Bighorn National Forest
Groundwater-Dependent Ecosystem/
Fen Inventory

2014 - 2015

Final Report for
Challenge Cost Share Agreement 13-CS-11020200-033
Between The
USDA Forest Service, Bighorn National Forest
and the
University of Wyoming, Wyoming Natural Diversity Database

George P. Jones
May 1, 2017

Cover photo: View looking east at site R202-15-150729, a fen on the headwaters of Willet Creek, approx. 0.75 mile (1.2 km) southwest of Woodchuck Pass. Peat 43 cm thick was measured here.

Suggested Citation: Jones, George P. 2017. Bighorn National Forest Groundwater-Dependent Ecosystem/Fen Survey, 2014 - 2015. Unpublished Final Report For U.S. Forest Service Challenge Cost-Share Agreement 13-CS-11020200-033. Wyoming Natural Diversity Database, University of Wyoming.

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ACKNOWLEDGEMENTS

This project was possible because of assistance from the following people. Chris Williams and Amy Nowakowski of the Bighorn National Forest participated fully in the design of the project and provided invaluable assistance with administrative and logistical matters. Kat Brown, Drew King, and Nick Bertrand, also with the Bighorn Forest, assisted with field sampling. Kate Dwire (Forest Service Rocky Mountain Experiment Station) and Joe Gurrieri (Forest Service Region 4 and Washington Office) shared their expertise in their technical fields and their thorough knowledge of the GDE methods. At the Wyoming Natural Diversity Database, Bonnie Heidel (lead botanist) provided useful information about wetland plant species and mosses; Joy Handley (assistant botanist) was the crew leader during most of both field seasons; Mark Andersen (spatial ecologist) performed the GIS work for selecting sampling sites and advised on development and use of the logistic regression model; Gary Beauvais (director) helped with project design; and Mary Louise Jacques and Charlotte Reed were enthusiastic field aides.

ABSTRACT

Staff of the Bighorn National Forest and the Wyoming Natural Diversity Database cooperated on a two-year project to survey groundwater-dependent ecosystems (GDEs) on the Forest, with an emphasis on fens. Potential sampling sites were selected from the National Wetland Inventory's digital layer using a generalized random tessellation stratified (GRTS) procedure. Three-hundred thirty-two wetlands were visited during two field seasons. GDEs were present at 287 wetlands, and fens (GDEs with peat $\geq$ 20 cm thick) were documented at 88 of the wetlands. The Forest Service's GDE Level I methods were used to collect information on vegetation structure, presence of plants of special interest, hydrologic features, water pH and electrical conductance, and to document signs of disturbance. The GDE methods were augmented by the collection of additional information of interest to Bighorn Forest staff. Fens and non-fen GDEs occur mostly in the central glaciated area of the Bighorns but are found throughout the national forest. They are more common in larger wetlands, and most are helocrenes (seeps from unconfined aquifers) or rheocrenes (springs that emerge directly into stream channels). The vegetation in fens and other GDEs is dominated by graminoids (primarily water sedge and Northwest Territory sedge), and low shrubs (especially diamondleaf willow) are common in many. Fens are more heavily dominated by obligate hydrophytes, have greater cover of mosses, and are more likely to contain *Sphagnum* spp. mosses, than are other GDEs. Water pH values vary among different places in fens and water is most acidic in the peat. Some 90% of fens and GDEs have been browsed or grazed by ungulates, and over half show signs of soil disturbance. Soil alteration is significantly more common in non-fen GDEs, but other types of disturbance seem to be about equally common in the two groups of wetlands. The GDE sampling methods and database should be used for future wetlands work on the Forest, so that information is collected and handled systematically.

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I. INTRODUCTION

A. BACKGROUND AND OBJECTIVES

In January of 2014, the Bighorn National Forest and the University of Wyoming's Natural Diversity Database began a cooperative project to collect information about the vegetation, soils, hydrological features, and other aspects of fen wetlands[1] on the Forest. The two parties undertook the project with three objectives in mind. First, we sought to characterize fens and other groundwater-dependent wetlands on the Bighorns, by collecting information through field sampling of as many individual wetlands as time and money permitted. Forest Service biologists and managers want this information to more efficiently conduct resource inventories, and to better plan and carry out projects. Natural Diversity Database biologists need the information to provide parties involved in development, management, and conservation of Wyoming's biological resources with a more comprehensive understanding of the state's wetlands.

A second objective was to develop procedures that Forest Service biologists can use in the future to collect information from additional wetlands and to manage and retrieve that information, all in systematic ways. To this end, the sampling methods of the Forest Service's national Groundwater-Dependent Ecosystem (GDE) Initiative (http://www.fs.fed.us/geology/groundwater.html) were used in this project for collecting the data, and the Initiative's relational database was used to store the information. The sampling methods and database each provide a structure developed by the Forest Service for use by the agency's biologists and managers, and both are supported by the agency.

Finally, as a third objective, we hoped to develop a way to identify wetlands where fens are likely to be found, based in part on the National Wetland Inventory's (NWI) digital layer of wetland features (USDI Fish and Wildlife Service, No date). There are thousands of wetland features mapped by the NWI on the Bighorns, and having a tool that allows Forest Service biologists and managers to identify those likely to support fens would be of considerable help in guiding the allocation of time and effort in resource surveys.

A primary resource for this project is Heidel's (2011) recent summary of rare plant species in fens on the Bighorns. Heidel provides detailed information about floristic resources of fens, and good general characterizations of their vegetation, environmental setting, and distribution. She also discusses the role of the NWI layer in identifying fens. In addition to providing a valuable complement to this GDE-based project, Heidel's work provides Forest Service biologists and managers with information about and interpretation of the floristic resources beyond those this project can produce.

Planning of the sampling design (for selecting sampling sites) and the field sampling were completed in the spring of 2014. Forest Service staff from the GDE Initiative trained the project participants (from the Bighorn National Forest and the Natural Diversity Database) and others in use of the GDE methods in June of 2014. During the 2014 field season, a two-person crew from the Natural Diversity Database sampled wetlands throughout the Forest. The first season's data were analyzed during the fall of 2014 and the winter of 2014-2015, and the results of the analysis were used in selecting sampling points for the 2015 season. During the 2015 season, a two-person

[1] Fens are wetlands in which peat, or undecomposed plant material, accumulates and serves as the substrate for plants. Peat accumulates in wetlands that remain saturated for most of the growing season. Because of the high water-holding capacity of peat, and the biogeochemical conditions created by prolonged saturation, the hydrological and ecological properties of fens set them apart from other wetlands.

Database crew and seasonal Forest Service botanists collected information from a second set of wetlands distributed across the Forest. This report presents the results from both years' sampling.

B. STUDY AREA

Field work was conducted in the Bighorn National Forest in north-central Wyoming (Figure 1). The Forest covers 1,115,073 acres (451,605 hectares) between approximately $44^0 1'$ and 45^0 north latitude, and $106^0 57'$ and $107^0 57'$ west longitude. The national forest lies on the Bighorn Mountains, which N.H. Darton (1906) described as an anticline oriented north-northwest in the northern half and north-south in the southern half, and consisting of three general areas: (1) the steep eastern and western flanks, on steeply-dipping sedimentary rocks; (2) the central area on crystalline (mostly granitic) bedrock and glacial deposits, much of it at high elevation and formed by glaciers into rugged peaks and deep valleys; and (3) north and south of the central area, the central plateau, which "...presents broad areas of tabular surfaces...but is deeply entrenched by numerous canyons..." (Darton, 1906, p. 11), and is formed largely on carbonate rocks (limestone and dolomite) and shale.

The national forest includes slightly more than the northern half of the Bighorn Mountains anticline. The eastern and western edges of the forest include only parts of the steep flanks. Darton's central area takes up most of the southern half of the national forest (Figure 2). The highest elevations of the central area are within the 189,000-acre (76,545-hectare) Cloud Peak Wilderness Area (Figure 3). The northern half of the Forest is on Darton's central plateau at an elevation of approximately 2,450 to 3,050 meters (approximately 8,000 to 10,000 feet) (Figure 3).

Our study area included the portion of Darton's central area below approximately 2,950 meters (9,680 feet) elevation, and nearly all of his central plateau to the north of the central area. We did not specifically exclude the steep flanks but very few wetlands occur there.

Figure 1. Ranger districts and major highways in the Bighorn National Forest

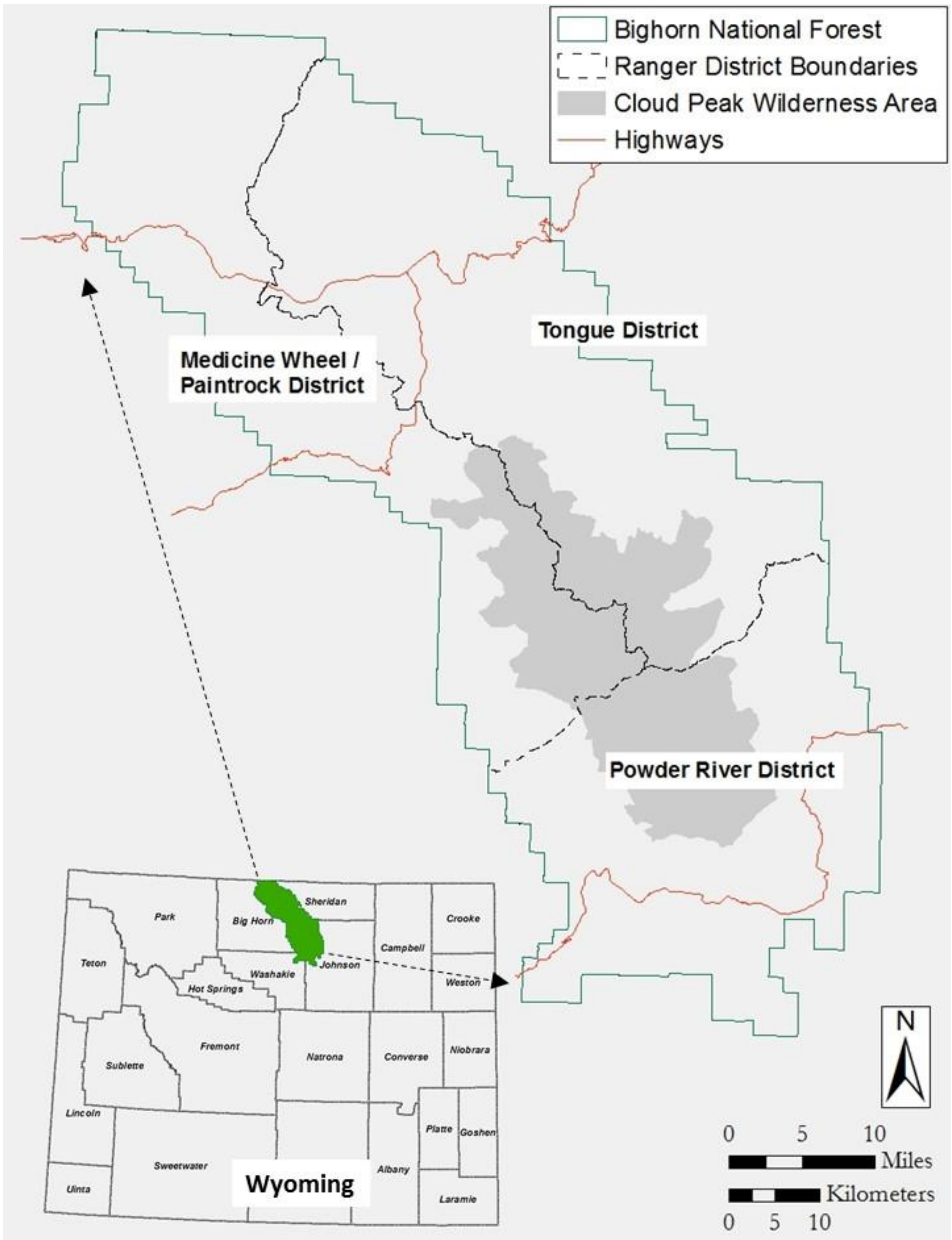


Figure 2. Geological substrate-types of the Bighorn National Forest.

Substrate categories are generalizations of the bedrock geology map units (Wyoming State Geological Survey 1994). See section II.A.2 below for explanation.

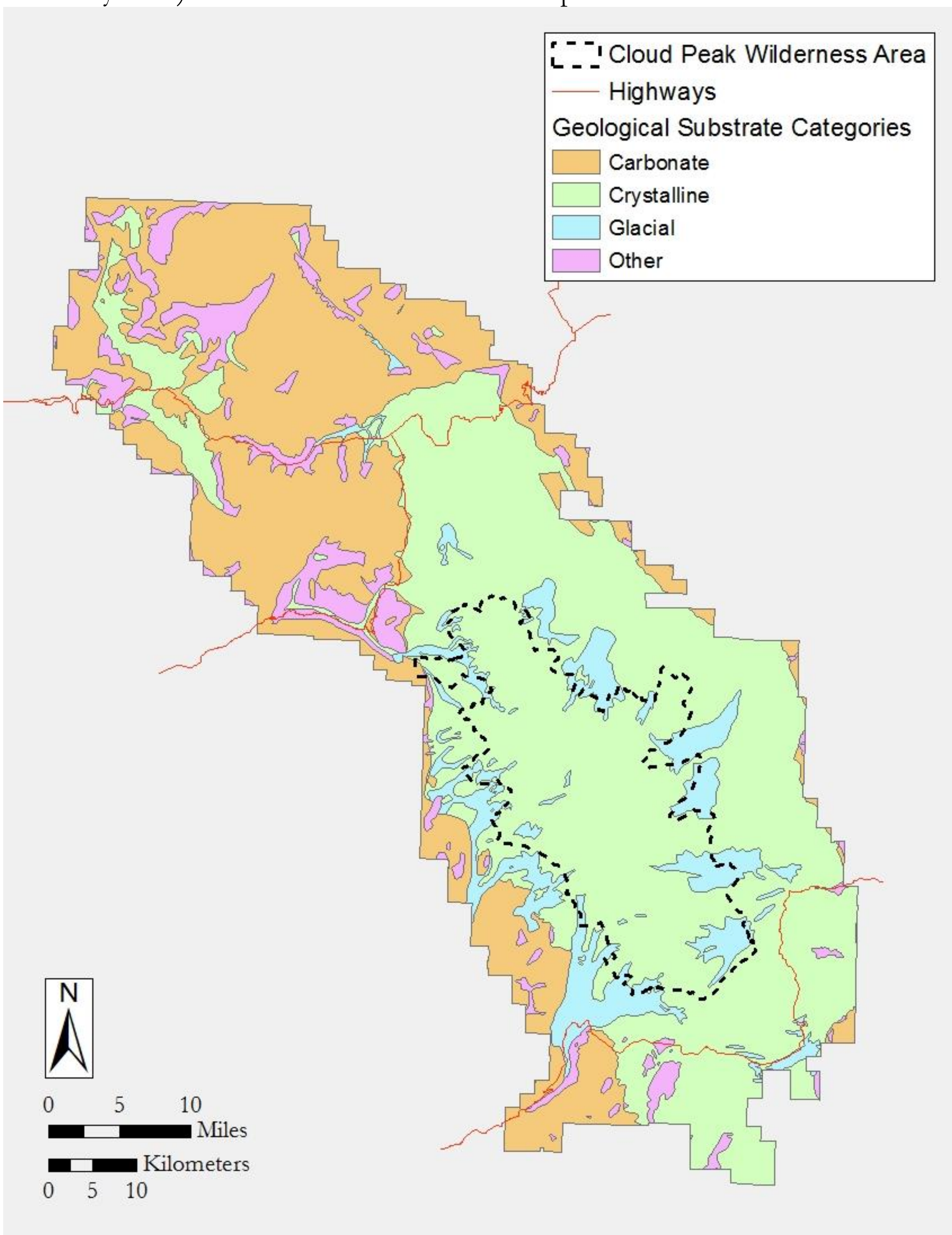
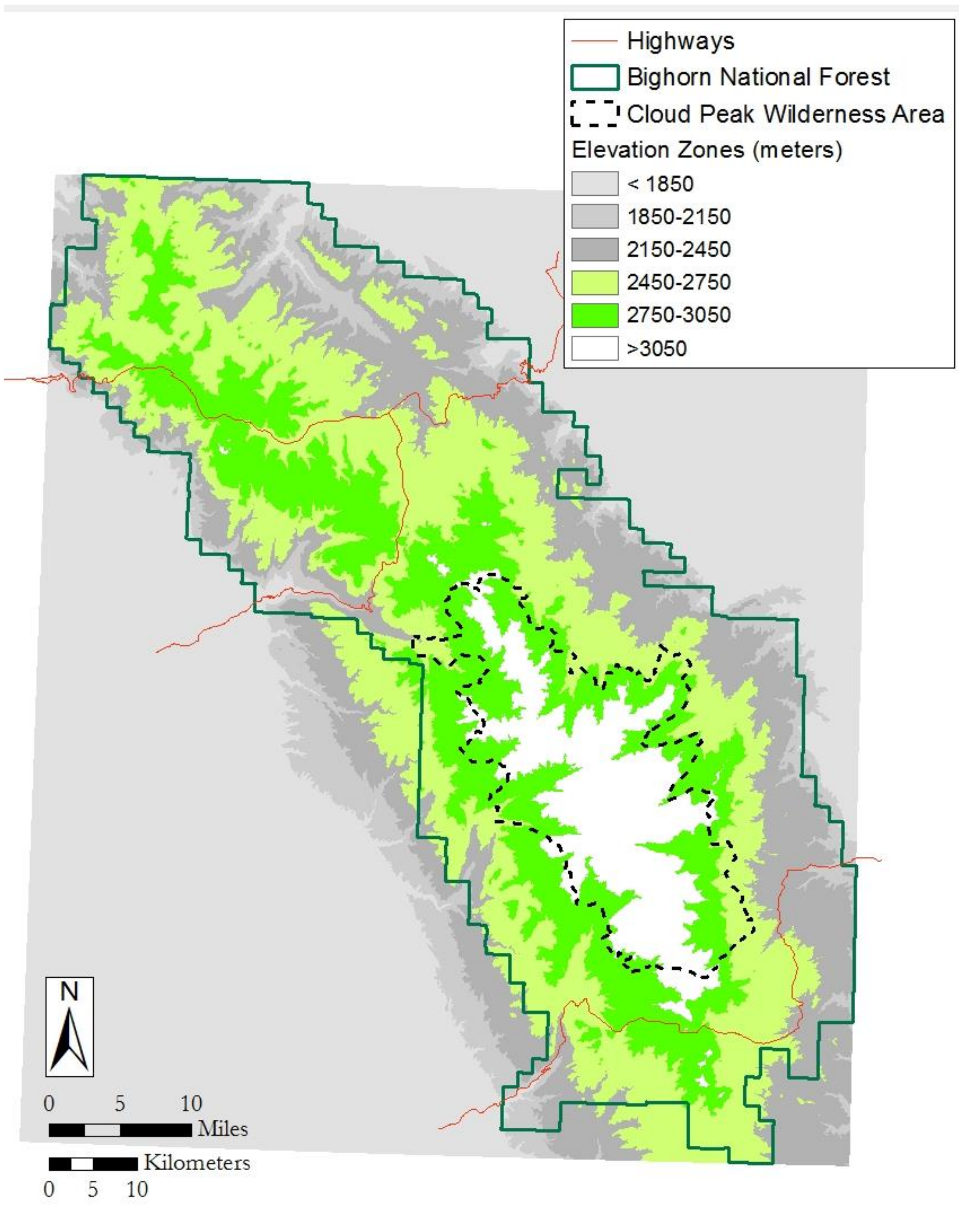


Figure 3. Elevation of the Bighorn National Forest.



