *Poa pratensis – Phleum pratense* were found in the montane and upper montane in wetlands near roads, stock trails, and sites of historic homesteading. This vegetation type is characterized by early spring saturation followed by deep summer water table draw down, mineral soils, and diverse stands native and non-native vegetation, some of which are commonly associated with grazing (See photo 10, Appendix C). Associated species include shrubs *Pentaphylloides floribunda* and *Seriphidium canum* which had high cover in some stands and herbaceous species *Juncus arcticus* ssp. *ater, Achillea lanulosa, Thermopsis spp., Fragaria spp., Taraxacum officinale* and *Iris missouriensis.* CNHP does not document a similar wetland vegetation type in Colorado but the National Vegetation Classification system (NatureServe 2009) has identified a *Poa pratensis* semi-natural wetland Ecological Alliance present throughout the West that corresponds to vegetation types found in Rocky Mountain National Park.

Similar NatureServe Ecological Alliance (available at *http://www.natureserve.org)*

Ecological Alliance	**Scientific name**
Kentucky Bluegrass Semi-natural Seasonally Flooded Herbaceous Alliance	*Poa pratensis* Semi-natural Seasonally Flooded Herbaceous Alliance

B. Shrub Vegetation Types

Salix planifolia – herbaceous understory

Wetlands dominated by *Salix planifolia* are common and occur in the montane to upper subalpine in wide valleys and floodplains, snow melt basins, on lake fringes, in willow carrs, and low to moderate gradient subalpine slopes. This vegetation type is characterized by variable peat layers (20 - >100cm thick) and soils are moist to saturated with water tables near the ground surface for most of the growing season (See photos 1 and 9, Appendix C). The *Salix planifolia* – herbaceous understory vegetation type is generalized and includes sites with co-dominant shrub species *Salix wolfii, Salix brachycarpa,* or *Betula occidentalis.* Dominant understory vegetation included sites with *Carex aquatilis, Calamagrostis canadensis,* and diverse forb communities. Other associated species include *Carex brunnescens, Carex nova, Carex deweyana, Carex utriculata, Psychrophila leptosepala,* and *Swertia perennis.* This generalized vegetation type corresponds to several CNHP *Salix planifolia* plant associations. In order to better classify the different types of *Salix planifolia* communities present in Rocky Mountain National Park more data and sample locations are needed.

Similar CNHP wetland plant associations (Carsey *et al.* 2003, pages 246-255):

Plant Association	**Scientific name**	**State rank**
Planeleaf willow / Bluejoint reedgrass Shrubland	*Salix planifolia / Calamagrostis canadensis*	S3
Planeleaf willow / Water sedge Shrubland	*Salix planifolia / Carex aquatilis*	S4
Planeleaf willow / Beaked sedge Shrubland	*Salix planifolia / Carex utriculata*	S2
Planeleaf willow / Mesic forb Shrubland	*Salix planifolia /* Mesic forb	S4

C. Forested Vegetation Types

Picea engelmanii - shrub

Wetlands with a canopy of *Picea engelmanii* occur in the upper montane to lower subalpine in valley bottoms and isolated slopes and terraces. This vegetation type is characterized by thick peat horizons, water tables near the surface for the entire growing season, hummocks, and thick moss canopies. The *Picea engelmannii* – shrub vegetation type is generalized and includes sites with *Pinus contortus* and *Abies bifolia* in the canopy and different sub-dominant understory shrub and herbaceous species (See photos 11 and 16, Appendix C). Possible sub-dominant shrub species include *Salix wolfii, Alnus incana* ssp. *tenufolia, Salix planifolia,* and *Betula occidentalis.* Herbaceous understories were commonly *Carex aquatilis, Calamagrostis canadensis, Sphagnum spp.*or diverse forb communities. Other associated species include *Thalictrum fendleri, Geranium richarsonii, Equisetum pretense, Luzula parviflora, Carex disperma, Glyceria elata,* and the bryophyte *Tomentypnum nitens.* This generalized vegetation type corresponds to several CNHP forested wetland plant associations. In order to better classify the different types of *Picea engelmanii* wetland communities present in Rocky Mountain National Park more data and sample locations are needed.

Similar CNHP wetland plant associations (Carsey *et al.* 2003, pages 52-57):

Plant Association	**Scientific name**	**State rank**
Subalpine fir-Engleman spruce/Thinleaf alder Forest	*Abies lasiocarpa-Picea engelmanni / Alnus incana* ssp. *tenufolia*	S5
Subalpine fir-Engleman spruce/Bluejoint reedgrass Forest	*Abies lasiocarpa-Picea engelmanni / Calamagrostis canadensis*	S3
Subalpine fir-Engleman spruce/ Water sedge Forest	*Abies lasiocarpa-Picea engelmanni / Carex aquatilis*	S5

APPENDIX A REFERENCES

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APPENDIX B: Vascular Plant and Bryophyte Species Lists for RMNP wetlands

Appendix B1: Vascular plant species list for RMNP wetlands. *n* = number of sample sites in which the species was found. Nomenclature follows Weber and Wittman (2001).

