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Identifying wetland meadows in Grand Teton National Park using remote sensing and average wetland values

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Abstract

Six spectrally and ecologically distinct montane meadow community types were identified and mapped within Grand Teton National Park by analysis of Indian IRS-1B LISS-II imagery. A distinct hydric-to-xeric gradient among the meadow types was predicted by analysis of the satellite data. Thirty sites (five replicates for each of six meadow types) were selected for intensive field sampling. At each of the 30 sites, meadow vegetation was sampled in 20 m by 20 m square plots for canopy cover of all species. Using wetland indexes (on a scale of 1–5, where obligate wetland species = 1, facultative wetland = 2, facultative = 3, facultative upland = 4 and upland species = 5), average wetland values were calculated and ranged from 1.88 for A-type meadows and 2.86 for B meadows to 4.40, 4.49, 4.74, and 4.43 for C, D, E and F meadows, respectively. Because average wetland values of A and B meadows were < 3.00, they were determined to be indicative of wetlands. Eight out of ten obligate wetland plants had their greatest cover on A meadows (the wettest of the gradient) and had significant cover differences among meadow types using the non-parametric Kruskal-Wallis test. Average wetland values and plant species cover were used, in conjunction with remotely sensed data, to identify as wetlands 1,258 hectares of A meadows and 1,711 hectares of B meadows within Grand Teton National Park.

Introduction

Wetlands are valuable for wildlife habitat, floodwater management, and water quality improvement, as well as having esthetic and educational benefits to humans (Mitsch and Gosselink, 1993). Increased awareness of wetland functions and benefits has shifted wetlands to the forefront of conservation science (Hoffstetter, 1983; McCormick, 1978), resulting in expanded efforts to inventory wetland ecosystems.

Analysis of remotely sensed data is an efficient technique for mapping wetlands across broad geographic areas. Several different types of remotely sensed data have been evaluated for use in identification and mapping of wetlands, including aerial photography (Lyon and Greene, 1992), airborne video imagery (Thomasson et al., 1994), and satellite imagery (Sader et al., 1995; Jensen et al., 1993; Jensen et al., 1992). Wetland soils, the presence of standing water, and differences in vegetation type can be detected using remotely sensed data (Lyon, 1993). Remotely sensed data are especially appropriate for identifying wetlands that frequently occur in rugged or inaccessible terrain, and for monitoring seasonal or directional changes in wetlands (Jensen et al., 1993; Lyon and Greene, 1992).

Ground-truthing is necessary to verify the accuracy of remotely sensed data. Field wetland determinations require observation of the three wetland parameters: hydric soils, hydrology, and hydrophytic vegetation (Environmental Laboratory, 1987). In this study, vegetation data are used as an integrator of these wetland parameters, since a prevalence of wetland vegetation usually indicates the presence of other wetland characteristics.

Methods

Study area

This research was conducted in and near Grand Teton National Park (GTNP), Wyoming. GTNP has been maintained as a national park since 1929 and was expanded in 1950 to incorporate Jackson Hole National Monument (Stark, 1984). It is part of the Greater Yellowstone Ecosystem, which includes Yellowstone National Park, seven national forests, an elk refuge and two wildlife refuges (Marston and Anderson, 1991). Geographically, Marston and Anderson (1991) roughly define the Greater Yellowstone Ecosystem as the Yellowstone Plateau and elevations above 2130 m in the surrounding region. At a local scale, the region includes a wide range of elevation and moisture gradients. Non-forest plant communities within the ecosystem range from hydric willow and sedge meadows to high-altitude tundra and xeric rock meadows (Knight, 1994). Our study examined montane meadows and shrub lands.

Wetlands in GTNP are typified by two wetland community types. The wettest meadows, hydric willow flats along rivers and lakes, are dominated by *Salix* spp. and *Carex* spp., and typically have standing water throughout the growing season. Slightly higher in elevation are hydric meadows along foothill slopes near lakes and rivers and in montane depressions. This wetland type is dominated by *Carex* spp. and experiences only periodic flooding, although the soil is saturated during a substantial portion of the growing season.

Remote sensing

Indian IRS LISS-II multispectral satellite imagery was acquired for August 12, 1995. The LISS-II acquires data in three visible bands (blue, 0.45–0.52 m; green, 0.52–0.59 m; red, 0.62–0.68 m) and one near-infrared band (near-IR, 0.77–0.86 m) of the spectrum. The LISS-II has a spatial resolution of 36.5 meters and 7-bit radiometric resolution (128 brightness levels). The satellite imagery was geo-referenced to a Universal Transverse Mercator (UTM) coordinate system to allow it to be matched with topographic maps of the region.