C. DEFINITION OF "FEN"

For our sampling protocol, we needed a definition of "fen" that the crew could apply readily and consistently in the field, and we settled on this: **For this project, a fen is a groundwater-dependent wetland with a layer of peat at least 20 centimeters (7.9 inches) thick.**

Our definition recognizes the importance of groundwater in creating the conditions in which a fen can develop. Peat (undecomposed and partially decomposed plant material) accumulates in sites that are saturated throughout much of the year, because saturated soil and plant litter contain very little oxygen, and therefore rates of decomposition are very slow. Groundwater creates those saturated conditions. Surface water, in contrast, generally is too intermittent to saturate a site for long periods. To determine whether a wetland was supported by groundwater, we used the methods from the Forest Service's GDE Initiative (USDA, Forest Service 2012).

In using 20 centimeters of peat as the criterion for a fen, we are departing from customary usage of the term "fen" in North America. Wetland scientists and botanists in the U.S. and Canada usually reserve the term for wetlands where the peat is at least 40 cm (16 inches) thick, and refer to wetlands with thinner peat deposits as some other kind of wetland. But this criterion is not universal. In many countries, 30 cm of peat is considered the amount necessary to classify a wetland as a fen or other type of peatland (Rydin and Jeglum 2013). And recent research in the Rocky Mountains of Colorado (Driver 2010) has shown that hydrologic regimes and vegetation in wetlands with 20 cm to 40 cm of peat cannot be readily distinguished from those in wetlands with $\geq$ 40 cm of peat.

Moreover, the only clear definition of "fen" that we are aware of is that used by the U.S. Fish and Wildlife Service in Region 6 (USDI, Fish and Wildlife Service 1999), in which a wetland can be considered a fen if it has enough organic matter (peat) for the soil to qualify as a histosol (an organic soil), or as a mineral soil with a histic epipedon (an organic layer atop a mineral soil). The Natural Resources Conservation Service defines these soil terms precisely, based on the thickness of the organic layer, the amount and type of organic carbon present in the layer, and the nature of other layers in the soil (Soil Survey Staff 1999). Those detailed definitions often are shortened to simple thickness thresholds: the presence of a peat layer at least 40 cm thick is said to indicate a histosol, and a layer 20 cm to 40 cm thick to indicate a histic epipedon. Consequently, our use of 20 cm of peat as the threshold for a fen is in keeping with the Fish and Wildlife Service's definition.

We identified peat in the field, using guidelines in the GDE Field Guide (USDA, Forest Service 2012, p. 57), and we are confident that this method allowed us to identify fens as they are commonly understood. If questions arise about the soils at specific locations, soil scientists can return to them and take more-precise measurements, and also collect soil samples for laboratory analysis of organic matter. And since we recorded the thickness of the peat at each sampling site, the wetlands that we have classified as fens can be re-classified based on different thickness thresholds.

II. METHODS

A. SITE SELECTION

The National Wetlands Inventory (NWI), a program of the U.S. Fish and Wildlife Service, has mapped wetlands across the U.S. The portion of the NWI layer that covers the Bighorn National Forest is available in a digital layer, and we used that layer to identify the population of wetlands from which we drew our sampling sites.

In selecting the sites, we had to balance two opposing emphases. To meet our first objective of sampling as many fens as possible with finite funds and time, we would have intentionally selected from the NWI layer a set of wetlands most likely to contain fens. We could have accomplished this by considering only the NWI wetlands in the areas where we already knew (from Heidel 2011) that fens occurred, and further restricting the selection by using aerial photographs to look for wetlands with features that are associated with fens. But to characterize the variety of fens on the Forest, and to address our second objective of assessing the utility of the NWI layer for identifying fens, we needed to select a random set of widely distributed wetlands that represented a range in environmental conditions. Considering only wetlands with certain features and that occurred in limited areas would have prevented this. As a compromise, we first selected from the NWI layer a large subset of wetlands that we thought provided conditions suitable for the development of fens, and from that subset selected a second, smaller subset of wetlands distributed across the Bighorns.

1. Qualifying Wetlands

From the NWI web site (http://www.fws.gov/wetlands/Data/DataDownload.html), we downloaded a geodatabase of wetland polygons, current as of August 26, 2013, and used a shape file of the Bighorn National Forest boundary to clip a shape file of the 10,479 polygons mapped on the Bighorn National Forest[2]. Because clipping likely split the wetland polygons lying near the Forest boundary, we re-calculated the areas and the perimeter lengths of all the polygons in the new layer. Because our method of selecting sampling sites required that we have a layer of points, not polygons, we used the "Feature to Point" tool in ArcMap to create a shapefile of points, in which each point feature was the centroid of an NWI polygon.

From the shapefile of 10,479 points, we deleted 505 points: 15 points representing excavated polygons ("x" on the end of the wetland code in the "Attribute" field of the attribute table), 165 points representing diked or impounded polygons ("h" on the end of the wetland code), and 325 points representing polygons influenced by beaver ("b" on the end of the wetland code) (Table 1). The resulting shapefile contained 9,974 points representing wetlands primarily in the Palustrine Emergent Class (PEM wetland code), Palustrine Scrub-Shrub Class (PSS code), or Palustrine Forested Class (PFO code). Peat is most likely to accumulate in saturated conditions, so to focus our sampling on wetlands most likely to contain fens, we extracted the 6,319 points representing polygons classified by NWI as having a saturated hydrologic regime ("B" at the end of the wetland code).

[2] GIS work was done in the ESRI ArcMap program, version 10.1

Table 1. Selection of potential sampling points from the set of all NWI points*.

All NWI points on Bighorn National Forest	10,479
Points Removed:	505
Excavated wetlands (x)	*15*
Diked or impounded wetlands (h)	*165*
Beaver-influenced wetlands (b)	*325*
Remaining eligible points	9,974
Qualifying points:	6,372
Points in saturated wetlands (hydrologic regime = B)	*6,319*
Points in PFO or PSS Classes surrounded by saturated polygons	*4*
Points in PEMC or PEMF wetlands adjoining Lacustrine wetlands	*49*

*The NWI points are centroids of the NWI polygons.

Colleagues in Montana and Colorado advised us that, in certain situations, wetland features classified by NWI as having unsaturated hydrologic regimes are likely to be erroneously classified and are actually saturated. Acting on their advice, we added the points representing the following 53 unsaturated polygons: 4 unsaturated Palustrine Forested Class (PFO) polygons or Palustrine Scrub-Shrub Class (PSS) polygons surrounded by saturated polygons, and 49 polygons classified as Palustrine Emergent Class, seasonally flooded (PEMC) or Palustrine Emergent Class, semi-permanently flooded (PEMF) that share a perimeter with a Lacustrine System (i.e., deep water wetland) polygon. These 53 polygons were selected manually, through visual inspection of the polygons in GIS. The resulting 6,372 points represent the wetland polygons that qualify for selection as potential sampling points.

2. 2014 Sampling Points

To reduce the time needed to travel to potential points, we selected from the set of 6,372 qualifying points the 1,016 points that lie within 0.16 km (0.1 mile) of either side of an open road. The digital road layer that we used in this selection was derived from the "Roads With Complete Linear Events" layer that we had received in a database from the GIS specialist on the Bighorn National Forest. From that roads layer, we removed features with the following attributes: 25 decommissioned road features (OJBECTIVE attribute = Decommissioned), 32 road features on private lands (PRIMARY_MA attribute = private), and 637 closed road features (OPER_MAINT attribute = 1 - BASIC CUSTODIAL CARE (CLOSED)). We also used visual inspection in GIS to identify and remove isolated road features that appeared to be unconnected to other roads. The remaining roads were then buffered with a 0.1-mile-wide buffer on both sides, creating a polygon layer that we used to clip 1,016 potential sampling points from the set of qualifying points.

To increase the likelihood that we would sample across the range of fen types, we stratified the potential sampling points using three elevation zones (<2640 meters, 2640 - 2850 meters, and 2850 - 4200 meters) and four geologic substrate-types. To construct the elevation zones, we used a 30-meter digital elevation model, assigning each cell in the Forest to one of the elevation zones. For the substrate-types, we clipped out the portion of the Wyoming bedrock geology map (Wyoming State Geological Survey 2014) that covers the Bighorn National Forest, and then combined the map units into 4 categories: carbonate, crystalline, glacial, and other (Table 2).

Table 2. Bedrock geology map-units that compose the geologic substrate categories used for stratification in selecting sampling points in 2014.

Carbonate
Bighorn dolomite
Bighorn dolomite, Gallatin limestone, Gros Ventre formation, and Flathead sandstone
Gallatin Limestone, Gros Ventre Formation and equivalents, and Flathead Sandstone
Madison limestone and Darby formation
Ten Sleep sandstone and Amsden formation
Crystalline
Metamorphosed Mafic and Ultramafic Rocks
Oldest Gneiss Complex
Plutonic Rocks
Glacial
Glacial deposits
Undivided surficial deposits
Other
Alluvium and colluvium
Chugwater and Goose Egg formations
Cloverly and Morrison formations
Frontier formation and Mowry and Thermopolis shales
Goose egg formation
Gravel, pediment, and fan deposits
Landslide deposits
Lower Miocene rocks, Bighorn Mountains
Mowry and Thermopolis shales
Sundance and Gypsum Spring formations
Terrace gravel (Pleistocene and/or Pliocene)
Wasatch formation - Kingsbury conglomerate member
Wasatch formation - Moncrief member
Wasatch formation, main body
White River formation

Finally, we used a generalized random tessellation stratified (GRTS) procedure in the R software package to choose a set of 302 points from the 1,016 potential sampling points. GRTS selection combines the statistical benefit of random sample selection (which allows statistically-valid inferences to be drawn from the data) with the efficiency of a set of points that are well distributed throughout the study area (Stevens and Jensen 2007).

3. 2015 Sampling Points

After the 2014 season, 6,211 qualifying wetlands remained unsampled. For the 2015 field season, we drew points from this set of qualifying wetlands, but used different rules for selecting those points than we had used in 2014.

Two-Stage Sampling

For 2015, we implemented a two-stage sampling procedure using pairs of points. One point in each pair was the primary point, selected with a stratified-random GRTS procedure. At the primary points, we sampled in the same way as we had at the 2014 points. The other point in the pair was the secondary point, and in most pairs it was simply the qualifying point nearest to the primary point. At the secondary point we just noted whether or not a GDE was present and recorded the peat thickness.

Primary Sampling Points

Analysis of our 2014 data showed that we had found fens at only 20% of the sites we visited. Hoping to increase this percentage in 2015, we developed a logistic regression model from the 2014 data and used it to estimate the odds of finding fens at the remaining qualifying points. This model included elevation as a predictor variable, and to use it we had to choose 2015 sampling points within the elevation range over which we had sampled in 2014, causing us to reduce the number of potential points to 4,876 (Table 3). We used the logistic regression model to further reduce the number of potential points, by selecting the 881 points for which the model estimated at least 1:1 odds of having a fen. Finally, we restricted potential sampling points to within 500 meters (0.31 mile) of an open road (compared to the 160-m, or 0.1-mile, buffer used in 2014). The resulting 340 points constituted the set from which the GRTS procedure selected 96 potential sampling points.

Table 3. Narrowing of qualifying points to potential primary sampling points for 2015

Qualifying points remaining after 2014	6,211
Within acceptable elevation range	4,876
With odds $\geq$ 1:1 of a fen being present	881
Within 500 meters of open road	340
Selected by GRTS procedure	96

To further bias the selection of primary points toward wetlands with relatively high likelihood of having fens, we used the odds as a stratifying variable in the GRTS selection. We divided the 340 potential points into three odds-categories: odds from 1:1 up to 1.5:1, odds from 1.5:1 up to 2:1, and odds 2:1 or greater. We found that the largest proportion of the points was in the category with smallest odds, and the smallest proportion was in the category with the largest odds (Table 4). We had the GRTS procedure, though, select equal proportions of points in the three odds-categories, thereby over-selecting the points with larger estimated odds and under-selecting points with the smallest estimated odds. With this procedure for selecting the primary sampling points, we obtained a random and well-distributed set of points with the largest estimated odds of having fens. The GRTS procedure selected 96 primary sampling points, 32 in each odds-category.

Table 4. Stratifying 2015 GRTS primary-point selection by odds of a fen being present

Estimated odds	Proportion of 340 potential points	Proportion of GRTS points
Largest (≥ 2:1)	0.2	0.333
Medium (1.5:1 to 1.999:1)	0.29	0.333
Smallest (1:1 to 1.499:1)	0.51	0.333

Secondary Sampling Points

For 81 of the primary points selected with the GRTS procedure, we selected a secondary point from among the set of 4,536 qualifying points within the acceptable elevation range that were not within 500 meters of open roads, and so had not been identified as potential primary points. In most cases, the secondary point was the point closest to the primary point. Secondary points were chosen by inspection of the layers of points in a GIS project. We set no maximum value for the distance between the primary point and secondary point, and 37 of the secondary points lay at least 500 meters from their primary points. We did not allow a point to be sampled twice as a secondary point, and for 15 of the primary points we could not identify a point that we thought the crew could reach in a reasonable amount of time and that was not already a secondary point. Hence 15 of the primary points had no secondary points.

We used the information from the secondary points to assess the results of the logistic regression model, but that information is insufficient for characterizing the nature of the fens and other groundwater-dependent wetlands.

B. Field Sampling

Field sampling was conducted by a two-person crew. For each point, the crew was provided with the location coordinates, plus an aerial photograph and a topographic map, both showing the sampling point, and both at a scale of 1:1,000 to 1:1,500. Upon arriving at the wetland represented by the sampling point, the crew members applied the decision tree in the GDE Level I Inventory Field Guide (USDA Forest Service 2012, Box 1 on page 11) to determine if a GDE was present in the wetland. If not, they simply noted signs of groundwater (if any), chose a reference point (Level I

Inventory Field Guide, page 38) and recorded its coordinates, and sketched the reference point and other features on the aerial photograph.

If the wetland contained a GDE, then the crew used a soil auger to check the thickness of peat in places where they thought it was most likely to have accumulated. If they did not find peat ≥ 20 cm thick anywhere in the wetland, then it was not considered to be a fen, even if the crew observed some of the characteristics of fens (Level I Inventory Field Guide, pp. 60-62). The crew recorded the following information: GDE types present, fen characteristics observed, thickness of peat, geologic setting, life-forms of plants present (ranked by the relative amount of canopy cover they contributed), dominant species in each life-form, signs of disturbance, and the first 18 items on the Management Indicator Tool of the GDE inventory form (Appendix A). They also sketched, on the aerial photograph, the boundary of the GDE and the reference point. At most points, they took photographs. The botanist on the crew looked for rare or sensitive plant species on the list that WYNDD botanist, Bonnie Heidel, had suggested (Table 5) and, when the dominant plants in the vegetation could not be identified to species, collected specimens for identification later.

Table 5. Plant species that received special attention in GDE surveys in 2014 and 2015.

Scientific Name	Common Name
Carex diandra[1,3]	Lesser panicled sedge
Carex limosa[2]	Mud sedge
Carex sartwellii	Sartwell's sedge
Drosera anglica[1,3]	English sundew
Equisetum sylvaticum[3]	Wood horsetail
Eriophorum chamissonis[1,3]	Russet cottongrass
Eriophorum gracile[1,3]	Slender cottongrass
Hierochloe odorata	Sweetgrass
Potamogeton amplexifolius[3]	Large-leaved pondweed
Potamogeton praelongus[3]	White-stem pondweed
Rubus acaulis[1,3]	Northern blackberry
Utricularia minor[1,3]	Lesser bladderwort

[1] U.S. Forest Service Region 2 sensitive species
[2] Bighorn National Forest Species of Local Concern
[3] Tracked by WYNDD

If the crew found peat ≥ 20 cm thick, then the wetland was considered to contain a fen. At these sites, the crew recorded all of the information listed above, plus the following: depth to water table; flow rate of springs and channels; and pH, electrical conductance, and temperature of water in at least one location[3].