Scientific name	Common Name	*n*
Alliaceae		
Allium geyeri S. Watson	Geyer's onion	1
Alsinaceae		
Cerastium beeringianum Chamisso & Schlechtendal ssp. *earlei* (Rydberg) Hultén	Bering chickweed	6
Cerastium fontanum Baumgartner	common mouse-ear chickweed	17
Cerastium nutans Rafinesque var. *brachypodum* Engelmann ex A. Gray	shortstalk chickweed	4
Cerastium strictum L. Haenke	field chickweed	1
Lidia obtusiloba (Rydberg) Löve & Löve	twinflower sandwort	3
Moehringia lateriflora (L.) Fenzl	bluntleaf sandwort	4
Moehringia macrophylla (Hooker) Torrey	largeleaf sandwort	1
Sagina saginoides (L.) Karsten	arctic pearlwort	6
Stellaria calycantha (Ledebour) Bongard	northern starwort	10
Stellaria crassifolia Ehrhart	fleshy starwort	2
Stellaria graminea L.	grass-like starwort	6
Stellaria longifolia Mühlenberg ex Willdenow	longleaf starwort	25
Stellaria longipes Goldie	longstalk starwort	12
Stellaria obtusa Engelmann	Rocky Mountain chickweed	1
Stellaria umbellata Turczaninov ex Karilin & Kirilow	umbrella starwort	21
Tryphane rubella (Wahlenberg) Reichenbach	beautiful sandwort	1
Apiaceae		
Cicuta douglasii (De Candolle) Coulter & Rose	poison hemlock	6
Conioselinum scopulorum (A. Gray) Coulter & Rose	Rocky Mountain hemlockparsley	64
Heracleum sphondylium L. ssp. *montanum* (Schleicher ex Gaudin) Briquet in Schinz & Thellung	common cowparsnip	25
Osmorhiza depauperata Philippi	bluntseed sweetroot	13
Oxypolis fendleri (A. Gray) Heller	Fendler's cowbane	21
Asteraceae		
Achillea lanulosa Nuttall	western yarrow	56
Agoseris glauca (Pursh) Rafinesque	pale agoseris	12
Anaphalis margaritacea (L.) Bentham & Hooker	western pearly everlasting	8
Antennaria corymbosa E. Nelson	flat-top pussytoes	23
Antennaria media Greene	Rocky Mountain pussytoes	2
Antennaria rosea Greene	rosy pussytoes	1
Antennaria umbrinella Rydberg	umber pussytoes	8
Arnica chamissonis Lessing ssp. *foliosa* (Nuttall) Maguire	Chamisso arnica	1

Scientific name	Common Name	*n*
Asteraceae *continued*		
Arnica cordifolia Hooker	heartleaf arnica	2
Arnica longifolia D. C. Eaton	spearleaf arnica	1
Arnica mollis Hooker	hairy arnica	29
Artemisia frigida Willdenow	prairie sagewort	1
Artemisia scopulorum A. Gray	alpine sagebrush	13
Aster foliaceus Lindley ex De Candolle		8
Aster lanceolatus Willdenow ssp. *hesperius* (A. Gray) Semple & Chmielewski	white panicle aster	14
Breea arvensis (L.) Lessing	Canada thistle	21
Chlorocrepis tristis (Willdenow ex Sprengel) Löve & Löve ssp. *gracilis (*Hooker) W. A. Weber	slender hawkweed	3
Cirsium eatonii (A. Gray) B. L. Robinson	Eaton's thistle	5
Cirsium scariosum Nuttall	meadow thistle	6
Erigeron eximius Greene	sprucefir fleabane	5
Erigeron melanocephalus A. Nelson	blackhead fleabane	9
Erigeron peregrinus (Banks ex Pursh) Greene ssp. *callianthemus* (Greene) Cronquist	subalpine fleabane	54
Erigeron simplex Greene	onestem fleabane	6
Erigeron vetensis Rydberg	early bluetop fleabane	1
Ligularia bigelovii (A. Gray) W. A. Weber var. *hallii* (A. Gray) W. A. Weber	Hall's ragwort	22
Microseris nutans (Geyer ex Hooker) Schultz-Bipontinus	nodding microseris	2
Oreochrysum parryi (A. Gray) Rydberg	Parry's goldenrod	1
Packera crocata (Rydberg) Weber & Löve	saffron ragwort	45
Petasites sagittatus (Banks ex Pursh) A. Gray	arrowleaf sweet coltsfoot	1
Rudbeckia ampla A. Nelson	cutleaf coneflower	7
Senecio atratus Greene	tall blacktip ragwort	1
Senecio crassulus A. Gray	thickleaf ragwort	1
Senecio triangularis Hooker	arrowleaf ragwort	64
Seriphidium canum (Pursh) W. A. Weber	silver sagebrush	1
Solidago canadensis L.	Canada goldenrod	4
Solidago multiradiata Aiton	Rocky Mountain goldenrod	4
Taraxacum officinale G. H. Weber ex Wiggers	common dandelion	61
Tragopogon pratensis L.	Jack-go-to-bed-at-noon	2
Virgulus campestris (Nuttall) Reveal & Keener	western meadow aster	2
Betulaceae		
Alnus incana (L.) Moench ssp. *tenuifolia* (Nuttall) Breitung	thinleaf alder	35
Betula glandulosa Michaux	resin birch	35