An unsupervised classification procedure was used to create a map of spectrally distinct non-forested vegetation classes within the study area to guide field sampling. In an unsupervised classification, pixels with similar spectral characteristics in the different bands of a satellite sensor are identified and grouped into spectral classes using a statistical clustering procedure. The spectral classes are then identified as being representative of a particular land cover, land use, vegetation type, or condition with the aid of aerial photographs or information gathered in ground investigations.

An Iterative Self-Organizing Data Analysis (ISODATA) clustering algorithm in the ERDAS image processing software was applied to the four-band image file to identify spectrally similar pixels. Fifty initial clusters were specified for the ISODATA clustering, producing a map of fifty spectral classes. Each spectral class was composed of pixels with statistically similar spectral reflectance characteristics. Based on spectral similarity, and visual interpretation of the classes with the assistance of aerial photography and knowledge of the study area, the 50 preliminary classes were combined to create a final map of spectrally distinct non-forested vegetation classes. Six meadow types (A to F), representing a distinct hydric-to-xeric gradient were identified and mapped by analysis of the satellite data.

Field sampling was conducted at sites within polygons selected from the meadow classes. Placement of sample sites within the study area was guided by the map of spectrally distinct vegetation classes. The sample sites were located in the field with the aid of aerial photography, 1:24,000

USGS topographic maps, and compass readings from identifiable landmarks. Particular care was taken in the field to ensure that sites were located in the center of a class polygon to avoid edge effects.

Vegetation sampling

The vegetation of five spatially distinct areas for each of the six remotely sensed meadow types was surveyed during July 1996. Sample plots were randomly selected in accessible areas within both GTNP and the adjacent Teton National Forest (Figure 1), which due to topography led to a generalized clustering of sites. At each sample area, meadow vegetation was surveyed in 20 m by 20 m plots. Each plot was surveyed to determine the plant cover (%) of all species of grass, forb, shrub, or tree, using the sampling methodology of Daubenmire (1959). When species were difficult to identify (i.e., *Carex* spp.), they were collected in the field and identified at the R.L. McGregor Herbarium, University of Kansas.

All plant species found in the montane meadow plots were assigned one of five wetland values defined in the 1987 Wetland Delineation Manual (Environmental Laboratory, 1987) and listed in the National List of Plant Species that Occur in Wetlands (Reed, 1988):

(1) obligate wetland plants (OBL) occur almost always (estimated probability > 99%) in wetlands, but occasionally are found in non-wetlands (estimated probability < 1%);
(2) facultative wetland plants (FACW) usually occur in wetlands (estimated probability 67% to 99%), but occasionally are found in non-wetlands (estimated probability 1% to 33%);
(3) facultative plants (FAC) share an equal likelihood (estimated probability 33% to 67%) of occurring in either wetlands or non-wetlands;
(4) facultative upland plants (FACU) usually occur in non-wetlands (estimated probability 67% to 99%), but occasionally are found in wetlands (estimated probability 1% to < 33%); and
(5) obligate upland plants (UPL) occur almost always (estimated probability > 99%) in non-wetlands.

These categories were used to calculate average wetland values where OBL = 1, FACW = 2, FAC = 3, FACU = 4 and UPL = 5. Average wetland values are calculated using a weighted average where each species, percent cover is multiplied by its wetland category number. The sum of these values for all species in a plot is the average wetland value. If the average wetland value is less than 3.00, then the area supports hydrophytic vegetation. This process is an expansion of the FAC-neutral test found in the Corps of Engineers Wetland Delineation Manual (Environmental Laboratory, 1987). Our application of the FAC-neutral test uses cover of all species present in an area, while the test is usually applied to dominant species only.

In our study, wetland values were assigned to all species found in each plot. The National List of Plant Species that occur in Wetlands (Reed, 1988) was intended to list plants found in wetlands, but because our study encompasses six meadow types along an environmental gradient, several species observed were not found in this list. The majority of these species do not occur in wetlands and are correctly considered upland (UPL) species. Although the National List is fairly comprehensive, some uncommon wetland species may not be given a listing. For example, *Heracleum sphondylium* and *Carex hoodii* are not listed and *Carex platylepis*, *C. geyerii*, and *Polemonium pulcherrimum* are perhaps questionably listed as upland. For the purpose of our study, all species not assigned a wetland value in the National List have been treated as upland species (only 11 species total), regardless of whether or not they might be incorrectly classified. Using upland values where no wetland value has been assigned provides a conservative estimate of the average wetland value and decreases the likelihood of incorrectly identifying a wetland plant community where it does not exist.