Data were recorded on a slightly-modified version of the Forest Service GDE Level I Inventory Form (available at http://www.fs.fed.us/geology/groundwater.html), following the

[3] pH, electrical conductance (μS/cm), and water temperature were measured with a Hanna Instruments HI 98129 pH-EC-TDS-ORP-Temperature tester. The pH electrode was calibrated daily using the two-point procedure and buffer solutions of pH = 7.01 and pH = 10.01. The EC/TDS probe was calibrated daily using solution HI7031. Buffer solutions were within the expiration dates.

instructions in the Level I Inventory Field Guide (USDA Forest Service 2012). In addition to collecting this standard GDE information, the crew noted whether *Sphagnum* spp. moss was present, recorded the amount of different categories of ground cover (bare substrate, plant litter, live plant base, bryophytes, rock, and water), recorded information about willows (abundance [none, minor amount, common, abundant], presence of catkins, and degree of browse [none, moderate, heavy]), and described vegetation structure and composition in more detail. Our field forms and the instructions that supplement the standard GDE Level I Field Guide are provided in the materials accompanying this report, as described in Appendix A.

Plant specimens collected at the sampling points were identified to species (when possible) using the collection at the University of Wyoming's Rocky Mountain Herbarium.

C. Data Summary and Analysis

Information that is part of the standard GDE sampling was entered into a copy of the USFS's national GDE database that had been provided to WYNDD. The additional information that we collected was entered into a separate Microsoft Access® database. All of the information and data in the databases was compared with the original information on the paper data sheets to identify errors, and those were corrected. Both databases and spreadsheets of information exported from them are provided in the materials accompanying this report, as described in Appendix A.

III. Results

A. Sampling Effort

1. Number of Samples

Over the two field seasons, we visited 332 sampling points distributed widely across the Bighorns (Figure 4). We found GDEs at 287 points (86% of all sampled points) and fens at 88 points (31% of the GDEs and 27% of all the points) (Table 6).

In 2014, when the GRTS procedure used elevation and geologic substrate as strata for distributing the points, we found fens at 20% of the sampling sites (33 of 165 sites). In 2015, when the GRTS procedure incorporated odds from the logistic regression model, the percentage of sites with fens increased to 33% (55 of 167 sampling points). In contrast, the percentage of sampling sites with GDEs that did not qualify as fens decreased very slightly, from 61% in 2014 (101 of 165 sites) to 59% in 2015 (98 of 167 points). The percentage of sites with any type of GDE increased substantially between 2014 (134 of 165, or 81%, of sites) and 2015 (153 of 167, or 92%, of sites).

Figure 4. Distribution of points visited in both years.

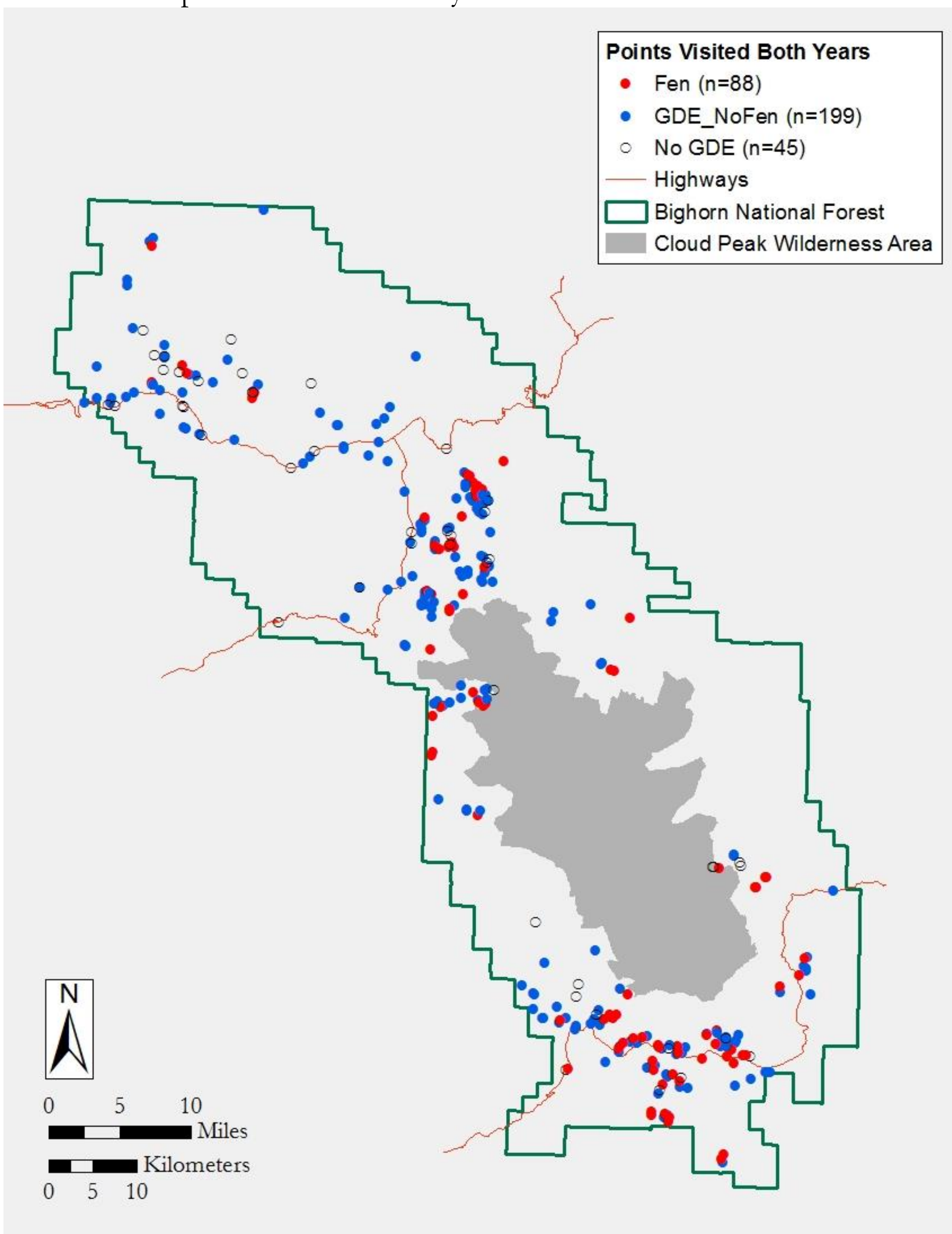


Table 6. Numbers of sampling points visited, GDEs sampled, and fens sampled.

a. 2014

		Fen Present?		
		Yes	No	Total
GDE Present?	Yes	33	101	134
	No		31	31
	Total	33	132	165

b. 2015

		Fen Present?		
		Yes	No	Total
GDE Present?	Yes	55	98	153
	No		14	14
	Total	55	112	167

c. Both Years Combined

		Fen Present?		
		Yes	No	Total
GDE Present?	Yes	88	188	287
	No		56	45
	Total	88	244	332

2. Sampling the Range of Potential Fen Wetlands

In choosing the sampling sites for this project, we selected from the NWI layer the subset of wetlands that we think are most likely to provide the environments in which fens develop: that is, the 6,372 qualifying wetlands. From them, we chose a second subset of partially-randomized wetlands, constrained by distance to open roads. By comparing the elevations, substrate-types, and sizes of these selected wetlands to the entire set of qualifying wetlands, we can get an idea of how well our randomized set of sampled locations covers the ranges in environmental factors likely to influence the characteristics of fens.

a. Distribution of Samples Across Elevation Range

Although the relationships between elevation, temperature, and annual precipitation are somewhat complicated, increasing elevation generally is accompanied by a decrease in temperature and an increase in precipitation (Knight *et al.* 2014). Because low temperatures and wet conditions slow the rate of decomposition, higher elevations are likely to provide relatively favorable environments for peat to accumulate. Moreover, preliminary analysis of the data we collected in

2014 indicated that increasing elevation was associated with higher odds that wetlands contained fens. Hence we thought it important to examine how well our samples span the range in elevation of the qualifying wetlands. In comparing the sampled wetlands to the set of qualifying wetlands, we divided the qualifying but unsampled wetlands into those outside of the Cloud Peak Wilderness Area and those inside the area (Figure 5), to illustrate more clearly the effect of keeping our sampling sites near to open roads.

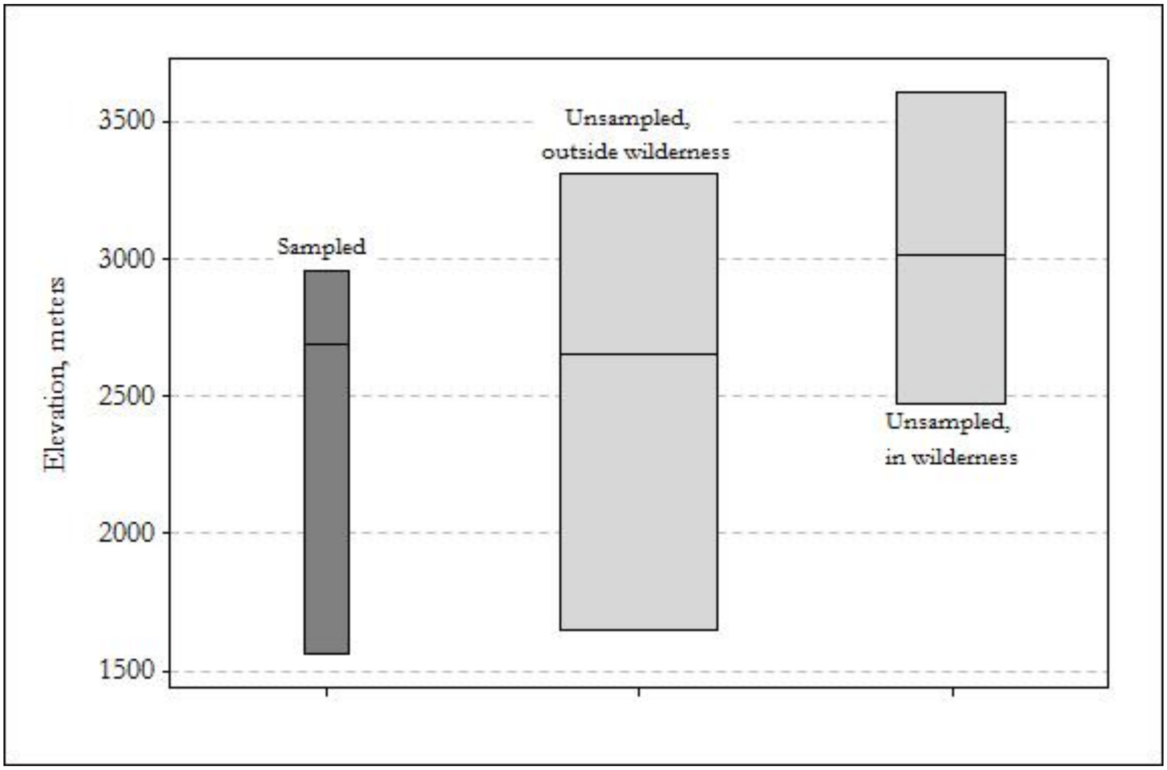
The set of sampled wetlands spans an elevation range of 1560 meters (5118 feet) to 2958 meters (9705 feet) and represents most of the elevation range of the saturated wetlands on the Bighorns (Figure 5). Our requirement that the sites sampled in this project be close to roads (to reduce travel time) means that wetlands where fens might form at the highest elevations may be unrepresented by our data.

b. Distribution of Samples Among Substrate-Types

Fens are often compared to one another by the chemical composition of their waters, especially the concentrations of calcium and magnesium. Because the chemical composition of the bedrock influences the chemical composition of groundwater, we classified the bedrock types of the study area into four broad classes that we assume differ in their chemical composition. The carbonate class includes limestone and dolomite, which contain high concentrations of calcium. Crystalline rocks are mainly granite and similar rocks rich in feldspars and quartz, although this class also includes small areas of crystalline rocks rich in magnesium and iron. Glacial substrates are derived mainly from crystalline rocks, and this class is based on landform instead of bedrock type. We recognized it as a substrate type because fen wetlands are known to be associated with glacial deposits. Finally, our “Other” class includes a large number of bedrock types (primarily sedimentary) that fit poorly into the other classes.

Figure 5. Elevation ranges of sampled wetlands and of unsampled qualifying wetlands inside and outside of the Cloud Peak Wilderness Area.

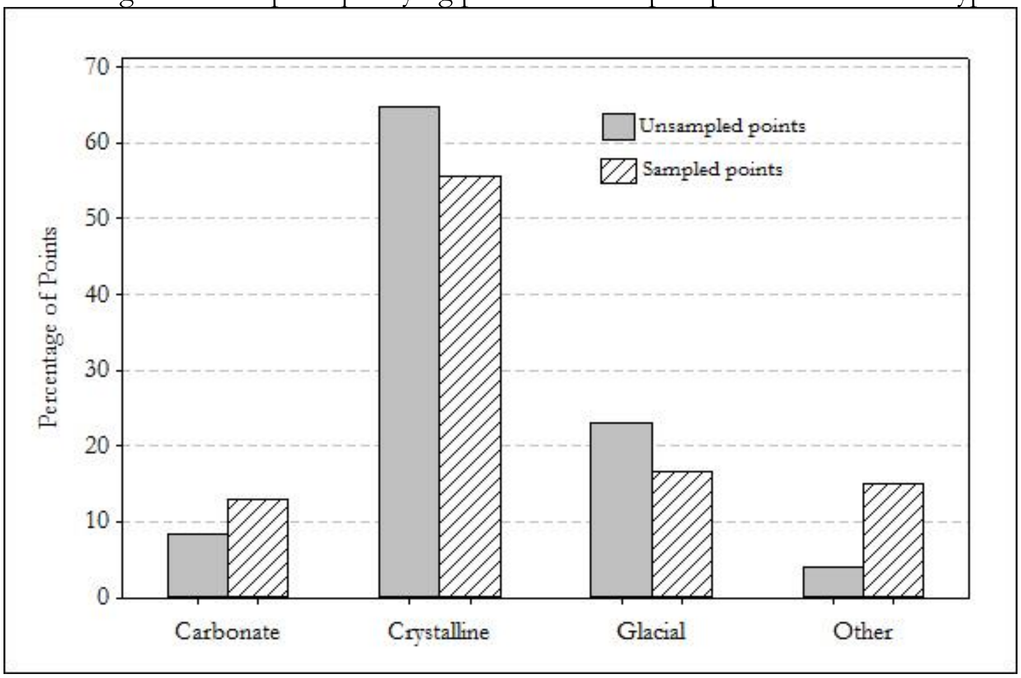
Each box includes all of the wetlands in the group. Widths of boxes show the relative number of wetlands in each group. Horizontal lines are median elevations.



If the sampled points represent the set of qualifying points in terms of their distribution among the four substrate types, then the unsampled points and the sampled points should occur in the same percentages on those types. Figure 6 suggest that this is not the case: Slightly smaller percentages of the sampled points than the qualifying but unsampled points occurred on crystalline rocks and glacial deposits (the two main substrate-types), while a slightly greater percentage of the sampled points fell on the carbonate rocks. The percentage of sampled points on other substrates was much larger than the percentage of qualifying but unsampled points. A chi-square test (Appendix B, Table B-1) shows that the differences between the proportions of sampled points and of unsampled points is statistically significant ($p < 0.001$). Hence the sample points are not a random sample of the substrate-types; rather, they are biased toward the carbonate rocks and the other substrates.

For each of the two substrate-types that contain the great majority of the saturated wetlands, the difference between the proportion of unsampled points and the proportion of sampled points on the type is small. Consequently, while the deviation from a random sample of substrates is statistically significant, we doubt that it is large enough to be significant ecologically.

Figure 6. Percentage of unsampled qualifying points and sampled points on bedrock-types.

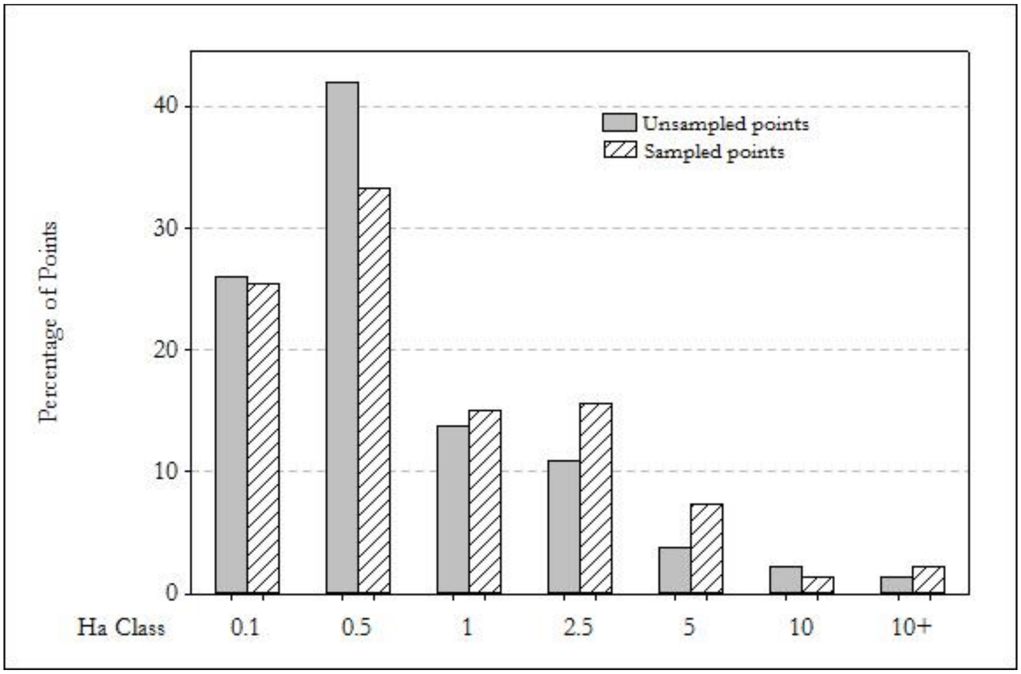


c. Distribution of Samples Across Wetland Size-Range

The great majority of the qualifying NWI wetland polygons are 0.5 ha (5,000 square meters) in size or smaller (Figure 7). Interest in fens sometimes focuses on larger fens, and the size of a fen is limited by the size of the wetland in which it occurs. We examined our data to see if our set of sample points was likely to be missing wetlands of particular sizes and therefore might also be missing either large or small fens. The size of each wetland polygon in the NWI layer is known, and we grouped the wetlands into seven size-classes: $\leq$ 0.1 ha, 0.1 to 0.5 ha, 0.5 to 1 ha, 1 to 2.5 ha, 2.5 to 5 ha, 5 to 10 ha, and 10 ha and larger.