Scientific name	Common Name	*n*
Boraginaceae		
Mertensia ciliata (James ex Torrey) G. Don	tall fringed bluebells	56
Plagiobothrys scouleri (Hooker & Arnott) I. M. Johnston ssp. penicillata (Greene) Löve	sleeping popcornflower	4
Brassicaeae		
Cardamine cordifolia A. Gray	heartleaf bittercress	27
Rorippa palustris (L.) Besser ssp. hispida (Desvaux) Jonsell	hispid yellowcress	2
Rorippa sinuata (Nuttall in Torrey & Gray) A. S. Hitchcock	spreading yellowcress	3
Rorippa teres (Michaux) Stuckey	bluntleaf yellowcress	2
Callitrichaceae		
Callitriche verna L. emend. Lönnroth	vernal water-starwort	1
Campanulaceae		
Campanula parryi A. Gray	Parry's bellflower	1
Campanula rotundifolia L.	bluebell bellflower	2
Caprifoliaceae		
Distegia involucrata (Banks ex Sprengel) Cockerell	twinberry honeysuckle	19
Linnaea borealis L.	twinflower	4
Sambucus microbotrys Rydberg	red elderberry	1
Symphoricarpos albus (L.) S. F. Blake	common snowberry	1
Caryophyllaceae		
Anotites menziesii (Hooker) Greene	Menzies' campion	4
Convallariaceae		
Maianthemum amplexicaule (Nuttall) W. A. Weber	feathery false lily of the valley	6
Maianthemum stellatum (L.) Link	starry false lily of the valley	12
Crassulaceae		
Clementsia rhodantha (A. Gray) Rose	redpod stonecrop	85
Tolmachevia integrifolia (Raf.) A. Löve & D. Löve	ledge stonecrop	18
Cupressaceae		
Juniperus communis L. ssp. *alpina* (J. E. Smith) Celakovsky	common juniper	15
Cyperaceae		
Carex albo-nigra Mackenzie in Rydberg	blackandwhite sedge	3
Carex angustior Mackenzie in Rydberg	star sedge	9
Carex aquatilis Wahlenberg	water sedge	99
Carex athrostachya Olney	slenderbeak sedge	3
Carex atrosquama Mackenzie	lesser blackscale sedge	2
Carex aurea Nuttall	golden sedge	12
Carex bella L. H. Bailey	southwestern showy sedge	1
Carex brunnescens (Persoon) Poiret in Lamarck	brownish sedge	4
Carex buxbaumii Wahlenberg	Buxbaum's sedge	1

Scientific name	Common Name	*n*
Cyperaceae *continued*		
Carex canescens L.	silvery sedge	41
Carex capillaris L.	hair-like sedge	4
Carex deweyana Schweinitz	Dewey sedge	5
Carex disperma Dewey	softleaf sedge	10
Carex ebenea Rydberg	ebony sedge	1
Carex epapillosa Mackenzie in Rydberg	different-nerve sedge	1
Carex festivella Mackenzie	smallwing sedge	16
Carex foenea Willdenow	dryspike sedge	3
Carex geyeri F. Boott	Geyer's sedge	3
Carex illota L. H. Bailey	sheep sedge	30
Carex interior L. H. Bailey	inland sedge	3
Carex lanuginosa Michaux	woolly sedge	9
Carex magellanica Lamarck ssp. *irrigua* (J. E. Smith) Hultén	boreal bog sedge	15
Carex microptera Mackenzie	smallwing sedge	11
Carex nebrascensis Dewey	Nebraska sedge	9
Carex nelsonii Mackenzie in Rydberg	Nelson's sedge	7
Carex neurophora Mackenzie in Abrams	alpine nerve sedge	7
Carex nigricans C. A. Meyer	black alpine sedge	30
Carex norvegica Retzius	Norway sedge	1
Carex nova L. H. Bailey	black sedge	4
Carex pachystachya Chamisso ex Steudel	chamisso sedge	9
Carex petasata Dewey	Liddon sedge	3
Carex praeceptorum Mackenzie	early sedge	11
Carex praegracilis F. Boott	clustered field sedge	4
Carex praticola Rydberg	meadow sedge	3
Carex saxatilis L. ssp. *laxa* (Trautvetter) Kalela	rock sedge	2
Carex scopulorum Holm	mountain sedge	32
Carex simulata Mackenzie	analogue sedge	6
Carex stevenii (Holm) Kalea	Steven's sedge	8
Carex utriculata F. Boott	Northwest Territory sedge	80
Carex vesicaria L.	blister sedge	4
Eleocharis macrostachya Britton	pale spikerush	9
Eleocharis quinqueflora (F. X. Hartman) Schwartz	fewflower spikerush	46
Eriophorum angustifolium Honckeny	tall cottongrass	6
Kobresia myosuroides (Villars) Fiori & Paoli	Bellardi bog sedge	4
Equisetaceae		
Equisetum arvense L.	field horsetail	60
Equisetum pratense Ehrhart	meadow horsetail	4