Soils and hydrology

Montane meadow soils range from being poorly drained on floodplains to well-drained on steep slopes of foothills. Seven of the ten A and B meadows sampled were located on the hydric soil nam-

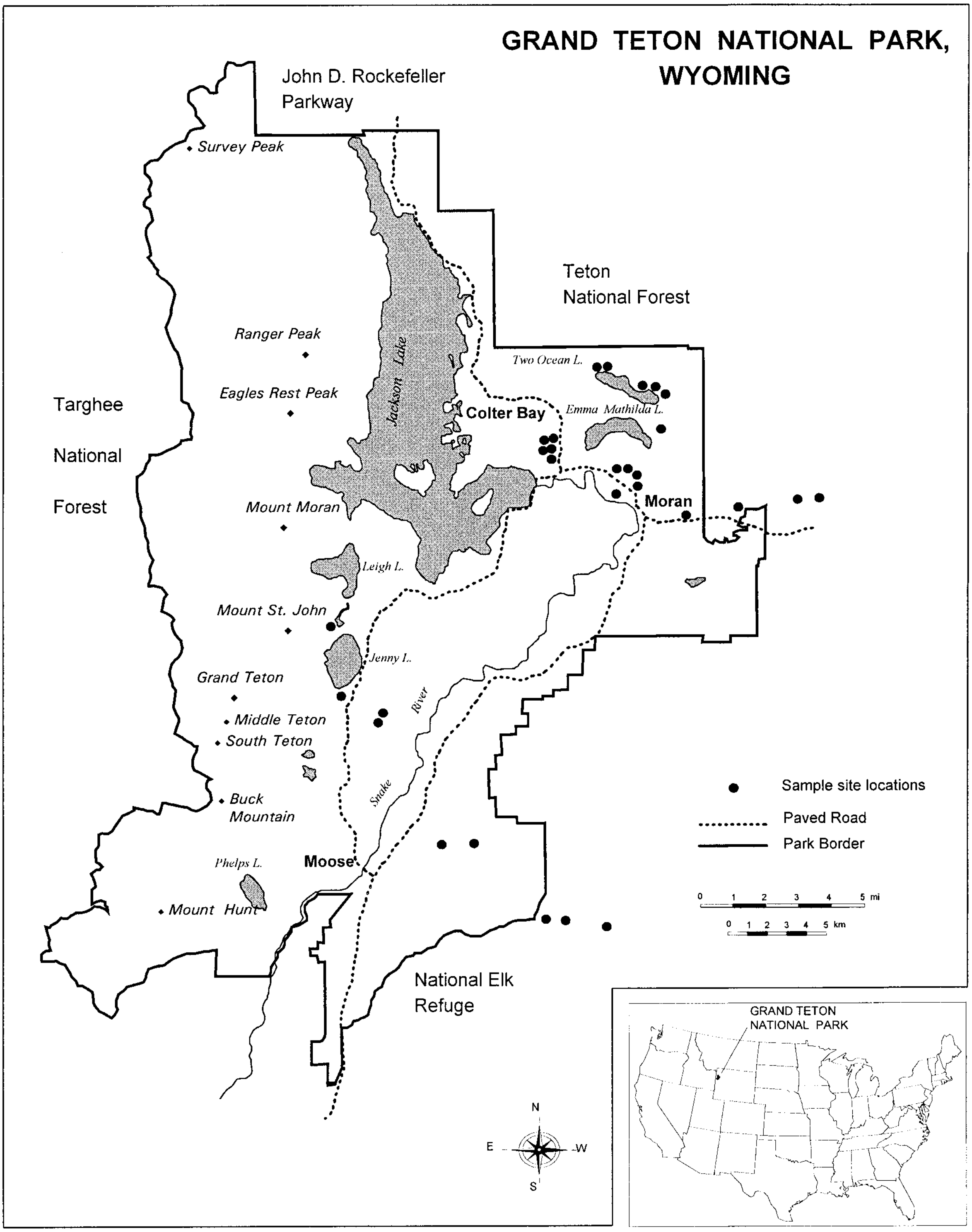

Figure 1. Map of study site locations in and near Grand Teton National Park, Wyoming.