Figure 7 suggests that our set of sample points over-represents wetlands in the intermediate and largest size-classes, and under-represents the smaller wetlands (especially those 0.1 – 0.5 ha in area). A chi-square test (Appendix B, Table B-2) confirms that the proportions of sampled points and of unsampled points in different size-classes are statistically different ($p < 0.001$). The sampled points, then, are not a random sample of wetlands of different sizes. As with the distribution of sampled sites on substrate-types, we doubt that the departure from a random sample of wetland sizes is significant ecologically: for the size-class with the great majority of saturated wetlands, the difference in the proportion of unsampled wetlands and the proportion of sampled wetlands is relatively small.

Figure 7. Percentage of unsampled qualifying points and sampled points in each wetland size-class. Values on the X axis are the upper limits (in hectares) of the size-classes, except 10+, which includes wetlands ≥ 10 hectares in size.

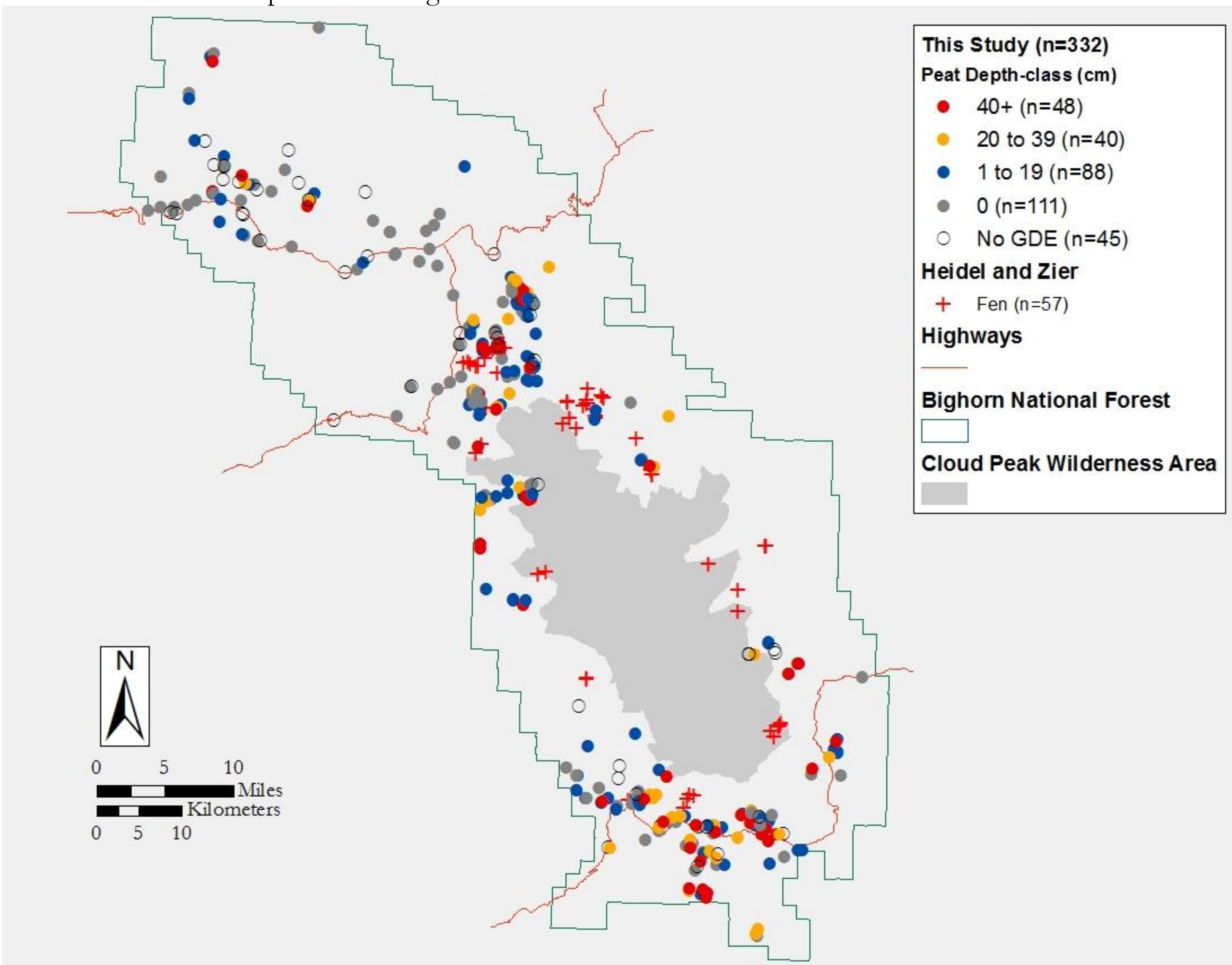


B. CHARACTERISTICS OF FENS AND OTHER GROUNDWATER-DEPENDENT WETLANDS ON THE BIGHORNS

1. Geographic Distribution

Heidel and Zier (Heidel 2011) had already shown that wetlands that qualify as fens by the customary criterion (peat ≥ 40 cm thick) are present in Darton's (1906) central area, near to the Cloud Peak Wilderness Area (Figure 8). Our results augment that earlier picture of distribution and abundance in three ways.

Figure 8. Fens and other GDEs with peat on the Bighorn National Forest.



First, while confirming that fens are concentrated on glaciated terrain around the area of the high peaks, this study shows that peat-accumulating wetlands (some of them with thick peat deposits) are widespread (Figure 8). One prominent example is the northern end of the Forest (along and north of U.S. Highway 14/14A), where 19 of 71 sample sites have some peat, 7 sites have $\geq$ 20 cm of peat, and 4 sites have $\geq$ 40 cm of peat. A second area is the southern end of the Forest, south of U.S. Highway 16, where 19 of 29 sites have some peat, 12 sites have $\geq$ 20 cm of peat, and 6 sites have $\geq$ 40 cm of peat.

Second, our results show that peat is more common in wetlands than might be expected. While only 17% of the GDEs had peat $\geq$ 40 cm thick, peat 20 cm to 40 cm thick was found in an additional 15% of the GDEs, and an additional 30% of the GDEs had peat < 20 cm thick (Table 7). Sixty-one percent of the GDEs had some amount of peat.

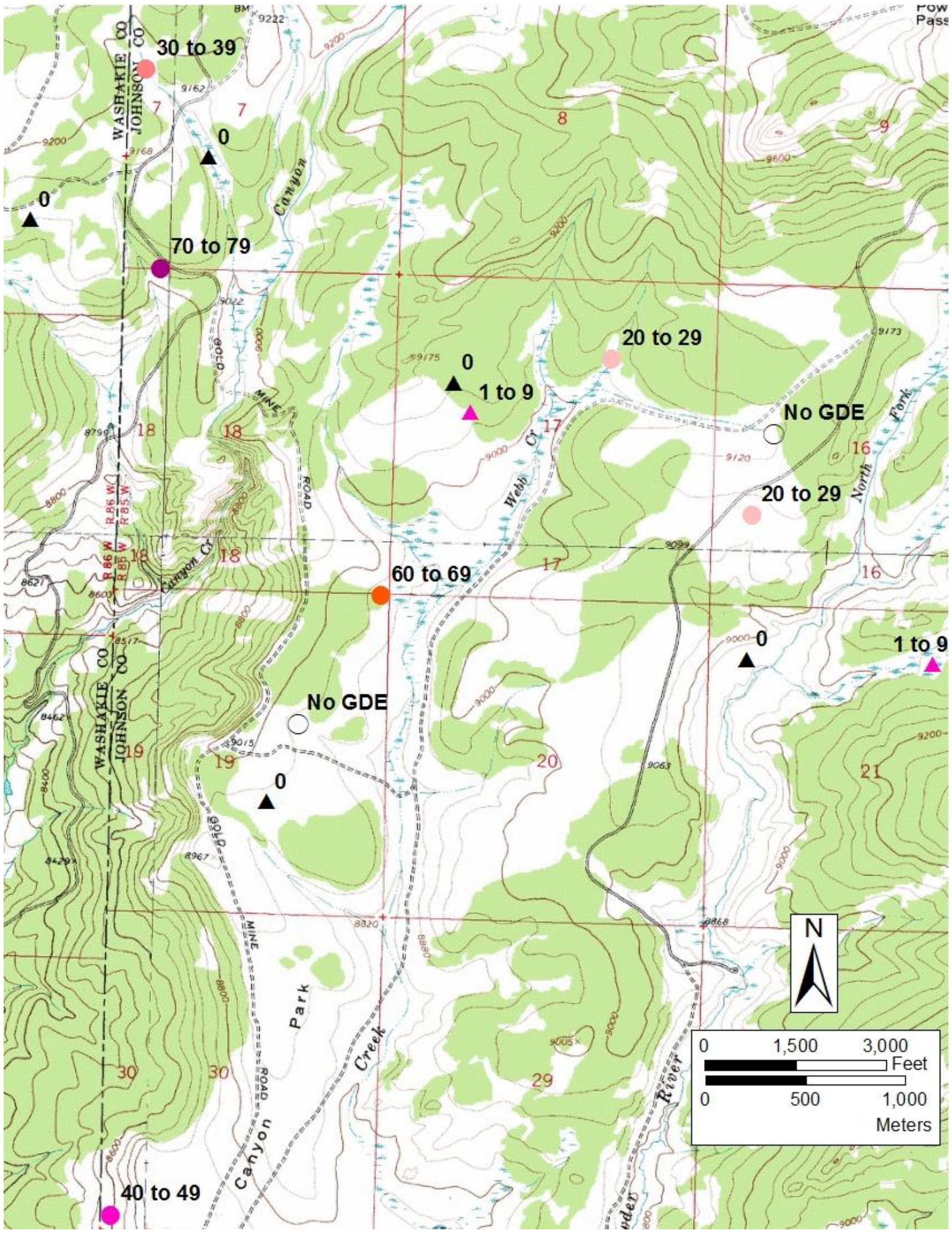
Table 7. Thickness of peat at 287 sampling points that contain GDEs.

Peat thickness	# points	% GDEs	% fens
None	111	39%	
1-9 cm	38	13%	
10-19 cm	50	17%	
20-29 cm[1]	22	8%	25%
30-39 cm[1]	18	7%	20%
$\geq$40 cm[1,2]	48	17%	55%
Total	287	100%	100%

1. Considered in this project to be fens.
2. Traditionally used as a criterion for a fen

Third, our results illustrate the complicated intermingling of wetlands with different thicknesses of peat. Sites with thick peat, thin peat, no peat, and no GDE commonly are found within several hundred meters of one another (Figure 9).

Figure 9. Example of intermingling of sites with different thicknesses of peat.
Numbers are centimeters of peat. Sites are at the southern end of the Forest, in upper Canyon Creek and North Fork Powder River watersheds.

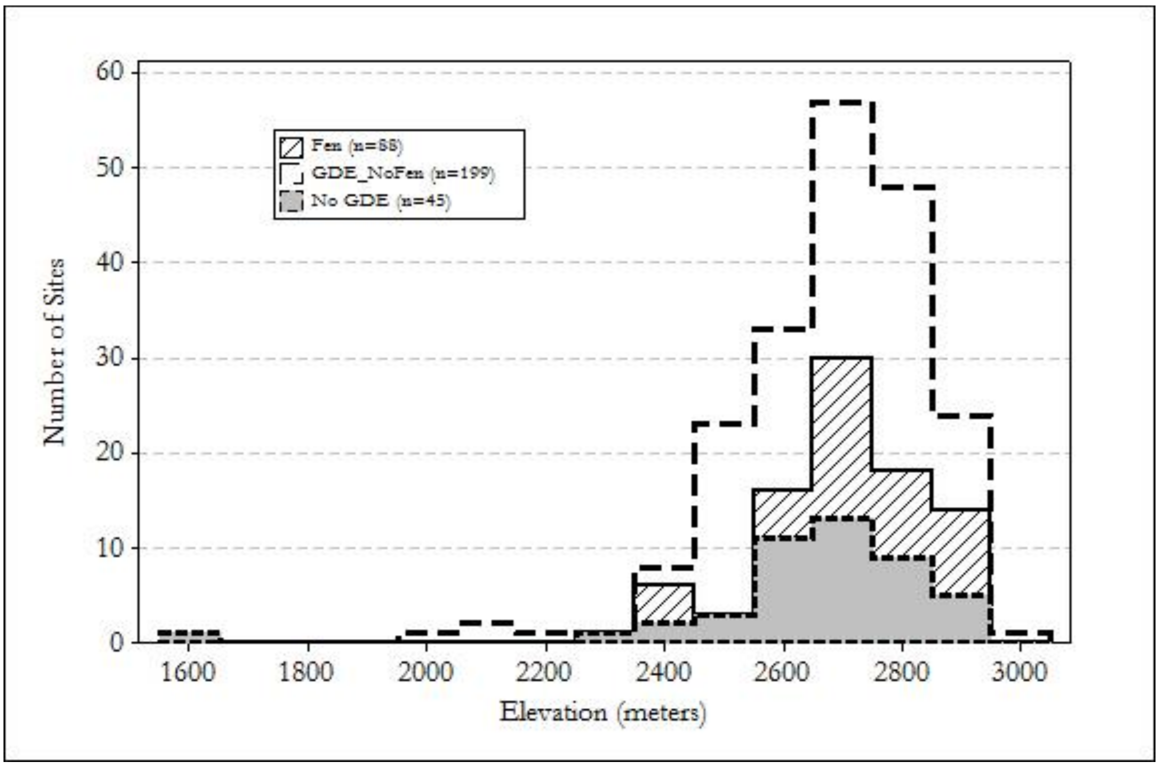


2. Relationships of Fens to Environmental Factors and Size of Wetland

a. Elevation

We sampled sites at elevations between 1,557 meters and 2,899 meters. Virtually all of the sites are at elevations between 2,300 meters and 2,950 meters (Figure 10). There appears to be no difference among the elevation ranges of fens, GDEs without fens, and sites without GDEs. The data from the 2014 field season indicated that fens occurred in a slightly higher elevation range than other sites, but that slight difference seems to disappear when data from both field seasons are considered.

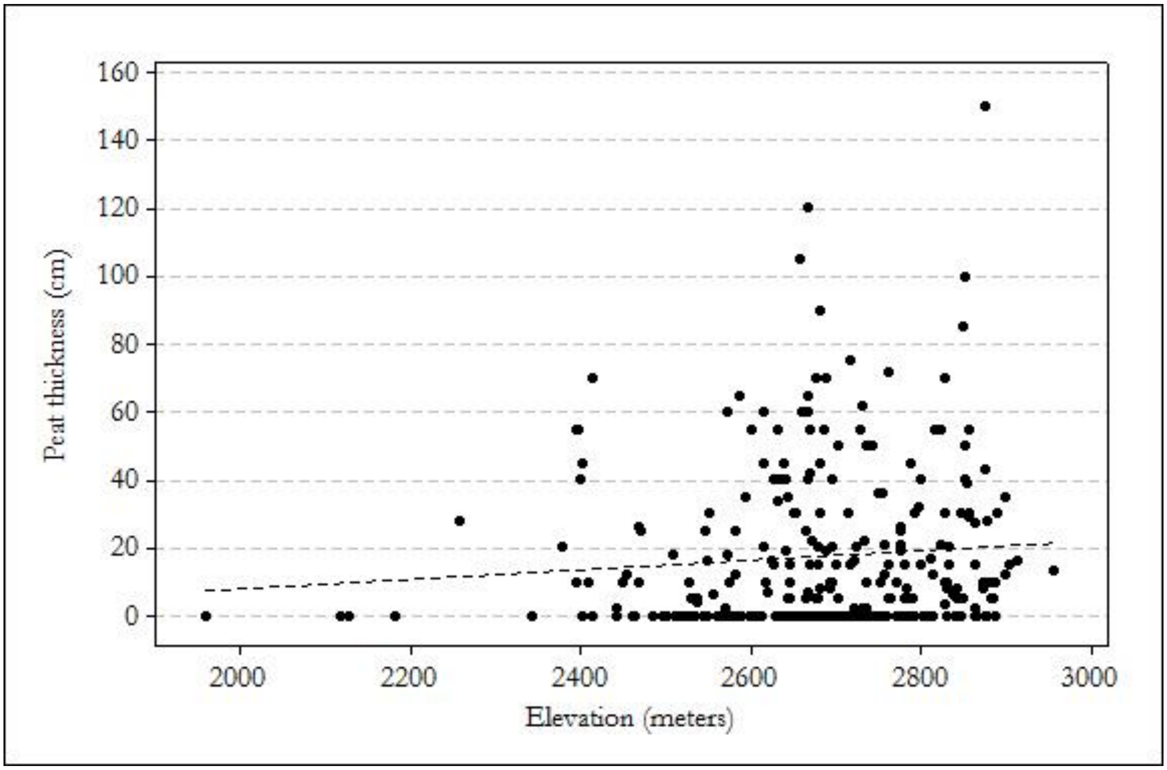
Figure 10. Distribution by elevation of 332 sampled sites with fens, GDEs but no fens, and no GDEs.



Not only doe the occurrence of fens appear to be unrelated to elevation, the thickness of peat in a wetland also appears to be unrelated to elevation (Figure 11).