Scientific name	Common Name	*n*
Equisetaceae *continued*		
Hippochaete hyemalis (L.) Bruhin	scouringrush horsetail	1
Hippochaete variegata (Schleicher) Bruhin	variegated scouringrush	9
Ericaceae		
Gaultheria humifusa (R. Graham) Rydberg	alpine spicywintergreen	6
Kalmia microphylla (Hooker) Heller	alpine laurel	13
Vaccinium cespitosum Michaux	dwarf bilberry	24
Fabaceae		
Astragalus flexuosus (Hooker) G. Don	flexile milkvetch	5
Astragalus parryi A. Gray	Parry's milkvetch	2
Lupinus lepidus Douglas ssp. *caespitosus* (Nuttall) Detling	stemless dwarf lupine	9
Thermopsis divaricarpa A. Nelson	spreadfruit goldenbanner	4
Thermopsis montana Nuttall ex Torrey & Gray	mountain goldenbanner	4
Trifolium dasyphyllum Torrey & Gray	alpine clover	13
Trifolium hybridum L.	alsike clover	8
Trifolium longipes Nuttall	longstalk clover	5
Trifolium parryi A. Gray	Parry's clover	2
Trifolium pratense L.	red clover	6
Trifolium repens L.	white clover	26
Gentianaceae		
Chondrophylla prostrata (Haenke ex Jacquin) J. P. Anderson	pygmy gentian	1
Frasera speciosa Walter	green gentian	1
Gentianella acuta (Michaux) Hiitonen	autumn dwarf gentian	21
Gentianella strictiflora (Rydberg) W. A. Weber	autumn dwarf gentian	5
Gentianodes algida (Pallas) Löve & Löve	whitish gentian	11
Gentianopsis thermalis (Kuntze) Iltis	Rocky Mountain fringed gentian	22
Pneumonanthe affinis (Grisebach) Greene	pleated gentian	2
Swertia perennis L.	felwort	36
Geraniaceae		
Geranium caespitosum James ex Torrey ssp. *caespitosum*	pineywoods geranium	1
Geranium richardsonii Fischer & Trautvetter	Richardson's geranium	38
Grossulariaceae		
Ribes coloradense Coville	trailing black currant	2
Ribes inerme Rydberg	whitestem gooseberry	8
Ribes lacustre (Persoon) Poiret	prickly currant	7
Haloragaceae		
Myriophyllum sibiricum Komarov	shortspike watermilfoil	1

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Helleboraceae		
Aconitum columbianum Nuttall ex Torrey & Gray	Columbian monkshood	8
Aquilegia saximontana Rydberg ex B. L. Robinson in A. Gray	Rocky Mountain blue columbine	1
Delphinium geyeri Greene	Geyer's larkspur	3
Delphinium ramosum Rydberg	mountain larkspur	1
Psychrophila leptosepala (De Candolle) W. A. Weber	white marsh marigold	71
Trollius albiflorus (A. Gray) Rydberg	American globeflower	23
Hypericaceae		
Hypericum formosum Humboldt, Bonpland, & Kunth		2
Iridaceae		
Iris missouriensis Nuttall	Rocky Mountain iris	2
Sisyrinchium pallidum Cholewa & Henderson	pale blue-eyed grass	2
Juncaeae		
Juncus arcticus Willdenow ssp. *ater* (Rydberg) Hultén	mountain rush	25
Juncus bufonius L. var. *occidentalis* F. J. Hermann	toad rush	1
Juncus castaneus J. E. Smith	chestnut rush	1
Juncus drummondii E. Meyer	Drummond's rush	47
Juncus effusus L.	common rush	1
Juncus filiformis L.	thread rush	8
Juncus longistylis Torrey	longstyle rush	11
Juncus mertensianus Bongard	Mertens' rush	8
Juncus parryi Engelmann	Parry's rush	5
Juncus saximontanus A. Nelson	Rocky Mountain rush	7
Juncus tracyi Rydberg	Tracy's rush	16
Juncus triglumis L.	three-hulled rush	8
Luzula comosa E. Meyer	Pacific woodrush	20
Luzula parviflora (Ehrhart) Desvaux	smallflowered woodrush	43
Luzula spicata (L.) De Candolle	spiked woodrush	4
Laminaceae		
Mentha arvensis L.	wild mint	10
Prunella vulgaris L.	common selfheal	2
Scutellaria galericulata L. var. *epilobiifolia* (Hamilton) Jordal	marsh skullcap	1
Stachys palustris L. ssp. *pilosa* (Nuttall) Epling	hairy hedgenettle	2
Lemnaceae		
Lemna L.	duckweed	3
Lycopodiaceae		
Lycopodium annotinum L.	stiff clubmoss	1
Lycopodium dubium Zoëga	stiff clubmoss	1

Scientific name	Common Name	*n*
Onagraceae		
Chamerion danielsii D. Löve	fireweed	49
Epilobium anagallidifolium Lamarck	pimpernel willowherb	41
Epilobium ciliatum Rafinesque	fringed willowherb	11
Epilobium hornemannii Reichenbach	Hornemann's willowherb	3
Epilobium lactiflorum Haussknecht	milkflower willowherb	6
Epilobium leptocarpum Hausskn.	slenderfruit willowherb	11
Epilobium leptophyllum Rafinesque	bog willowherb	3
Epilobium saximontanum Haussknecht	Rocky Mountain willowherb	9
Orchidaceae		
Coeloglossum viride (L.) C. J. Hartman ssp. *bracteatum* (Mühlenberg ex Willdenow) Hultén	longbract frog orchid	2
Corallorhiza trifida (L.) Chatelain	yellow coralroot	1
Limnorchis dilatata (Pursh) Rydberg ssp. *albiflora* (Chamisso) Löve & Simon	scentbottle	17
Limnorchis hyperborea (L.) Rydberg	northern green orchid	22
Limnorchis stricta (Lindley) Rydberg	slender bog orchid	4
Listera cordata (L.) R. Brown ssp. *nephrophylla* (Rydberg) Löve & Löve	heartleaf twayblade	8
Spiranthes romanzoffiana Chamisso	hooded lady's tresses	15
Parnassiaceae		
Parnassia fimbriata Konig	fringed grass of Parnassus	1
Pinaceae		
Abies bifolia A. Murray	subalpine fir	11
Picea engelmannii Parry ex Engelmann	Engelmann spruce	55
Picea pungens Engelmann	blue spruce	2
Pinus contorta Douglas ex Loudon var. *latifolia* Engelmann	lodgepole pine	38
Plantaginaceae		
Plantago major L.	common plantain	2
Plantago tweedyi A. Gray	Tweedy's plantain	1
Poaceae		
Agrostis gigantea Roth	redtop	9
Agrostis idahoensis Nash	Idaho bentgrass	8
Agrostis scabra Willdenow	rough bentgrass	51
Agrostis variabilis Rydberg	mountain bentgrass	2
Alopecurus aequalis Sobolewski	shortawn foxtail	4
Alopecurus pratensis L.	meadow foxtail	9
Beckmannia syzigachne (Steudel) Fernald ssp. *baicalensis* (Kuznetzow) Koyama & Kuwano	American sloughgrass	2
Bromopsis canadensis (Michaux) Holub	fringed brome	23