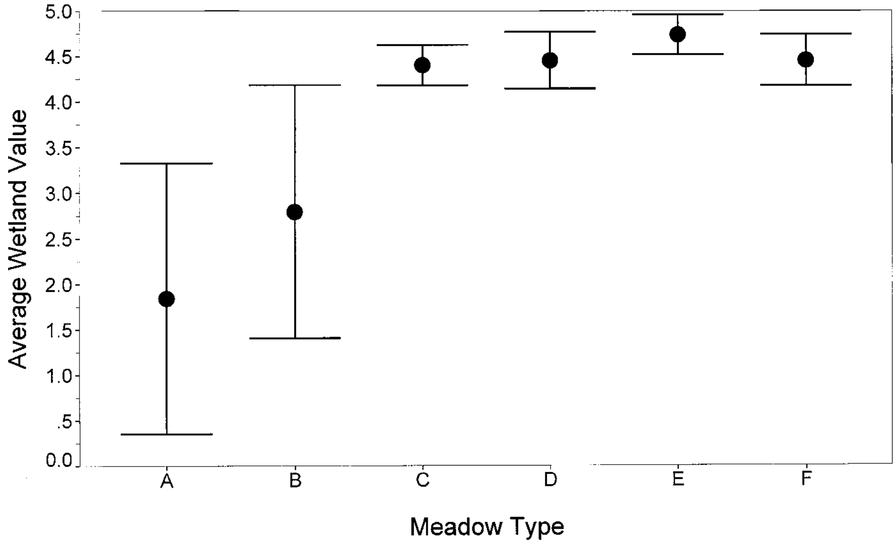

Figure 2. Means of 95% confidence intervals of average wetland values for six remotely sensed meadow types along an environmental gradient. The thirty montane meadows (5 per meadow type) were sampled in and near Grand Teton National Park in July 1996. Average wetland values are calculated as weighted averages of species cover multiplied by each species' wetland value. Means of average wetland values are 1.84, 2.79, 4.40, 4.75, and 4.46 for A, B, C, D, E and F meadows, respectively. Values less than 3.00 indicate wetland vegetation. Significant differences were found among groups using a Kruskal-Wallis test.

ed Cryaquolls-Cryofibrists as mapped in the Teton County Soil Survey (Young, 1982). Observations were made confirming that these areas of hydric soil also had dark chromas as found on the Munsell Soil Color chart (Munsell Color, 1992). The other three A and B meadows were mapped as non-hydric soils (Starman-Rubbleland-Midfork and Uhi-Roxal Association), but it is possible that the areas sampled may have been hydric soil inclusions. All C, D, E, and F meadows occurred on upland soil types and were less clayey, lighter in color, and typically well-drained.

Hydrologic observations were also made in the A and B meadows. At the time of sampling, standing water was present in four of five A meadows, and three of five B meadows. All three A and B meadows that did not contain standing water showed other evidence of past flooding: flood debris, deposition of gravel, or flattened vegetation were visible; and the meadows were hydrologically-influenced by a nearby stream or lake. No flooding, evidence of past flooding, or saturated soil was observed in C, D, E, and F meadows.

Data analysis

Plant species cover data from the thirty meadows were analyzed using the non-parametric Kruskal-Wallis test in the SPSS/PC+ software package (SPSS, 1988). The Kruskal-Wallis test was used to compare individual plant species across treatments because the variances were not equal among areas sampled even after the data were transformed (Sokal and Rolf, 1995). These unequal variances result in non-normal distributions because many species do not occur in all sample areas, or they have very low cover values.

Results

One hundred eighty-three species were found in the 30 meadows sampled. The greatest number of species (59) were classified as upland species and the fewest (10) were obligate wetland species. Significant differences ($p < 0.001$ level) were found among meadow types using the non-parametric Kruskal-Wallis test (Figure 2). Average wetland values for A-F meadows are 1.84, 2.79, 4.40, 4.45, 4.74, and 4.46, respectively. These