It's important to note that the results from these sites do not mean that elevation has no effect on peat accumulation and, therefore, on the occurrence of fens. The methods that we used to select sampling sites caused us to exclude wetlands in the Bighorns above approximately 3,000 meters (9,843 feet) elevation. Peat might accumulate faster, and peat deposits be thicker, at higher elevations where temperatures generally are lower and precipitation greater. Similarly, peat probably rarely accumulates in the relatively low (hence warmer and drier) basins adjoining the Bighorn Mountains.

Figure 11. Peat thickness vs. elevation for the 256 samples sites with GDEs.
Dashed line is the regression line from linear regression of peat thickness on elevation.



b. Substrate

Winters *et al.* (2006) describe the association between wetlands and glacial deposits on the Bighorn National Forest, and our results accord with that description: substantially greater percentages of our 332 partially-random sampled points are found on glaciated substrate and on crystalline rocks than would be expected, given the percentages of the study area on those substrates (Table 8). But those wetlands on the glacial and crystalline landscapes do not contain greater proportions of fens than would be expected by chance (chi-square test, $p > 0.1$; Appendix B, Table B-1). So, while glacial and crystalline substrates or landforms are especially favorable for the formation of wetlands, they apparently are not especially favorable for the development of fens.

Table 8. Percentage of 332 sampled points on substrate-types compared to percentage of study area on substrate-types.

Substrate-type	Area (Ha)[1]	Percent of area	# points	Percent of points
Carbonate	144,461	39%	43	13%
Crystalline	165,396	44%	186	56%
Glacial[4]	29,369	8%	54	16%
Other	32,703	9%	49	15%
All	371,930	100%	332	100%

1. These are areas for the Bighorn National Forest outside of the Cloud Peak Wilderness.

In addition to geologic substrate-types, we examined the distribution of sites among common land units (CLUs). These are subdivisions of the landscape generated from soil survey maps at 1:24,000 scale that also recognize vegetation, landform, and slope as factors in subdividing the landscape (Wyoming Water Development Office 1999). Sample points fell on 26 of the CLUs, and fens on 13 CLUs (Table 9). Chi-square analysis (Appendix B, Table B-2) shows that the fens were found on the different CLUs in approximately the same proportions as were the sample sites; that is, fens probably did not occur in greater or smaller numbers than expected on different CLUs ($0.05 < p < 0.1$). It appears, then, that the CLUs are not useful in predicting where on the Bighorn National Forest fens are likely to occur.

c. Slope

Both sites with fens and sites without fens occurred on gentle slopes as measured in the field (Figure 12). A test of the slope measurements shows no significant difference between the groups of sites (Mann-Whitney U-test, $p = 0.061$; Appendix B, Table B-3). Over the range of slopes that we measured, then, the steepness of the wetland apparently has little or no effect on whether enough peat has accumulated to create a fen.

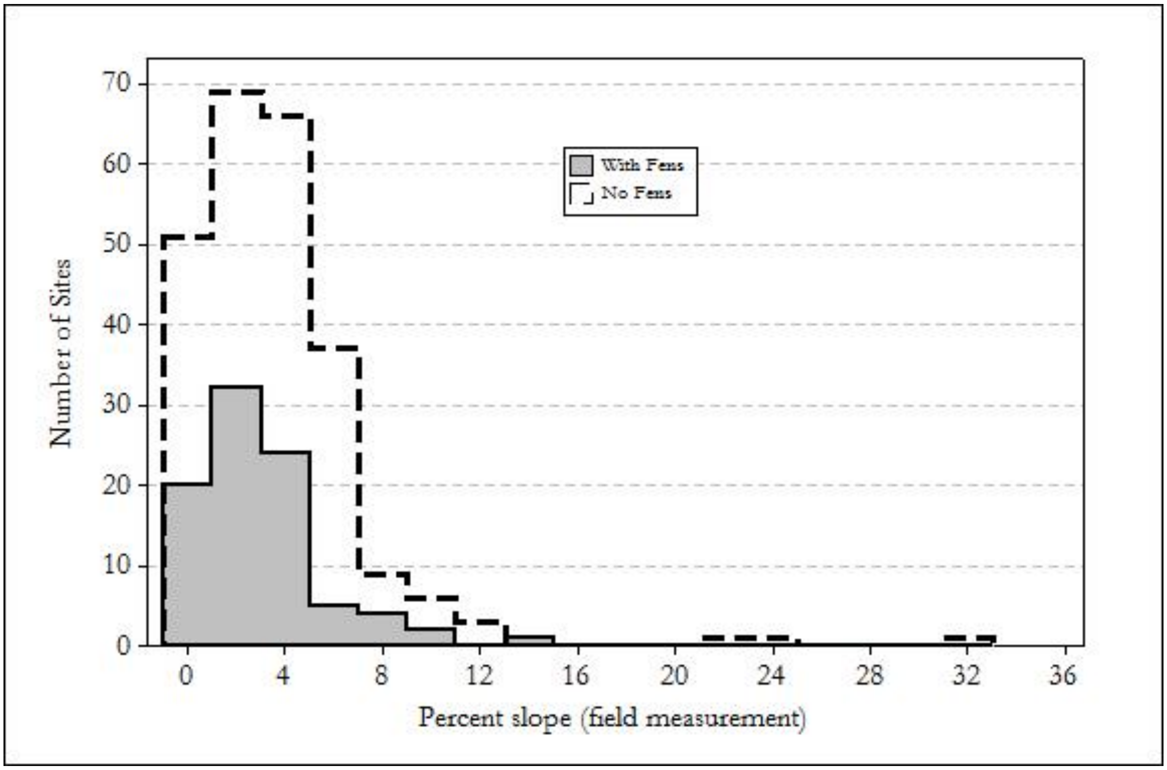
[4] Substrate-type was determined from the map of bedrock geology (Wyoming State Geological Survey 2014). The number of sampled points that actually lie on glacial substrates may be larger than shown here, and the number on crystalline substrates lower, because the bedrock geology map shows only the largest, thickest glacial deposits. Areas shown on the map as crystalline bedrock may be covered with thin glacial deposits (Chris Williams, Bighorn National Forest, personal communication).

Table 9. Numbers of sampling sites with fens or without fens on common land units (CLUs).

CLU number	CLU Description	Fen	Not Fen	Both
10	PIC0/VASC Agneston-Granite-Rock outcrop association on montane & subalpine mountain slopes, 5-50 % slopes.	10	15	25
11	PIEN/VASC Agneston-Leighcan association on montane & subalpine mountain slopes, 5-30 % slopes.	1	10	11
14*	PSME/PHMO4-PIEN/VASC Cloud Peak gravelly silt loam on montane & subalpine mountain slopes, 5-45 % slopes.	0	1	1
16	SALIX/JUCO Cryaquolls on montane & subalpine mountain slopes, 0-5 % slopes.	25	43	68
17*	ARTR2/FEID Farlow-Pishkun association on montane mountain slopes, 5-40 % slopes.	0	2	2
18	FEID/LUSE4 Fourmile loam on montane & subalpine mountain slopes, 2-30 % slopes.	8	13	21
19A	PICO/VASC Frisco-Troutville association on montane & subalpine glacial till, 2-40 % slopes.	2	9	11
19b	PICO/PIEN/VASC Frisco-Troutville association on montane & subalpine glacial moraines, 2-40 % slopes.	5	12	17
20*	JUOS/ARNO4/ELSP3 Grobutte very gravelly loam on montane mountain slopes, 8-60 % slopes.	0	1	1
21*	FEID/LUSE4 Hanson-Raynesford association on montane & subalpine mountain slopes, 0-30%.	0	2	2
23*	FEID/CAREX Inchau-Carbol association on montane & subalpine mountain slopes, 2-20%	0	1	1
24	FEID/LUSE4 Leavitt-Passcreek association on montane & subalpine mountain slopes, 2-30%	0	5	5
25	FEID/CAREX Lucky-Burgess-Hazton association on montane & subalpine mountain slopes, 2-30%	4	13	17
26	ALPINE Mirror-Teewinot-Bross association on subalpine & alpine mountain slopes, 2-40%	6	9	15
27	FEID/LUSE4/CAREX Nathrop-Passcreek-Starley association on montane & subalpine mountain slopes, 2-30 % slopes.	0	5	5
29	ARTR2/FEID Own Creek-Echjemoor-Bynum association on montane & subalpine mountain slopes, 2-30 % slopes.	0	22	22
30	ARTR/FEID Owen Creek-Waybe association on montane & subalpine mountain slopes, 5-35%	4	12	16
33*	Alpine Rock outcrop-Mirror-Teewinot association on subalpine & alpine mountain slopes, 5-35%	0	1	1
34*	FEID/CAREX Rock outcrop-Starman association on montane & subalpine mountain slopes, 5-70%	0	1	1
36*	ALPINE/PEIN/VASC Rock outcrop-Teewinot-Agneston association on subalpine mountain slopes, 5-35 % slopes	1	0	1
39*	PEID/CAREX Starman-Starley association on montane & subalpine mountain slopes, 2-30%	0	3	3
40	PICO/VASC Tellman-Granile-Agneston association on montane & subalpine mountain slopes, 2-20%	20	53	73
41A	ARTR2/FEID/LUSE4 Tine-Fourmile association on montane & subalpine glacial moraines, 2-30%	1	3	4
42*	ELSP3/KOMA Tolman-Beenom Variant-Carbol Variant association on montane mountain slopes, 5-35%	0	1	1
43*	PICO/VASC/PEIN Tongue River-Gateway association on montane & subalpine mountain slopes, 2-35% slopes.	1	6	7
W*	?	0	1	1

* These CLUs were combined into an “Other” category for chi-square analysis.

Figure 12. Slopes of sampling points with fens or without fens.

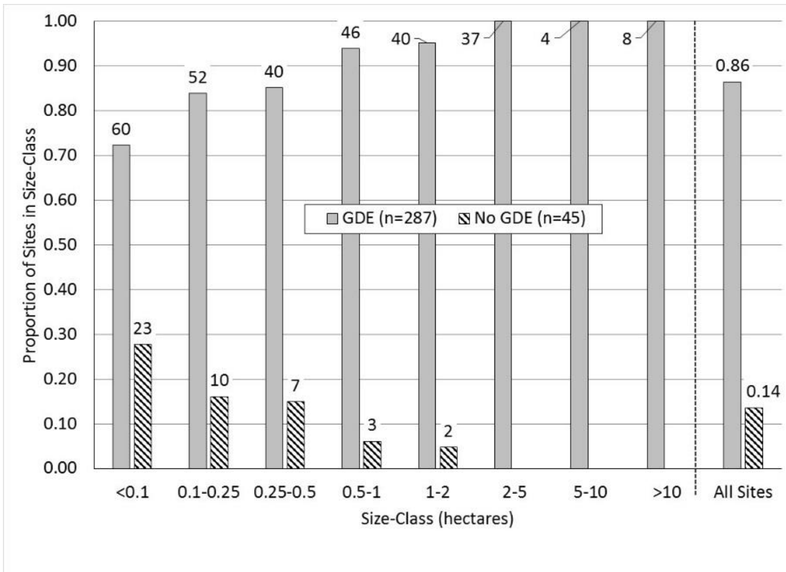


d. Wetland Size

The NWI wetland polygons in which our sample points were located ranged in size from 0.015 ha (0.037 acre) to 638 ha (1,576 acres). To look for a relationship between wetland size and occurrence of fens, we grouped the sampled sites into 8 size-classes (size is the area in hectares of the NWI polygon) and the proportions of the sites with GDEs and without GDEs were calculated for each size-class. Since 0.86 of all sites had GDEs (287 of 332 sites) and 0.14 of all sites had no GDEs (45 of 332 sites), the expected proportions of sites in each wetland size-class also are 0.86 sites with GDEs and 0.14 sites without GDEs. The observed proportions of sites with GDEs and without GDEs differed from expected in nearly all size classes (Figure 13). A chi-square contingency test (Appendix B, Table B-4) showed that the deviation from the expected proportions was statistically significant ($0.01 < P < 0.025$). The data show, then, that the larger an NWI wetland polygon, the greater the likelihood that it contains a GDE. This is useful information to keep in mind when using the NWI layer to identify wetlands that might have fens.

Figure 13. Proportions of all sites with GDE present or GDE absent, in each wetland size-class.

“All Sites” bars show the proportions of all sites with or without GDEs. Numbers above size-class bars are numbers of sites in the size-classes; numbers above “All Sites” bars are proportions of all sites.



The relationship between fens and wetland size is less clear. In general, among the sites with GDEs, the proportion that contains fens (as opposed to non-fen GDEs) increases with increasing wetland size (Figure 14). But the increase in the proportion of fens with increasing wetland size is not uniform. Among the 287 GDEs, 88 are fens (0.31 of the GDEs) and 199 are other (non-fen) GDEs (0.69 of the GDEs). So the expected proportions of fens and of other GDEs in each wetland size-class are 0.31 and 0.69. The proportion of GDEs with fens is greater than expected in four of the eight wetland size-classes and less than expected in three of the 8 size-classes. A chi-square contingency test (Appendix B, Table B-5) showed that the deviation from the expected proportions was statistically significant ($P < 0.0001$). Data from more wetlands might show a clearer relationship between occurrence of fens and size of NWI wetlands, but our results only suggest that GDEs are more likely to have enough peat to qualify as fens in larger wetlands than in smaller.

Another way to look at the influence of wetland size on the occurrence of fens is to examine the relationship between peat thickness and wetland size. Figure 15 suggests only a loose relationship, and linear regression analysis confirms that impression: the area of the NWI polygon containing a wetland explains only 5.6% of the variation in peat thickness ($r^2 = 5.6$, $p = 0.00$; Appendix B, Table B-6).

Figure 14. Proportions of sites with GDEs that are fens or other GDEs, in each wetland size-class.

"All GDEs" bars show the proportions of all GDEs that are fens or other GDEs. Numbers above size-class bars are numbers of fens or other GDEs in the size-classes; numbers above "All GDEs" bars are proportions of all GDEs

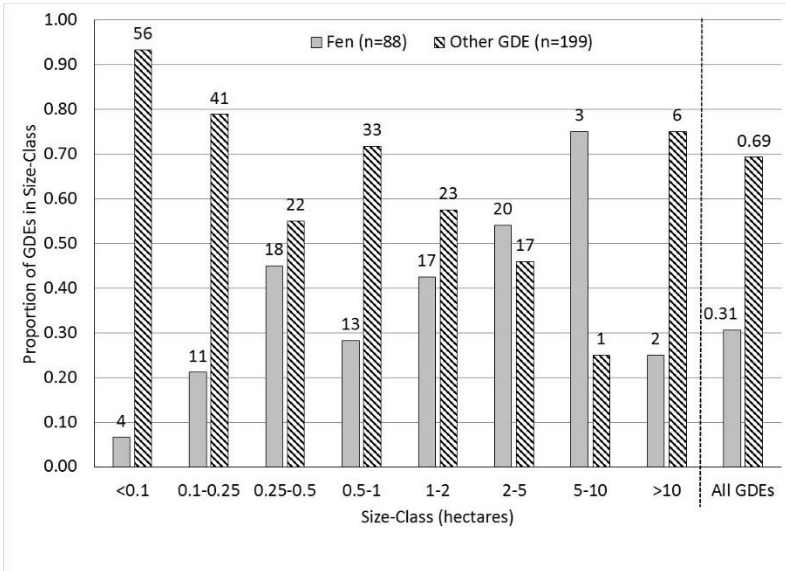
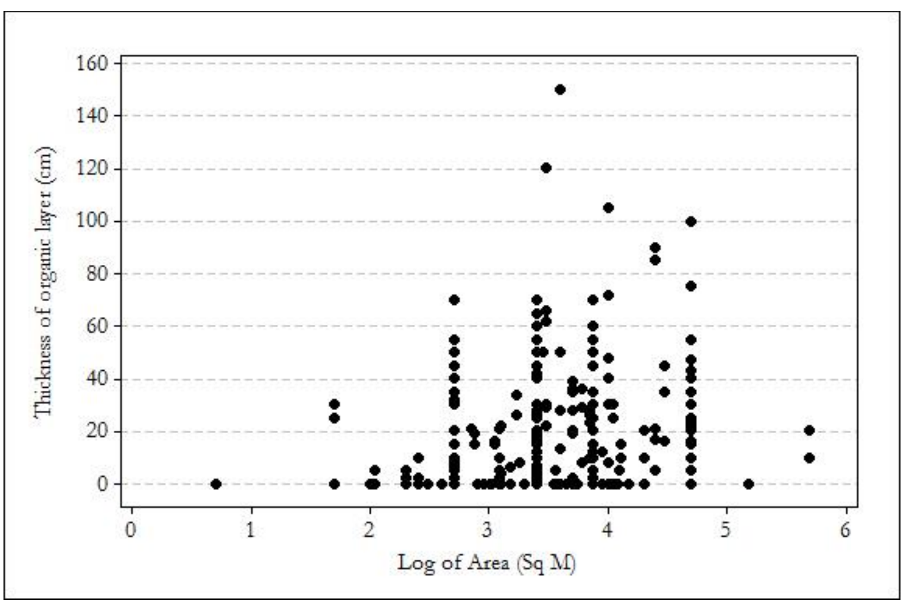


Figure 15. Relationship between thickness of peat layer and area of wetland.



e. Summary

The occurrence of fens in NWI-mapped wetlands apparently is unrelated to elevation, and so elevation is not a useful predictor of where fens are likely to be found. Similarly, fens were not found in higher proportions of wetlands on any of the four geologic substrate types or on any of the CLUs. Hence the occurrence of fens in NWI wetlands also apparently is unrelated to the type of bedrock or combination of vegetation, soil, and slope, and these also are not useful predictors of where wetlands are likely to have a high proportion of fens. This is not to say that wetlands are not more common on glacial deposits or crystalline bedrock. Rather, we have found that fens are not a more common feature of the wetlands on those substrates than in wetlands on other substrates. Likewise, slope steepness apparently does not differ between wetlands with fens and wetlands without fens.