Scientific name	Common Name	*n*
Poaceae *continued*		
Bromopsis inermis (Leysser) Holub	smooth brome	4
Bromopsis porteri (Coulter) Holub	Porter brome	1
Calamagrostis canadensis (Michaux) P. Beauvois	bluejoint	92
Calamagrostis stricta (Timm) Koeler	slimstem reedgrass	1
Critesion brachyantherum (Nevski) Barkworth & Dewey	meadow barley	2
Critesion glaucum (Steudel) Löve	smooth barley	1
Danthonia intermedia Vasey	timber oatgrass	6
Deschampsia cespitosa (L.) P. Beauvois	tufted hairgrass	89
Elymus glaucus Buckley	blue wildrye	6
Elymus lanceolatus (Scribner & Smith) Gould	thickspike wheatgrass	2
Elymus trachycaulus (Link) Gould	slender wheatgrass	6
Festuca brachyphylla Schultes ssp. *coloradensis* Fredriksen	Colorado fescue	12
Festuca minutiflora Rydberg	smallflower fescue	2
Festuca pratensis Hudson	meadow fescue	2
Festuca saximontana Rydberg	Rocky Mountain fescue	1
Glyceria elata (Nash ex Rydberg) Jones	fowl mannagrass	4
Glyceria grandis S. Watson in A. Gray	American mannagrass	1
Glyceria striata (Lamarck) Hitchcock	fowl mannagrass	10
Hierochloë hirta (Schrank) Borbas ssp. *arctica* (J. Presl in K. Presl) G. Weimarck	northern sweetgrass	12
Muhlenbergia filiformis (Thurber ex S. Watson) Rydberg	pullup muhly	2
Pascopyrum smithii (Rydberg) Löve	western wheatgrass	6
Phleum commutatum Gaudin	alpine timothy	47
Phleum pratense L.	timothy	44
Poa agassizensis Boivin & D. Löve	Kentucky bluegrass	1
Poa alpina L.	alpine bluegrass	9
Poa annua L.	annual bluegrass	1
Poa compressa L.	Canada bluegrass	8
Poa cusickii Vasey ssp. *epilis* (Scribner) W. A. Weber	Cusick's bluegrass	1
Poa glauca M. Vahl ssp. *rupicola* (Nash) W. A. Weber	timberline bluegrass	5
Poa leptocoma Trinius	marsh bluegrass	5
Poa lettermanii Vasey	Letterman's bluegrass	1
Poa nemoralis L. ssp. *interior* (Rydberg) W. A. Weber	inland bluegrass	3
Poa palustris L.	fowl bluegrass	19
Poa pratensis L.	Kentucky bluegrass	45
Poa reflexa Vasey & Scribner	nodding bluegrass	18
Podagrostis humilis (Vasey) Björkman	alpine bentgrass	27
Torreyochloa pauciflora (J. Presl in K. Presl) Church	pale false mannagrass	1

Scientific name	Common Name	*n*
Poaceae *continued*		
Trisetum spicatum (L.) Richter	spike trisetum	4
Trisetum wolfii Vasey in Rothrock	Wolf's trisetum	26
Vahlodea atropurpurea (Wahlenberg) E. Fries ssp. *latifolia* (Hooker) Porsild	mountain hairgrass	2
Polemoniaceae		
Polemonium caeruleum L. ssp. *amygdalinum* (Wherry) Munz	western polemonium	32
Polemonium foliosissimum (A. Gray) A. Gray	towering Jacob's-ladder	7
Polemonium pulcherrimum Hooker ssp. delicatum (Rydberg) Brand	Jacob's-ladder	5
Polygonaceae		
Acetosella vulgaris (K. Koch) Fourreau	common sheep sorrel	8
Bistorta bistortoides (Pursh) Small	American bistort	38
Bistorta vivipara (L.) S. Gray	alpine bistort	34
Rumex aquaticus L. ssp. *occidentalis* (S. Watson) Hultén	western dock	15
Rumex crispus L.	curly dock	5
Portulacaceae		
Claytonia lanceolata Pursh	lanceleaf springbeauty	1
Crunocallis chamissoi (Ledebour ex Sprengel) Rydberg	water minerslettuce	13
Potamogetonaceae		
Potamogeton gramineus L.	variableleaf pondweed	1
Primulaceae		
Androsace filiformis Retzius	filiform rockjasmine	1
Androsace septentrionalis L.	pygmyflower rockjasmine	2
Primula parryi A. Gray	Parry's primrose	1
Pyrolaceae		
Chimaphila umbellata (L.) W. Barton ssp. *occidentalis* (Rydberg) Hultén	pipsissewa	1
Moneses uniflora (L.) A. Gray	single delight	1
Orthilia secunda (L.) House	sidebells wintergreen	11
Pyrola rotundifolia L. ssp. *asarifolia* (Michaux) Löve	liverleaf wintergreen	8
Ranunculaceae		
Anemonastrum narcissiflorum (L.) Holub ssp. *zephyrum* (A. Nelson) W. A. Weber	narcissus anemone	8
Ranunculus abortivus L. ssp. *acrolasius* (Fernald) Kapoor & Löve	littleleaf buttercup	5
Ranunculus alismifolius Geyer ex Bentham var. *montanus* S. Watson	waterplantain buttercup	3
Ranunculus gmelinii De Candolle var. *hookeri* (D. Don) L. Benson	Gmelin's buttercup	3
Ranunculus pedatifidus J. E. Smith	surefoot buttercup	1