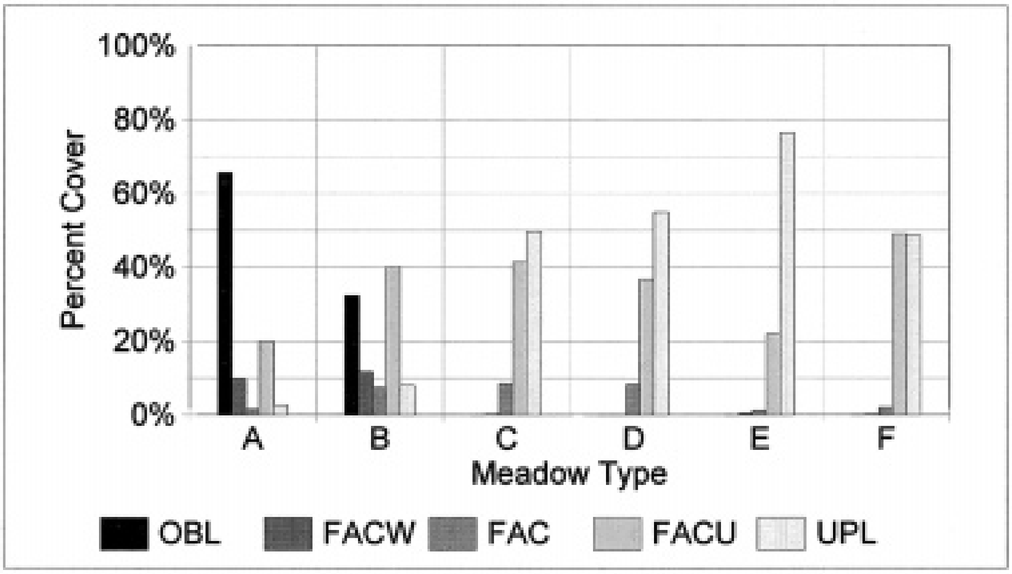

Figure 3. Mean percent plant species cover by wetland prevalence index for each of six remotely sensed meadow types along an environmental gradient near the Teton range in Wyoming. OBL = obligate wetland species, FACW = facultative wetland species, FAC = facultative wetland species, FACU = facultative upland species, and UPL = upland species.

average wetland values suggest that both A and B meadows have wetland vegetation since even these conservative values are below 3.00 (Figure 2). These numbers indicate that the average cover of all species on these areas shows strong wetland affinity, and C-F meadows are distinctively non-wetland (not even close to the 3.00 value).

The percent cover data provides striking results that A and B meadows are dominated by wetland vegetation (Figure 3). Obligate wetland species comprise 65.7% of A meadows and 32.5% of B meadows, then sharply decline to 0.1% in C meadows and 0.0% in D, E, and F meadows. Similarly, facultative wetland species comprise 9.9% and 11.8% of A and B meadows, but are less than 0.5% of species cover in all other meadows. In contrast, upland and facultative upland species dominate C through F meadows (Figure 3).

These differences are highlighted by comparing individual species across meadow types (Table 1). Eight out of ten obligate wetland species had significant differences among meadow types. All obligate species were found only on A and B meadows, with only one minor exception (0.4% cover of *Senecio hydrophilus* on one C meadow). In addition, three of four facultative wetland species that showed significant differences also only occur on the A and B meadows.

From the ground-truthed vegetation data, it appears that A and B meadows are wetlands. Using our meadow classifications of the remotely sensed satellite data, we were able to identify 1,258 hectares of A meadows and 1,711 hectares of B meadows as potential wetlands within Grand Teton National Park.

Discussion

Satellite remotely sensed data can be used to identify spectrally and ecologically distinct meadow communities within the Greater Yellowstone Ecosystem. Because vegetation composition and structure govern the spectral reflectance of meadows, spectral response characteristics can be linked to distinct plant species assemblages to identify montane wetlands. However, ground-truthing is necessary to verify the accuracy of the classification.

Seventy percent (7 out of 10) of the areas identified as A and B meadows by satellite data were dominated by wetland vegetation. All of the other 20 meadows sampled had average wetland values greater than 3.00, indicating that C through F

Table 1. Comparison of species cover for all obligate and facultative wetland species among meadow types (A–F), listing species names, common names, wetland prevalence index (from Reed, 1988), standard deviations, and probability values where * = $p < 0.05$, ** = $p < 0.01$, and *** = $p < 0.001$.