Fens are uncommon in very small NWI wetland polygons. Whether this is due to mapping error or to the nature of very small wetlands is unclear. But for either reason, very small wetlands as mapped by NWI are poor places to look for fens.

3. Vegetation of Fens

a. Vascular Plant Life-forms and Dominant Species

We collected data suitable for assessing the relative dominance of plant life-forms in 85 sites with fens and 163 sites with GDEs other than fens, and the identity of the dominant species in each life-form in 87 sites with fens and 162 sites with other GDEs.

Relative dominance is the amount of canopy cover that a life-form contributes relative to the other life-forms. At a site, each of the five life-forms (tree, shrub, graminoid, forb, and aquatic plant) was assigned a rank from 1 (contributed the most cover) to 5 (contributed the least cover). The ranks were assigned for the life-forms in the entire wetland site, not just in the part that appeared to qualify as a fen. If the dominant life-form at a site was ranked 1, then the next-most common life-form could be assigned a rank of 3 (or even 4), instead of 2. Life-forms absent from a site received a rank of 0. Two life-forms could receive the same rank if they contributed approximately the same amount of cover.

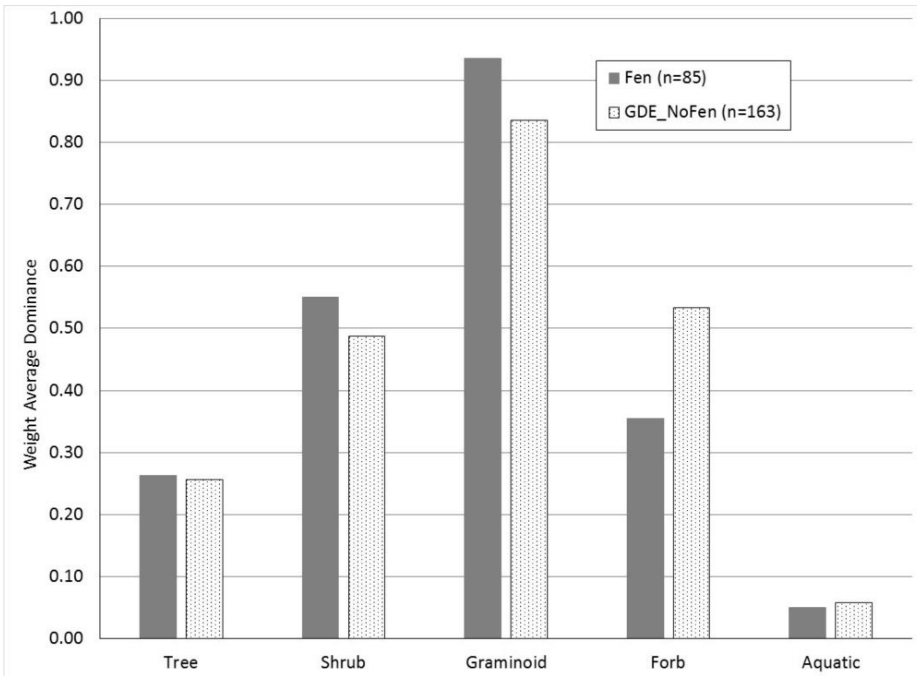
The weighted-average dominance was calculated for each of the five life-forms in each of the two types of sites (fen or other GDE). The weights used in the calculations were the inverses of the ranks (1/rank) instead of the ranks themselves, because the inverses produce intuitive graphs of the results. The equation used for calculating the weighted-average dominance (WAD) is:

$$\begin{array}{l}\text{WAD} \\ \text{of life-form } x \\ \text{in site-type } y\end{array} = \sum_{\text{ranks}} [(1/\text{rank}) * (\#\ y \text{ sites in which life-form } x \text{ had this rank }]$$

Absence of a life-form was given a weight of 0.

In fens and in other GDEs, the vegetation was dominated by graminoids (Figure 16). Two obligate wetland sedge species, water sedge (*Carex aquatilis*) and Northwest Territory sedge (*C. utriculata*), were by far the most common dominant species in both types of sites (Table 10). Additional common dominants in non-fen GDEs were other sedges (*Carex* spp.) and bluejoint reedgrass (*Calamagrostis canadensis*, a facultative wetland species), and in nearly a tenth of those sites, the graminoid component was a mixture of species without a clear single dominant.

Figure 16. Weighted-average dominance (using inverses of ranks) of 5 plant life-forms in fens and GDEs other than fens.



Shrubs were the second-most common life-form of plants in the fens and contributed a substantial amount of the canopy cover in other GDEs (Figure 16). The overwhelmingly common dominant in both types of sites, diamondleaf willow (*Salix planifolia*), is an obligate wetland species (Table 10). In fens, no other species dominated the shrub component in more than 5% of sites. In other GDEs, several shrubs dominated the shrub canopy in almost 10% of sites each: wolf willow (*S. wolfii*), shrubby cinquefoil (*Potentilla fruticosa*), and grouse whortleberry (*Vaccinium scoparium*).

Forbs contributed a substantial amount of the cover in fens and were the second-greatest contributor of canopy cover in the non-fen GDEs (Figure 16). Dominance of the forb component in fens was spread among a number of species, with white marsh marigold (*Caltha leptosepala*) and elephanthead lousewort (*Pedicularis groenlandica*) the most common of them (Table 10). Both are obligate wetland species. The mix of dominant forbs in over 10% of the fens usually included these two species. In the other GDEs, arrowleaf ragwort (*Senecio triangularis*) was the most common dominant forb, and white marsh marigold (less often than in fens), American globeflower (*Trollius laxus*), or a mixture of species dominated the forb component in a substantial number of sites.

Trees contributed little cover to the vegetation in fens or in other GDEs (Figure 16). Engelmann spruce (*Picea engelmannii*) and lodgepole pine (*Pinus contorta*), both facultative species, are virtually the only trees present (Table 10). Aquatic plants were minor constituents of the vegetation in all sites. Fens had a wider variety of dominants among the aquatic plants than did other GDEs, including speedwell (*Veronica* spp.), Rocky Mountain pond lily (*Nuphar polysepala*), and water whorlgrass (*Catabrosa aquatic*) chief among them. In the non-fen GDEs, species of speedwell were the common dominant aquatic dominants.

Table 10. Proportions of sites of each type in which different plant species occurred as the dominant in their life-form.

Scientific Name[1] - Wetland Affinity[2]	Fen (n=87)	GDE_NoFen (n=162)	Scientific Name[1] - Wetland Affinity[2]	Fen (n=87)	GDE_NoFen (n=162)
TREES			Carex - ?	0.03	0.06
Abies lasiocarpa - FACU	0.00	0.02	Carex aquatilis - OBL	0.47	0.21
Picea engelmannii - FAC	0.49	0.53	Carex canescens - OBL	0.02	0.00
Pinus contorta - FAC	0.48	0.42	Carex disperma - FACW	0.01	0.00
Populus tremuloides - FACU	0.04	0.03	Carex microptera - FACU	0.00	0.01
SHRUBS			Carex nebrascensis - OBL	0.01	0.00
Artemisia tridentata ssp. vaseyana - ?	0.00	0.03	Carex utriculata - OBL	0.29	0.31
Betula occidentalis - FACW	0.00	0.01	Deschampsia caespitosa - FACW	0.00	0.05
Juniperus communis - UPL	0.01	0.01	Juncus - FACW?	0.00	0.01
Kalmia microphylla - OBL	0.00	0.01	Juncus balticus - FACW	0.03	0.06
Potentilla fruticosa - FAC	0.00	0.08	Juncus longistylis - FACW	0.00	0.01
Ribes - ?	0.00	0.01	Mixed -- no clear dominant - ?	0.08	0.12
Salix - ?	0.00	0.01	Poa - ?	0.00	0.01
Salix bebbiana - FACW	0.01	0.03	**FORBS**		
Salix boothii - FACW	0.00	0.05	Allium schoenoprasum - FACW	0.02	0.06
Salix drummondiana - FACW	0.00	0.01	Antennaria corymbosa - FAC	0.01	0.01
Salix geyeriana - FACW	0.01	0.03	Arnica longifolia - FACW	0.00	0.01
Salix lutea - OBL	0.00	0.01	Caltha leptosepala - OBL	0.31	0.14
Salix planifolia - OBL	0.91	0.51	Cirsium arvense - FAC	0.01	0.00
Salix wolfii - OBL	0.05	0.07	Epilobium - ?	0.01	0.01
Vaccinium scoparium - FACU	0.01	0.09	Epilobium halleanum - FACW	0.00	0.01
GRAMINOIDS			Equisetum arvense - FAC	0.02	0.02
Agrostis scabra - FAC	0.00	0.01	Fragaria virginiana - FACU	0.00	0.01
Bromus inermis - FAC	0.00	0.01	Galium - ?	0.01	0.00
Calamagrostis canadensis - FACW	0.05	0.15	Galium bifolium - ?	0.01	0.00

Table 10 (continued).

Scientific Name[1] - Wetland Affinity[2]	Fen (n=87)	GDE_NoFen (n=162)	Scientific Name[1] - Wetland Affinity[2]	Fen (n=87)	GDE_NoFen (n=162)
Geranium richardsonii - FAC	0.01	0.03	Senecio triangularis - FACW	0.08	0.21
Geranium viscosissimum - FACU	0.00	0.01	Taraxacum - FACU	0.00	0.03
Geum macrophyllum - FAC	0.05	0.02	Trifolium repens - FAC	0.00	0.02
Heracleum maximum - FAC	0.00	0.01	Trollius laxus - OBL	0.02	0.09
Iris missouriensis - FACW	0.00	0.01	unknown Forb - ?	0.01	0.00
Mentha arvensis - FACW	0.00	0.01	Valeriana - ?	0.00	0.01
Mertensia ciliata - FACW	0.03	0.03	Viola - ?	0.00	0.01
Mimulus glabratus - OBL	0.01	0.00	Viola canadensis - FACU	0.00	0.01
Mixed -- no clear dominant - ?	0.16	0.11	Viola sororia - ?	0.01	0.00
Packera paupercula - FACW	0.01	0.00	**AQUATICS**		
Parnassia fimbriata - OBL	0.01	0.00	Callitriche palustris - OBL	0.00	0.02
Pedicularis groenlandica - OBL	0.10	0.02	Catabrosa aquatica - OBL	0.13	0.00
Platanthera aquilonis - FACW	0.00	0.01	Mimulus guttatus - OBL	0.07	0.00
Polygonum bistortoides - FACW	0.00	0.02	Nuphar lutea - OBL	0.20	0.05
Potentilla - ?	0.01	0.00	Ranunculus - ?	0.00	0.02
Potentilla gracilis var. brunnescens - FAC	0.00	0.01	Ranunculus flammula - FACW	0.00	0.02
Ranunculus flammula - FACW	0.00	0.01	Saxifraga odontoloma - ?	0.13	0.00
Rhodiola rhodantha - FACW	0.02	0.00	Utricularia macrorhiza - OBL	0.07	0.02
Saxifraga odontoloma - FACW	0.01	0.01	Veronica - OBL	0.20	0.12
Senecio - ?	0.01	0.00	Veronica americana - OBL	0.20	0.68
Senecio sphaerocephalus - FACW	0.01	0.07	Veronica anagallis-aquatica - OBL	0.00	0.05

Notes.
1. Scientific names are those used in the GDE Initiative database
2. Wetland-affinity classes are from Lichvar *et al.* (2014) for western mountains, valleys, and coast region. Codes, from wet to dry, are: OBL = obligate wetland, FACW = facultative wetland, FAC = facultative, FACU = facultative upland, UPL = upland, Unknown = taxon not found in 2014 list.

Fens on the Bighorns seem to differ only slightly from other GDEs in vegetation structure (that is, relative cover of different plant life-forms). The difference between them in dominant species is somewhat greater, and this latter difference is made a bit clearer by examining the relative dominance in each type of site by plants in different wetland-affinity classes (Table 11). Dominance of the graminoids, shrubs, and forbs (the major components of the vegetation) is more strongly concentrated in obligate wetland species in the fens than it is in the other GDEs. In the latter sites, facultative wetland species account for substantial proportions of the dominance in all three life-forms. The tree stratum (a minor component of the vegetation) is almost entirely dominated by facultative species in both types of sites. Obligate wetland species of all life-forms are stronger dominants in fens than in the non-fen GDEs. Like the thicker accumulation of peat, this likely illustrates longer or more-frequent periods of saturation in the fen sites.

Assigning sampling sites to wetland vegetation-types was not a purpose of this study, but our data are sufficient to show similarities between our sites and vegetation-types identified in other wetland studies. The dominance in our sites of water sedge and Northwest Territory sedge, and the amount of diamondleaf willow in many of them, indicate similarities to several common vegetation-types named by Girard *et al.* (1997) from the Bighorn National Forest: (1) the *Carex rostrata*[5]-*Carex aquatilis* environmental type on wet riparian sites (often with ponded water) on sedimentary substrates, (2) the *Carex aquatilis* environmental type on wet sites on granitic or sedimentary substrates, and (3) the *Salix planifolia*/Wet *Carex* ecological type on wet sites at relatively high elevations. In the fens described by Heidel (2011) on the Bighorns, these species also are common components of the vegetation. Fens dominated by water sedge, where diamondleaf willow often is present, are common on the Medicine Bow-Routt National Forest in southern Wyoming (Heidel and Jones 2006). And diamondleaf willow/water sedge fens with acidic soils are described as rare in central and southwestern Montana (Chadde *et al.* 1998). It appears, then, that our data do not reveal the existence of heretofore-unknown wetland vegetation-types.

[5] *Carex rostrata* is the name formerly used for Northwest Territory sedge, which is now known as *C. utriculata*.

Table 11. Proportions of sites of each type dominated by plant species in each wetland-affinity class. Each cell value is the sum of the proportions of sites in that site-type in which the dominant plant species in a life-form belong to the indicated-affinity class. E.g., in 0.96 of the fen sites, facultative trees dominated the tree stratum.

		Fen (n=87)	GDE_NoFen (n=162)
TREES	FAC	0.96	0.95
	FACU	0.04	0.05
SHRUBS	OBL	0.95	0.60
	FACW	0.02	0.11
	FAC	0.00	0.08
	FACU	0.01	0.09
	UPL	0.01	0.01
	Unknown	0.00	0.05
GRAMINOIDS	OBL	0.79	0.52
	FACW	0.09	0.27
	FAC	0.00	0.01
	FACU	0.00	0.01
	FACW	0.11	0.19
	Unknown	0.46	0.25
FORBS	OBL	0.20	0.44
	FACW	0.10	0.12
	FAC	0.00	0.05
	FACU	0.24	0.12
	Unknown	0.87	0.95
AQUATICS	OBL	0.00	0.02
	FACW	0.13	0.02
	Unknown	3.07	2.32
All Life Forms	OBL	0.31	0.85
	FACW	1.07	1.16
	FAC	0.05	0.20
	FACU	0.01	0.01
	UPL	0.49	0.39
	Unknown	0.96	0.95

1. Wetland-affinity classes are from Lichvar *et al.* (2014) for western mountains, valleys, and coast region. Codes, from wet to dry, are: OBL = obligate wetland, FACW = facultative wetland, FAC = facultative, FACU = facultative upland, Unknown = taxon not found in 2014 list.

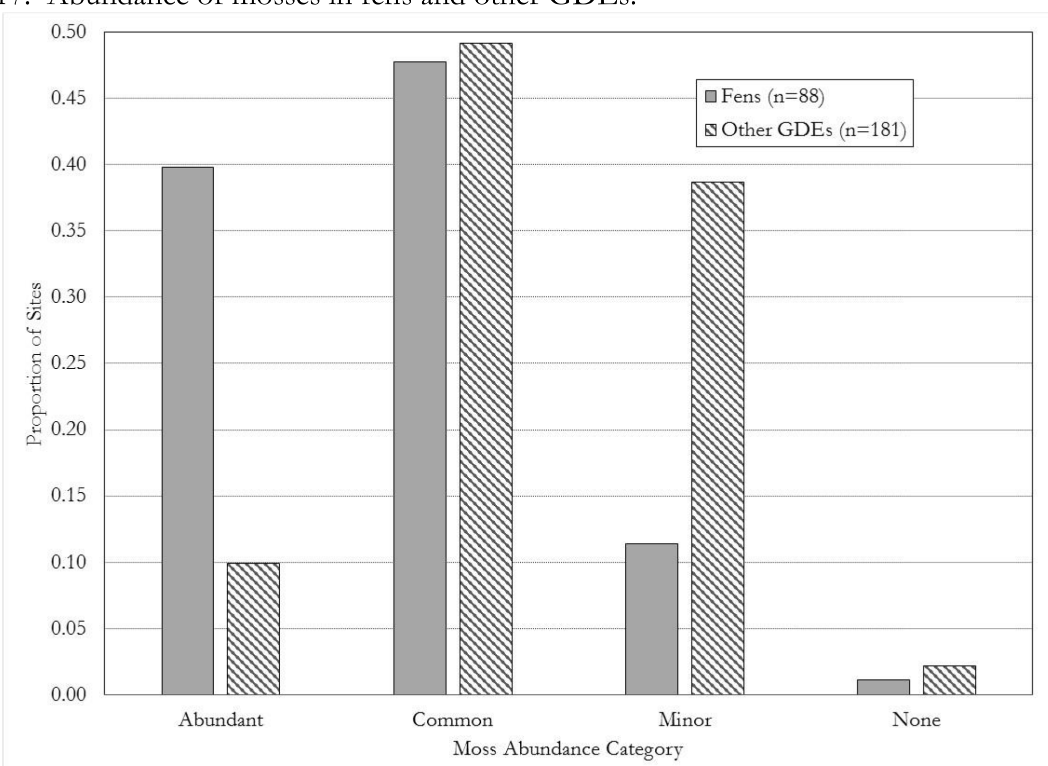
b. Mosses

The GDE Level I sampling methods include estimating the amount of bryophytes[6] present in the wetland (using broad categories; Table 12) and we collected information about bryophyte abundance in 88 fens and 181 other GDEs. Bryophytes were present in almost all sites of both types (Figure 17). Fens had a greater abundance of bryophytes, with almost 90% of fen sites in the "Abundant" or "Common" categories. In sites with other GDEs, bryophytes were ranked as abundant in only 10% of sites, and were minor components of the vegetation in almost 40%.