Scientific name	Common Name	*n*
Ranunculaceae *continued*		
Ranunculus reptans L. var. ovalis Torrey & Gray	greater creeping spearwort	1
Ranunculus uncinatus D. Don	woodland buttercup	3
Rosaceae		
Acomastylis rossii (R. Brown) Greene ssp. *turbinata* (Rydberg) W. A. Weber	Ross' avens	17
Fragaria vesca L. ssp. *bracteata* (Heller) Staudt	woodland strawberry	38
Fragaria virginiana P. Miller ssp. *glauca* (S. Watson) Staudt	Virginia strawberry	18
Geum macrophyllum Willdenow var. *perincisum* Raup	largeleaf avens	59
Padus virginiana (L.) P. Miller ssp. *melanocarpa* (A. Nelson) W. A. Weber	black chokecherry	4
Pentaphylloides floribunda (Pursh) Löve	shrubby cinquefoil	39
Physocarpus monogynus (Torrey) Coulter	mountain ninebark	1
Potentilla diversifolia Lehmann	variable leaf cinquefoil	13
Potentilla gracilis Douglas	slender cinquefoil	1
Potentilla norvegica L.	Norwegian cinquefoil	2
Potentilla pensylvanica L. var. *paucijuga* (Rydb.) Welsh & Johnston	Rocky Mountain cinquefoil	2
Potentilla pulcherrima Lehmann	beautiful cinquefoil	20
Potentilla subjuga Rydberg	Colorado cinquefoil	7
Rosa woodsii Lindley	Woods' rose	18
Rubus idaeus L. ssp. *melanolasius* (Dieck) Focke	grayleaf red raspberry	9
Sibbaldia procumbens L.	creeping sibbaldia	23
Sorbus scopulina Greene	Greene's mountain ash	3
Rubiaceae		
Galium septentrionale Roemer & Schultes	northern bedstraw	21
Galium trifidum L. ssp. *subbiflorum* (Wiegand) Puff	threepetal bedstraw	57
Galium triflorum Michaux	fragrant bedstraw	15
Salicaceae		
Populus tremuloides Michaux	quaking aspen	4
Salix bebbiana Sargent	Bebb willow	1
Salix boothii Dorn	Booth's willow	3
Salix brachycarpa Nuttall	shortfruit willow	4
Salix drummondiana Barratt	Drummond's willow	17
Salix eriocephala Michaux	Missouri River willow	8
Salix geyeriana Andersson	Geyer willow	36
Salix lucida Mühlenberg ssp. *lasiandra* (Bentham) E. Murray	Pacific willow	3
Salix monticola Bebb in Coulter	park willow	33
Salix nivalis Hook.	snow willow	6

Scientific name	Common Name	*n*
Salicaceae *continued*		
Salix petrophila Rydb.	alpine willow	3
Salix planifolia Pursh	diamondleaf willow	87
Salix wolfii Bebb	Wolf's willow	23
Saxifragaceae		
Micranthes odontoloma (Piper) Heller	brook saxifrage	21
Mitella pentandra Hooker	fivestamen miterwort	6
Mitella stauropetala Piper var. *stenopetala* (Piper) Rosendahl	drywoods miterwort	7
Scrophulariaceae		
Castilleja rhexifolia Rydberg	splitleaf Indian paintbrush	4
Castilleja sulphurea Rydberg	sulphur Indian paintbrush	26
Pedicularis crenulata Bentham in De Candolle	meadow lousewort	4
Pedicularis groenlandica Retzius	elephanthead lousewort	69
Pedicularis parryi A. Gray	Parry's lousewort	7
Pedicularis racemosa Douglas ex Hooker ssp. *alba* Pennell	sickletop lousewort	6
Penstemon confertus Douglas in Lindley ssp. *procerus* (Douglas ex R. Graham) D. Clark	pincushion beardtongue	5
Penstemon whippleanus A. Gray	Whipple's penstemon	2
Veronica americana Schweinitz ex Bentham	American speedwell	8
Veronica nutans Bongard	American alpine speedwell	79
Veronicastrum serpyllifolium L. ssp. *humifusum* (Dickson) W.A. Weber	brightblue speedwell	10
Thalictraceae		
Thalictrum alpinum L.	alpine meadow-rue	9
Thalictrum fendleri Engelmann ex A. Gray	Fendler's meadow-rue	28
Uvulariaceae		
Prosartes trachycarpa S. Watson	roughfruit fairybells	7
Streptopus fassettii Löve & Löve	tubercle twistedstalk	13
Valerianaceae		
Valeriana capitata Pallas ex Link ssp. *acutiloba* (Rydberg) F. G. Meyer	sharpleaf valerian	2
Valeriana edulis Nuttall	tobacco root	8
Violaceae		
Viola labradorica Schrank	alpine violet	17
Viola macloskeyi Lloyd ssp. *pallens* (Banks ex De Candolle) M. S. Baker	smooth white violet	75
Viola rydbergii Greene	creepingroot violet	4
Woodsiaceae		
Woodsia oregana D.C. Eaton ssp. *cathcartiana* (Robison) Windham	Oregon cliff fern	4
Woodsia scopulina D. C. Eaton	Rocky Mountain woodsia	1