Species name	Common name	Prevalence index	Mean	Standard deviation	*p*
Betula glandulosa	Bog birch	1	0.003	0.011	**
Carex aquatilis	Water sedge	1	0.001	0.003	*
Carex cusickii	Cusick's sedge	1	0.004	0.015	**
Carex rostrata	Beaked sedge	1	0.122	0.279	**
Juncus balticus	Baltic rush	1	0.002	0.005	*
Mimulus guttatus	Monkey flower	1	0.001	0.003	**
Pedicularis groenlandica	Elephant's head	1	0.001	0.003	
Salix boothii	Willow	1	0.035	0.091	**
Salix planifolia	Diamond leaf willow	1	0.078	0.191	***
Senecio hydrophilus	Alkali-marsh butterweed	1	0.001	0.003	
Angelica arguta	Angelica	2	0.000	0.002	
Arnica chamissonis	Leafy arnica	2	0.001	0.003	
Arnica longifolia	Seep-spring arnica	2	0.001	0.003	
Astragalus agrestis	Field milk-vetch	2	0.000	0.002	
Deschampsia cespitosa	Tufted hair grass	2	0.040	0.141	**
Equisetum hyemale	Scouring rush	2	0.001	0.003	*
Geum macrophyllum	Big-leaf avens	2	0.003	0.008	**
Platanthera hyperborea	Northern green orchid	2	0.001	0.003	**
Hordeum brachyantherum	Meadow barley	2	0.018	0.099	
Juncus ensifolius	Dagger-leaf rush	2	0.001	0.003	
Rumex crispus	Curly dock	2	0.000	0.002	
Rumex maritimus	Golden dock	2	0.000	0.002	
Rumex salicifolius	Willow dock	2	0.001	0.003	
Senecio pauperculus	Balsam groundsel	2	0.004	0.011	*
Senecio sphaerocephalus	Mountain-marsh butterweed	2	0.000	0.002	
Stellaria longipes	Starwort	2	0.001	0.003	

meadows are not wetlands. The three A and B meadows that did not have wetland vegetation were dominated by a disturbed, non-native plant community. One A meadow had an average wetland value greater than 3.00 (3.97). The two dominant species at this site were non-native grasses – *Poa pratensis* and *Phleum pratense*, with cover values of 40 and 35%, respectively. Two of five B meadows also had average wetland values greater than 3.00 (3.84 and 3.69) again with *Poa pratensis* and *Phleum pratense* ranking in first or second for cover of both. It should be noted that these three atypical areas also explain the large variances in average wetland values in Figure 2. When the average wetland values of these three disturbed meadows were recalculated after removing non-native and unlisted species, two of the three meadows had values of less than 3.00. Ninety percent of A and B meadows have a prevalence of wetland vegetation when only native species in the National List are considered.

Vegetation of disturbed areas, such as these three atypical meadows, present problems in determining wetland boundaries. Such areas have resulted in a special section of the Corps of Engineers Wetland Delineation Manual that concerns Atypical Situations (Environmental Laboratory, 1987) and makes allowances to identify wetlands in areas with disturbed vegetation (such as agricultural lands and where prolonged flooding has occurred). We believe that when the atypical situations are taken into account, that all A and B meadows we sampled would be delineated as wetlands because of their observed soils, hydrological factors, and disturbed vegetation.

The use of the prevalence index and average wetland values as a tool for ground-truthing could aid in the accuracy of remotely sensed mapping of wetlands across all ecosystems. While plant identification in the field is often difficult, a much shorter list of species can be used to identify wetlands when ground-truthing. More specifically, a subset of only obligate wetland and facultative wetland species (26 species at our sites, 10 of which were obligate) could be used to identify wetlands in GTNP. Since wetland plant communities are typically less diverse than mesic communities (Whittaker and Niering, 1974), a similar-sized subset would only need to be known for many other wetland ecosystems, especially if uncommon species are excluded. The more common species could be identified by preliminary field sampling, and could be accurately used as indicators in the determination that these areas are wetlands, especially if coupled with hydric soils maps and field observations of soils and hydrologic indicators.

Overall, field verification of the vegetation of remotely sensed wetland areas has resulted in a 70% accuracy rate of finding wetland vegetation at predicted locations. The average wetland value, coupled with statistics for both cover values by wetland plant category and for individual obligate and facultative wetland species, provides support for these results. When soils and hydrological factors are included, we believe that all of these areas could be delineated as wetlands. Using these results, we have identified 2,969 hectares of potential wetland meadows in Grand Teton National Park. Specifically, we have identified 1,258 hectares of A meadows and 1,711 hectares of B meadows, both of which are potential wetland plant communities.

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