Table 12. Classes used for recording the abundance of bryophytes at a site.

Value Recorded	Meaning
None	No bryophytes observed
Minor	Very few, scattered individuals or small patches observed
Common	Present throughout with sparse cover, or present in a few dense patches
Abundant	Present throughout with substantial cover

Figure 17. Abundance of mosses in fens and other GDEs.



[6] Bryophytes includes mosses and liverworts. Mosses are by far the more common group.

Sphagnum spp. mosses were on our list of plant taxa of interest (see subsection d. below) and we noted their presence or absence at 254 of the sites. S*phagnum* was present in 62 sites and absent from 192 sites and occurred in a much larger proportion of the fens (0.56) than the other GDEs (0.08) (Table 13).

Table 13. Proportions of fens and non-fen GDEs in which *Sphagnum* spp. mosses were noted as present or absent.

Type of GDE present	*Sphagnum* present	*Sphagnum* absent	All Sites in Type
Fen (n=87)	49 (0.56)	38 (0.44)	87 (1.00)
Other GDE (n=157)	13 (0.08)	144 (0.92)	157 (1.00)
Either type (n=254)	62 (0.24)	192 (0.76)	254 (1.00)

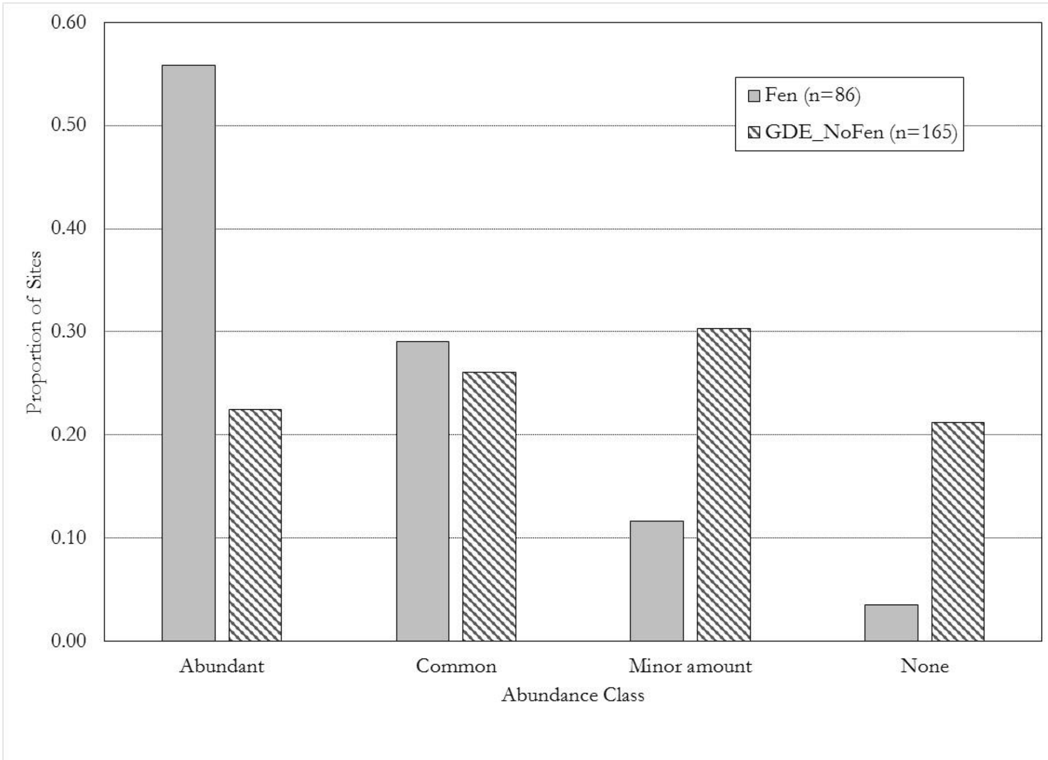
c. Willows

The Bighorn National Forest staff are interested in documenting the abundance of willows (*Salix* spp.) in wetlands and the intensity of browsing pressure on the willows, so we included the genus on our list of plant taxa of interest (see subsection d. below). In keeping with the philosophy of the GDE Level I methods, we used a sampling approach that allowed us to quickly collect data suitable for inventory of wetlands, not detailed data that can be used in quantitative monitoring. For recording willow abundance, we used four categories that required a minimum of judgment on the part of the crew (Table 14) and recorded the data at 251 sites (86 fens and 165 other GDEs). In fens, willows were present in all but a few of the sites, and they were abundant in over half of the sites and common in over a quarter of the sites (Figure 18). The great majority of non-fen GDEs also had willows (almost 80%), but in less than half of these sites were the willows either abundant or common. Almost one-third of the sites had only minor amounts of willow.

Table 14. Classes used for recording abundance of willows at a site.

Value Recorded	**Meaning**
None	No willows observed in the wetland
Minor	Very few, scattered individuals of small patches observed. Willow canopies cover < 10% of the wetland
Common	Willows present throughout with sparse cover, or present in a few, dense patches. Willow canopies cover 10% - 50% of the wetland
Abundant	Willows present throughout with substantial cover. Willow canopies cover > 50% of the wetland

Figure 18. Abundance of willows in the fens and other GDEs.



Evidence of browsing on willows is reported in section 7 below.

d. Plant Taxa of Interest

A standard part of the GDE Level I survey methods is documenting the presence of rare plants, invasive species, and other plants of interest to resource managers. In addition to *Sphagnum* spp. mosses (see subsection b. above) and willows (see subsection c. above), our list of taxa of interest included 12 wetland plant species known to occur in the Bighorn Mountains (Table 15). Six of those species are on the U.S. Forest Service Region 2 Sensitive Species List, one is a Bighorn National Forest Species of Local Concern, three have no USFS designation but are tracked by WYNDD, one (*Carex sartwellii*) is no longer tracked by WYNDD but WYNDD's botanist suggested that we add it to the list, and the last (*Hierochloe odorata*) is a species that Bighorn National Forest staff asked us to note in 2014.

In the two field seasons, we documented the presence of five of the herbaceous species of interest (Table 16). The only site at which we found mud sedge (*Carex limosa*) was already known through earlier work by Heidel and Zier (Heidel 2011). We found russet cottongrass (*Eriophorum chamissonis*) at four sites, three of which apparently had not been documented before. Sweetgrass (*Hierochloe odorata*) is by far the most common of the species of interest; we documented it at 27 sites, only 1 of which seems to have been a known location for the species (Heidel 2011). Our crew documented the presence of *Utricularia* sp. at 2 sites. The plant at one site, which had been visited previously by Heidel or Zier (Heidel 2011), was identified as *U. macrorhiza*. At the other site, the plant was not in flower and so we could not identify it to species. Finally, as noted in subsection b. above, we documented the presence of *Sphagnum* spp. moss at 62 sites and its absence from 192 sites.

Table 15. Herbaceous species of interest in GDE surveys in 2014 and 2015.

Scientific Name	Common Name	Found?
Carex diandra[1,3]	Lesser panicled sedge	No
Carex limosa[2]	Mud sedge	**Yes**
Carex sartwellii	Sartwell's sedge	No
Drosera anglica[1,3]	English sundew	No
Equisetum sylvaticum[3]	Wood horsetail	No
Eriophorum chamissonis[1,3]	Russet cottongrass	**Yes**
Eriophorum gracile[1,3]	Slender cottongrass	No
Hierochloe odorata	Sweetgrass	**Yes**
Potamogeton amplexifolius[3]	Large-leaved pondweed	No
Potamogeton praelongus[3]	White-stem pondweed	No
Rubus acaulis[1,3]	Northern blackberry	No
Utricularia minor[1,3]	Lesser bladderwort	**Possibly**
Sphagnum spp.	Sphagnum moss	**Yes**

[1] USFS R2 sensitive species
[2] Bighorn National Forest Species of Local Concern
[3] Tracked by WYNDD

Table 16. Numbers of sites at which forbs of interest and *Sphagnum* sp. were documented.

	Number of sites		
Species	**Total**	**Previously known**[1]	**New**
Carex limosa	1	1	0
Eriophorum chamissonis	4	1	3
Hierochloe odorata	27	1	26
Utricularia spp.[2]	2	1	1
Sphagnum sp.	62		

1. From Heidel (2011)
2. The previously-known site had *U. macrorhiza*. The *Utricularia* sp. noted at the new site was not in flower and could not be identified to species.

Figure 19 shows the distributions of the sites at which the species of interest (other than willows) were documented These plant species are concentrated in the glaciated central part of the Bighorns.

Figure 19. Sites at which plant species of interest were found.

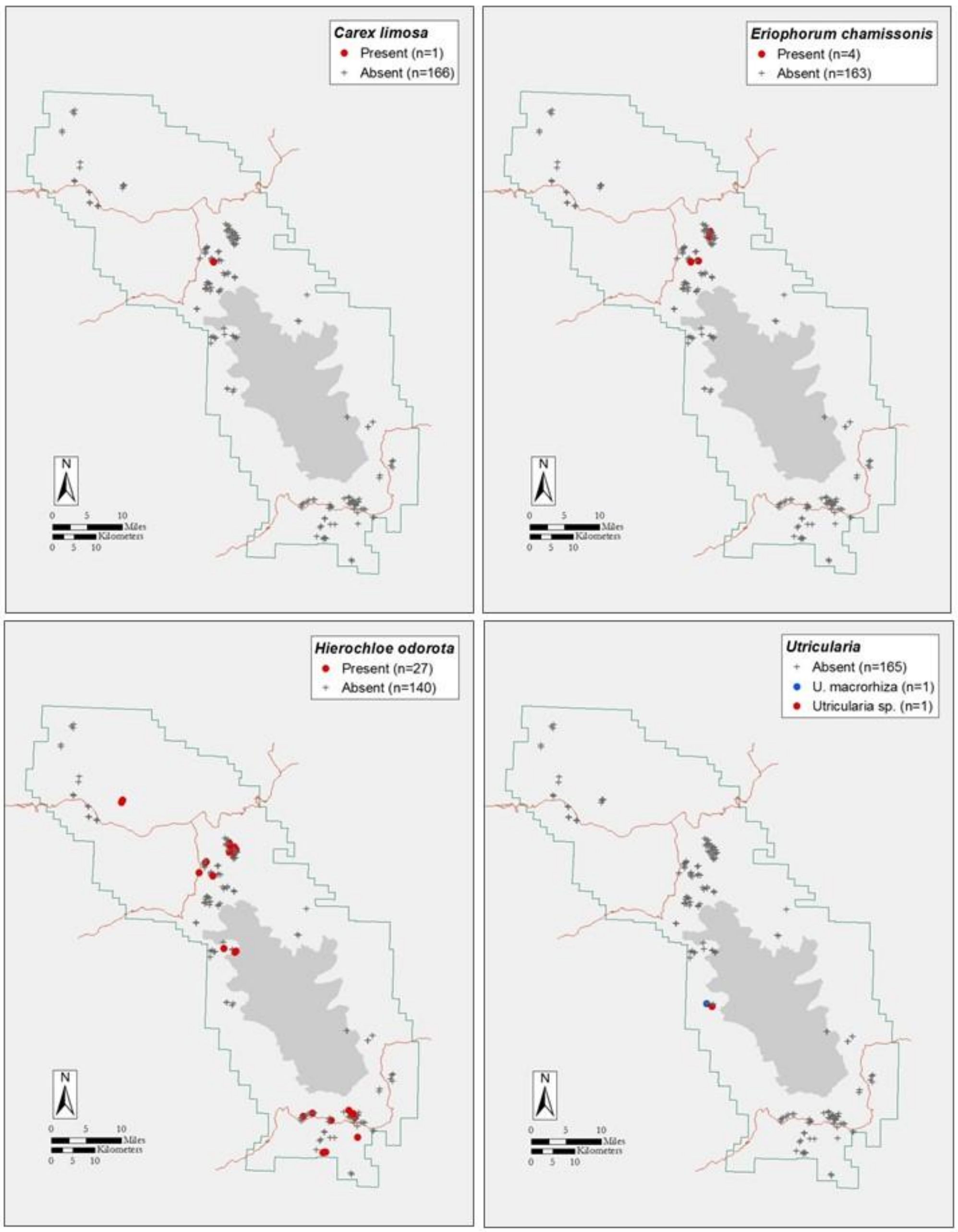
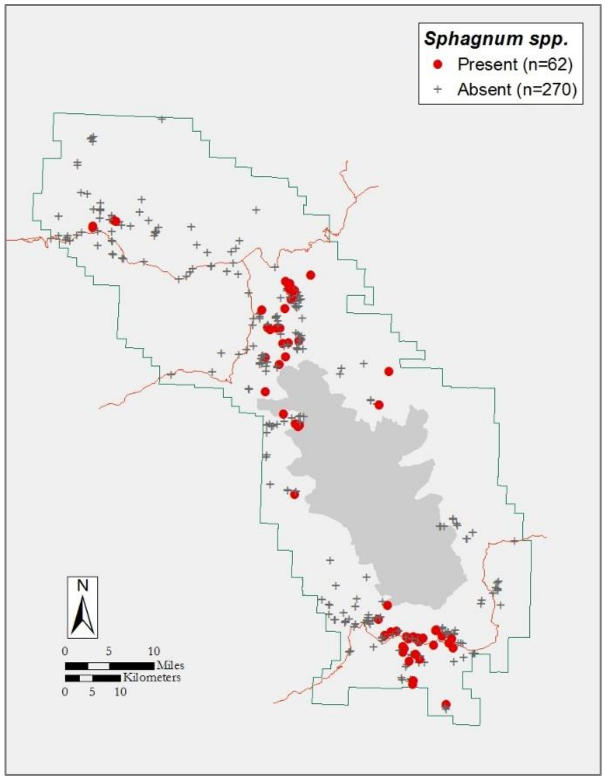


Figure 19 (continued).



5. Types of Springs Encountered at the Sampling Sites

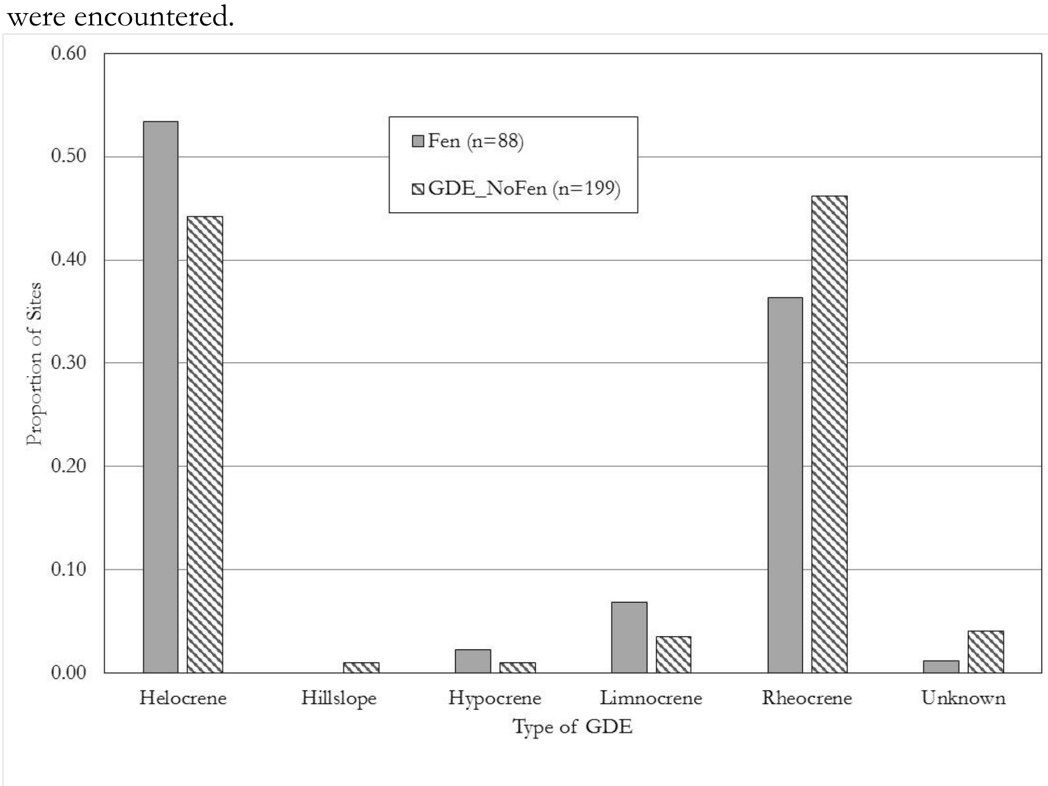
The groundwater-dependent initiative recognizes 12 types of springs that support groundwater-dependent ecosystems. These types of springs differ from one another in the microhabitats that they provide (Springer and Stevens 2009). We recorded information about the spring-types at 88 sites with fens and 199 sites with other GDEs, and documented five types of springs (Table 17). Over half of the fens were supported by helocrenes (diffuse springs on gentle slopes) and nearly 40% by rheocrenes (springs that emerge directly into flowing channels) (Figure 19). Limnocrenes (springs emerging into pools) supported approximately 5% of fens. In sites without fens, helocrenes and rheocrenes were also the major sources of groundwater. Limnocrenes, hypocrenes (buried springs where groundwater is near but below the ground surface), and hillslope springs each supported a small number of non-fen GDEs.