Appendix B2: Bryophyte species list for RMNP wetlands. *n* = number of sample sites in which the species was found. Nomenclature follows McQueen and Andrus (2007) for *Sphagnum* species and Weber and Wittman (2007) for all other species.

Scientific Name	Common Name	*n*
Amblystegiaceae		
Amblystegium riparium (Hedwig) Bruch & Schimper	streamside amblystegium moss	21
Amblystegium serpens (Hedw.) Schimp. in B.S.G. var. *juratzkanum* (Schimp.) Rau & Herv.	Juratzk's amblystegium moss	1
Calliergon cordifolium (Hedw.) Kindb.	calliergon moss	3
Calliergon giganteum (Schimp.) Kindb.	giant calliergon moss	1
Calliergon richardsonii (Mitten) Kindberg	calliergon moss	
Calliergon stramineum (Brid.) Kindb.	calliergon moss	1
Campylium stellatum (Hedw.) C. Jens.	star campylium moss	8
Campylium stellatum (Hedw.) C.E.O. Jensen var. *protensum* (Brid.) Bryhn	star campylium moss	1
Cratoneuron filicinum (Hedwig) Spruce	cratoneuron moss	3
Drepanocladus aduncus (Hedw.) Warnst.	drepanocladus moss	10
Hamatocaulis vernicosus (Mitten) Hedenäs	hamatocaulis moss	4
Hygrohypnum bestii (Renauld & Bryhn) Broth.	Best's hygrohypnum moss	1
Pseudocalliergon turgescens (T. Jensen) Loeske	pseudocalliergon moss	1
Sanionia uncinata (Hedw.) Loeske	sanionia moss	3
Sarmenthypnum sarmentosum (Wahlenb.) Tuom. & T. Kop.	sarmenthypnum moss	3
Scorpidium cossonii (Schimper) Hedenäs	Cosson's scorpidium moss	8
Straminergon stramineum (Bridel) Hedenäs	straminergon moss	5
Warnstorfia exannulata (Bruch & Schimper) Loeske	warnstorfia moss	24
Warnstorfia fluitans (Hedwig) Loeske	warnstorfia moss	2
Warnstorfia Loeske	warnstorfia moss	1
Aulacomniaceae		
Aulacomnium androgynum (Hedw.) Schwaegr.	aulacomnium moss	2
Aulacomnium palustre (Hedw.) Schwaegr.	aulacomnium moss	65
Bartramiaceae		
Bartramia subulata Bruch & Schimp.	bartramia moss	1
Philonotis americana Dism.	American philonotis moss	6
Philonotis fontana (Hedw.) Brid.	philonotis moss	14
Brachytheciaceae		
Brachythecium collinum (Schleich. ex Müll. Hal.) Schimp.	brachythecium moss	1
Brachythecium erythrorrhizon Bruch & Schimper	brachythecium moss	6
Brachythecium latifolium Kindb.	brachythecium moss	12
Tomentypnum nitens (Hedw.) Loeske	tomentypnum moss	26
Bryaceae		
Pohlia cruda (Hedw.) Lindb.	pohlia moss	1
Pohlia nutans (Hedw.) Lindb.	pohlia moss	3
Ptychostomum cf. *creberrimum* Taylor	bryum moss	4

Scientific Name	Common Name	*n*
Bryaceae *continued*		
Ptychostomum pallescens (Schleicher ex Schwaegrichen) Spence	bryum moss	3
Ptychostomum pendulum (Hornsch.) Schimp.	bryum moss	1
Ptychostomum pseudotriquetrum (Hedw.) Spence & Ramsay	common green bryum moss	21
Blasiaceae		
Blasia pusilla L.	liverwort	2
Cephaloziaceae		
Cephalozia pleniceps (Austin) Lindb.	liverwort	1
Climaceae		
Climacium dendroides (Hedw.) Web. & Mohr	tree climacium moss	28
Dicranaceae		
Dicranella (Müll. Hal.) Schimp.	dicranella moss	1
Dicranoweisia crispula (Hedw.) Lindb. ex Milde	dicranoweisia moss	1
Dicranum muehlenbeckii Bruch & Schimp.	dicranum moss	4
Oncophorus wahlenbergii Brid.	Wahlenberg's oncophorus moss	6
Paraleucobryum enerve (Thed.) Loeske	paraleucobryum moss	1
Ditrichaceae		
Ceratodon purpureus (Hedw.) Brid.	ceratodon moss	1
Encalyptaceae		
Encalypta ciliata Hedw.	fringed candle snuffer moss	1
Fontinalaceae		
Dichelyma falcatum (Hedw.) Myr	sickle dichelyma moss	1
Fontinalis antipyretica Hedwig	antifever fontinalis moss	4
Geocalycaceae		
Chiloscyphus pallescens (Ehrhart ex Hoffmann) Dumortier	leavy liverwort	6
Grimmiaceae		
Schistidium rivulare (Brid.) Podp.	streamside schistidium moss	2
Helodiaceae		
Helodium blandowii (Web. & Mohr) Warnst.	Blandow's helodium moss	3
Hypnaceae		
Breidleria pratensis (Koch ex Spruce) Loeske	hypmun moss	1
Hypnum cupressiforme Hedw.	hypnum moss	3
Hypnum lindbergii Mitt.	Lindberg's hypnum moss	2
Jugermanniaceae		
Jungermannia exsertifolia Steph.	liverwort	1
Jungermannia L. emend. Dumort.	liverwort	1
Jungermannia sphaerocarpa Hook.	liverwort	2
Lophozia (Dumort.) Dumort.	liverwort	7
Lophozia lycopodioides (Wallr.) Loeske	liverwort	3

Scientific Name	Common Name	*n*
Marchantiaceae		
Marchantia alpestris Nees	thalloid liverwort	8
Marchantia polymorpha L.	thalloid liverwort	1
Mniaceae		
Mnium arizonicum Amann	Arizona calcareous moss	2
Plagiomnium cuspidatum (Hedw.) Kop.	toothed plagiomnium moss	1
Plagiomnium ellipticum (Brid.) T. Kop.	elliptic plagiomnium moss	19
Rhizomnium magnifolium (Horik.) T. Kop	grandleaf rhizomnium moss	1
Rhizomnium pseudopunctatum (Bruch & Schimp.) T. Kop.	rhizomnium moss	7
Plagiotheciaceae		
*Plagiothecium denticulatum (*Hedw.) Schimp.	toothed plagiothecium moss	4
Plagiothecium laetum Schimp.	plagiothecium moss	4
Polytrichaceae		
Polytrichastrum alpinum (Hedw.) G.L. Sm.	alpine polytrichastrum moss	1
Polytrichastrum longisetum (Brid.) G.L. Sm.	polytrichastrum moss	48
Polytrichum juniperinum Hedw.	juniper polytrichum moss	1
Pottiaceae		
Weissia controversa Hedw.	controverial weissia moss	1
Sphagnaceae		
Sphagnum angustifolium (C.E.O. Jensen ex Russow) C.E.O. Jensen	sphagnum	1
Sphagnum contortum Schultz	contorted sphagnum	1
Sphagnum girgensohnii Russow	Girgensohn's sphagnum	4
Sphagnum russowii Warnst.	Russow's sphagnum	20
Sphagnum teres (Schimp.) Ångstr	sphagnum	2
Sphagnum warnstorfii Russow	Warnstorf's sphagnum	4
Timmiaceae		
Timmia austriaca Hedw.	Austria timmia moss	2

APPENDIX B REFERENCES

McQueen, C.R. & Andrus, R.E. (2007) Sphagnum-Sphagaceae *Flora of North America North of Mexico. Vol. 27: Bryophytes: Mosses, Part 1* (ed F. o. N. A. E. Commitee). Oxford University Press, New York.

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APPENDIX C: Photos of Selected RMNP wetlands

1. *Salix planifolia* wetland with *Betula glandulosa* and *Sphagnum* moss located in the Tonahutu watershed. Site # 541.

2. *Carex aquatilis* wetland with *Salix planifolia* located near Lawn Lake. Site # 520.

3. *Carex vesicaria* wetland with *Salix boothii* and *Salix geyeriana* located in North Inlet watershed. Site # 529.

4. *Carex illota* wetland with *Psychrophia leptosepala*, and *Pedicularis groenlandica* located in the Poudre River watershed. Site # 536.

5. *Carex aquatilis* wetland with high cover of *Carex praeceptorum* and *Sphagnum* moss located near Haynach Lakes. Site # 598.

6. *Eleocharis quinqueflora* wetland with *Pedicularis groenlandica* located below the Grand Ditch in the Skeleton Gulch watershed. Site # 533.

7. *Carex nigricans – Juncus drummondii* alpine wetland with *Philinotis fontana* near Trail Ridge Road above Forest Canyon. Site # 548.

8. *Carex scopulorum – Carex capillaris* alpine wetland above Trail Ridge Road. Site # 605.

9. Lacustrine fringe wetland dominated by *Salix planifolia* and *Carex* spp. on small subalpine tarn in Hayden Gulch. Site # 610.

10. *Poa pratensis –Phelum pretense* wetland with high cover of *Pentphylloides floribunda* and *Seriphidium canum* located along Trail Ridge Road in Kawuneeche Valley. Site # 592.

11. *Picea engelmanii – Salix wolfii* wetland with *Carex aquatilis* located in the Colorado River Valley near LuLu City. Site # 154.

12. *Calamagrostis canadensis* wetland located east of Kawuneeche Valley near western entrance gate. Site # 503.

13. *Carex utriculata* wetland located in Baker Gulch near the Bowen-Baker trail. Site # 549.

14. *Carex nebrascensis* wetland with *Hierochloë hirta* ssp. *arctica* and *Carex praegracilis* located in Moraine Park. Site # 506.

15. Kettle pond wetland dominated by *Eleocharis quinqueflora* with *Carex magellanica* located near Milner Pass. Site # 557.

16. *Picea engelmanii - Alnus incana* ssp. *tenufolia* wetland with *Salix wolfii* and *Calamagrostis canadensis* located in Kawuneeche Valley. Site # 591.