Table 17. Descriptions of types of springs and other water sources at the sampling sites.

Types are from the GDE Level I Inventory Field Guide. See Springer and Stevens (2009) for detailed descriptions.

Type	Description
Helocrene	Spring that emerges diffusely from low-gradient wetlands; often indistinct or multiple sources seeping from shallow, unconfined aquifers
Hillslope	Spring and/or wetland on a hillslope (generally 20- to 60-degree slope); often with indistinct or multiple sources of groundwater
Hypocrene	A buried spring where groundwater levels come near, but do not reach, the surface in arid regions. In humid regions these features may be equivalent to shallow groundwater areas including wet meadows.
Limnocrene	Groundwater emerges in a pool or pools
Rheocrene	Flowing spring that emerges directly into one or more stream channels

Figure 20. Proportions of sites with fens or with non-fen GDEs at which different types of water sources were encountered.



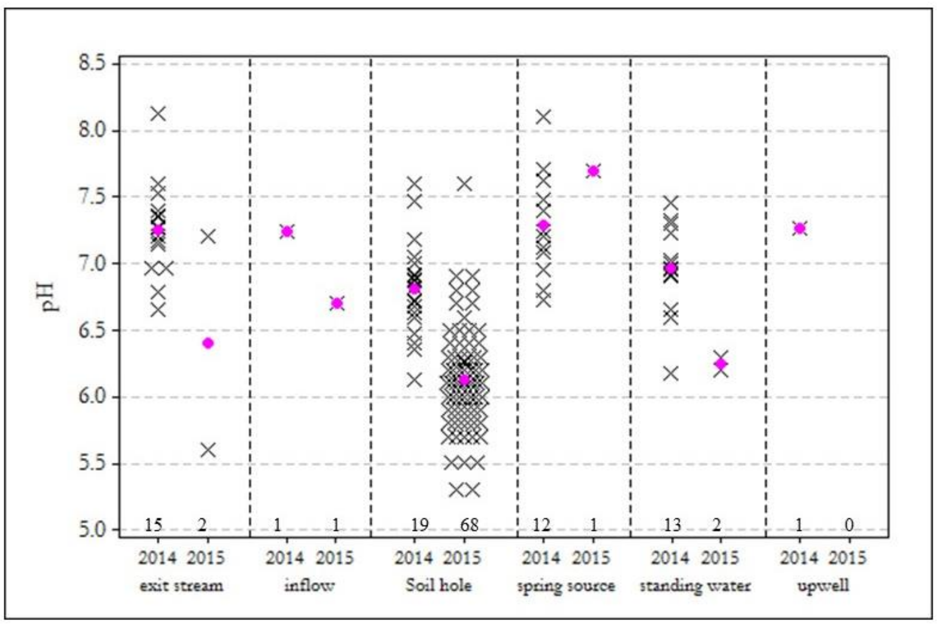
6. Water Chemistry

a. pH

pH was measured in 85 of the 88 fens. A single measurement was taken in 40 of those fens, two measurements were taken in 43 fens, and a third measurement was taken in 2 fens. pH values ranged from a low of 5.3 to a high of 8.12. The great majority of measurements were made in soil-core holes. Several measurements were made in streams exiting fens, springs issuing directly into fens, or standing water in fens. A handful of measurements were made in streams flowing into fens or in pools where water was upwelling into fens. The pH values measured in these different locations, when combined from all fens, overlap substantially, although values from soil holes generally are lower than values from other locations (Figure 21).

Figure 21. pH values recorded in 85 fens in 2014 or 2015, in different locations within a site.

Xs are individual values, colored circles are means. Numbers of samples are shown above the X axis.

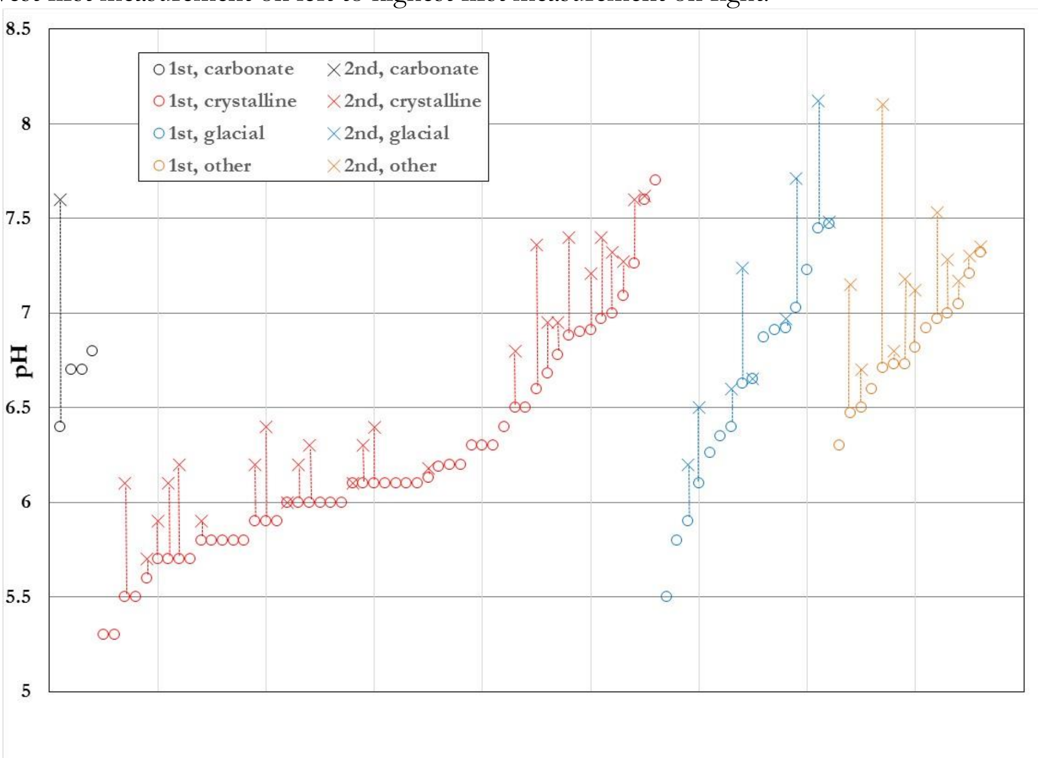


Enough values were measured in 2014 in exit streams, soil holes, springs sources, and standing water for examining differences in pH among locations. Analysis of variance (Appendix B, Table B-7) shows that mean pH (1) did not differ between exit (outflow) streams and spring sources, (2) was significantly lower in soil holes than in exit streams or spring sources, and (3) did not differ in standing water from the other locations.

Figure 22 shows the pH values measured in sites on four different types of substrates (see Table 2 above). Thirty-nine sites are represented by only a single pH measurement, and 47 are represented by two measurements. The degree of overlap among pH readings on different substrates suggests that the pH of a site is not influenced by the type of substrate (as we classify it) on which the site lies. Figure 22 also illustrates the substantial difference in pH measurements made in different locations in the same site.

Figure 22. pH values measured in sites on different types of substrate.

Each circle represents one measurement made in a site, and each X represents a second measurement (where pH was measured in more than one location in a site). Dotted lines connect the two measurements from the same site. Most sites with two measurements are from 2014. Sites are arranged within each substrate-type from lowest first measurement on left to highest first measurement on right.



Two aspects of the pH data are hard to explain. One is the year-to-year difference in values: for almost every type of location, pH values from 2014 are higher than 2015 values (Figure 21). The difference in the values from soil holes (the only location from which there are sufficient measurements for a comparison) is statistically significant (t-test, $p = 0.000$; Appendix B, Table B-8). This nearly-uniformly lower pH in 2015 is puzzling, as there is no obvious reason why the fens sampled in 2015 should be more acidic than those sampled in 2014. An alternative explanation is that measurements were erroneously high in 2014 or low in 2015. Different field technicians recorded the water chemistry values in the two years. But since the same water-quality meter was used in both years, and the calibration procedure was the same in both years, and the two field technicians were trained to take measurements in the same manner (and observations suggest that they did so), it's not at all apparent that the difference between the two years is due to a difference in how measurements were taken.

The second puzzling feature of the data is the magnitude of the difference between two pH measurements taken in some of the fens (Figure 22). These differences, too, suggest instrument error or measurement error. But those explanations seem unlikely, given that the same technician made both measurements at a site, with the same instrument, within a short time of each other.

b. Electrical conductance

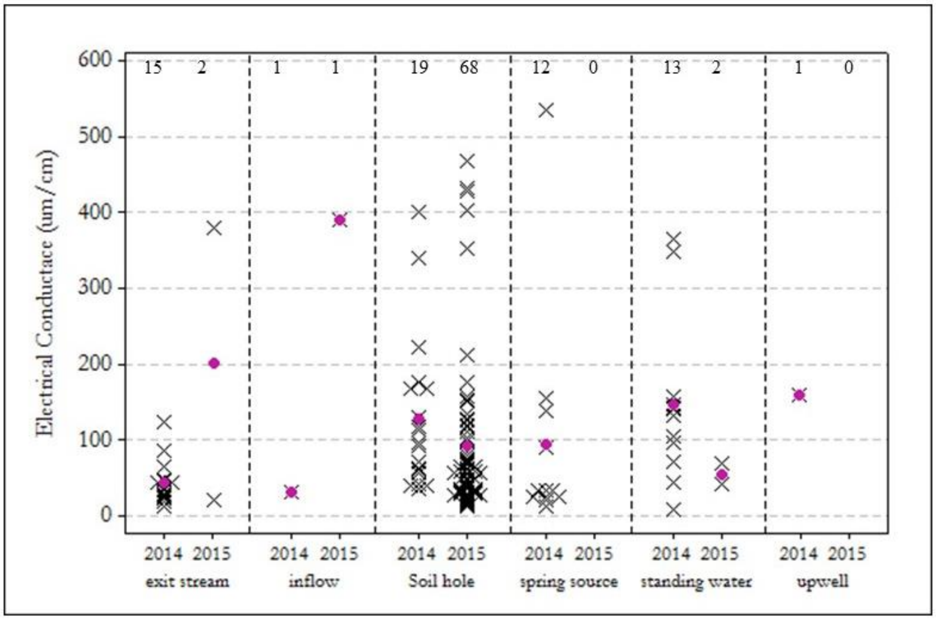
Electrical conductance is used as an index of the concentrations of ions in water: high conductance values indicate high concentrations of electrically-charged ions. Electrical conductance measurements were made at the same time as the pH measurements. Recorded values ranged from 8 μS/cm[7] to 853 μS/cm (Figure 23).

Examination of the 2014 measurements (Figure 23) suggests that, as with the pH measurements, conductance values differ among sampling locations within a site. Statistical testing (Kruskal-Wallis test; Appendix B, Table B-9) of the measurements from streams leaving the site (exit streams), soil holes, spring sources, and standing water shows that electrical conductance differs significantly among these locations ($p = 0.000$). (Measurements from inflow streams and upwelling vents were excluded from the analysis due to low numbers of samples.) Pairwise-comparisons of the measurements from those four locations (Appendix B, Table B-10) show that conductance values from streams exiting sites are significantly lower ($p = 0.05$) than values from standing water, but not from values measured in spring sources or in soil holes. The values measured in standing water also do not differ significantly from measurements in soil holes or spring sources.

[7] microSiemens / centimeter

Figure 23. Electrical conductance values recorded in 86 fens in 2014 or 2015, in different locations within a site.

Xs are individual values. Colored circles are means. Numbers of samples are shown across the top of the graph.

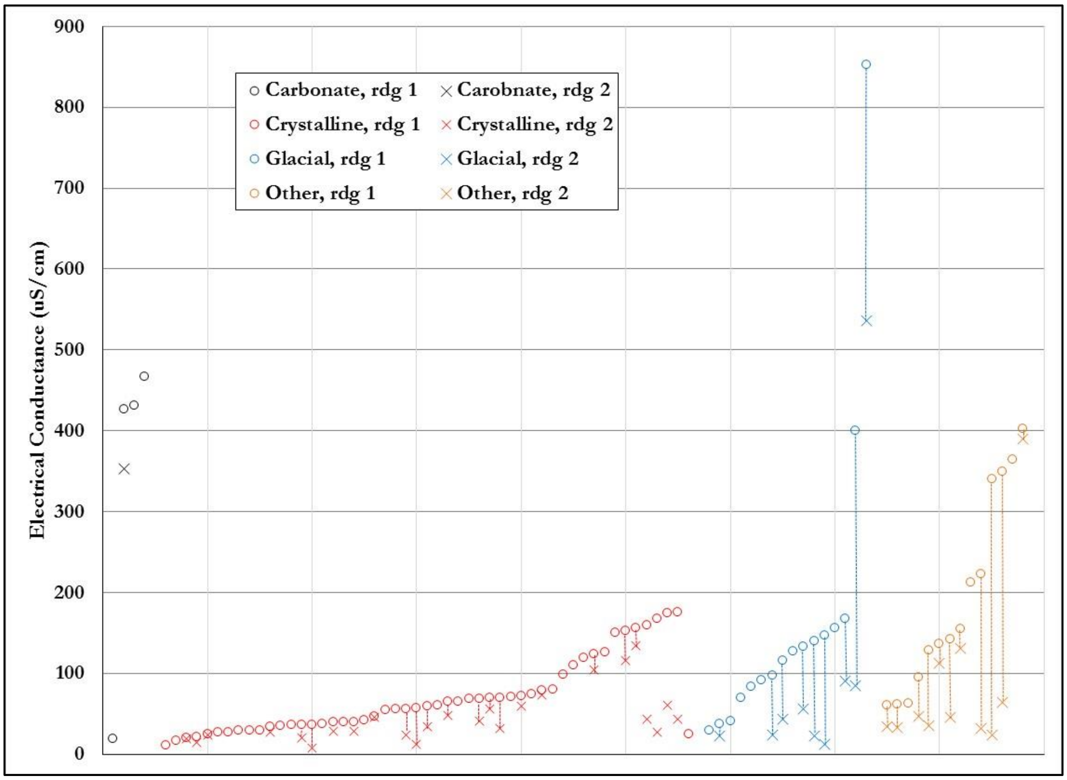


In contrast to the pH measurements (Figure 16), the electrical conductance measurements do not seem to have been consistently higher in one year than in the other (Figure 18). There are sufficient measurements from soil holes to test for a statistically-significant difference between the two years, and a two-sample t-test (Appendix B, Table B-11) indicates that the mean measurements do not differ between 2014 and 2015 ($p = 0.178$).

Electrical conductance values from sites on different substrates overlapped a great deal, but the data suggest that conductance may be higher in the fens on carbonate rocks and on some of the "Other" substrates (Figure 24). The carbonate rocks on the Bighorns consist of limestone and dolomite, which should be expected to yield relatively high concentrations of calcium and magnesium ions to the groundwater. The relatively high values on "Other" substrates may also be due to the sites lying on carbonate-rich rocks, but determining whether this is the case probably would require information obtained on-site. Three very high values on glacial substrates are puzzling, and may indicate erroneous readings. But given the care with which the testing meter was calibrated and used (as described above), this is not a certain explanation.

Figure 24. Electrical conductance values measured in sites on different types of substrate.

Each circle represents one measurement made at a site, and each X represents a second measurement (where conductance was measured in more than one location in a site). Dotted lines connect the two measurements from the same site. Most sites with two measurements are from 2014. Sites are arranged within each substrate-type from lowest first measurement on left to highest first measurement on right.



7. Signs of Disturbance

The GDE Level I field guide lists 62 types of disturbance (most anthropogenic) that are to be recorded in wetlands. Forty-six of these were recorded in this project (Table 18). The categories are not mutually exclusive, and many sites had evidence of several types of disturbance.

Evidence of disturbance by animals was documented in 90% of fens and of other GDEs (Figure 25). This disturbance was predominantly grazing or browsing of plants in the sites by ungulates (Figure 26). Signs of trampling were noted in nearly 30% of the non-fen GDEs but only 10% of fens. Animal trails, beaver gnawing, and other animal disturbance signs were rare.

Table 18. Categories and sub-categories of disturbance signs recorded in wetlands.

"Label in Figures" shows the abbreviations used in Figure 25 through Figure 32; "none" in that column indicates a type of disturbance not encountered or combined with another type.

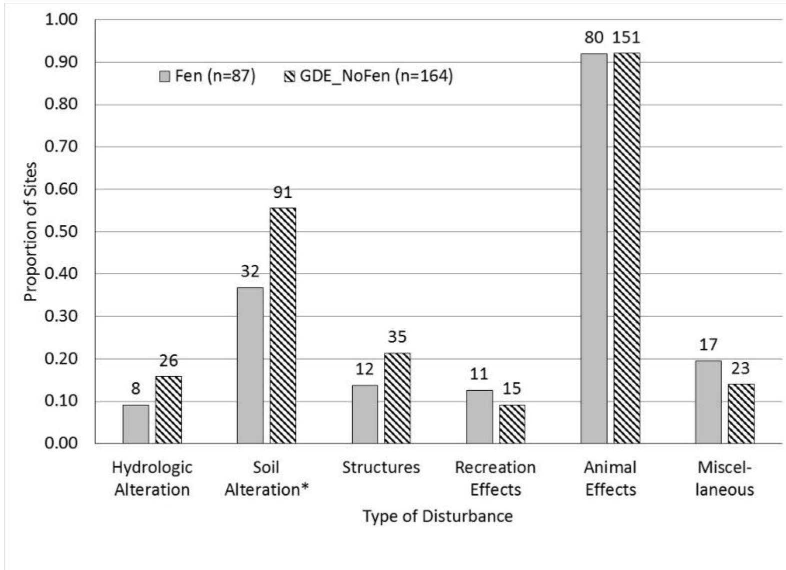
Type of Disturbance	**Label in Figures**
Hydrologic Alteration	
Water permanently diverted away from the wetland	Diversion, Perm.
Water diverted but eventually returns to the wetland	Diversion, Temp.
Extraction of surface water or groundwater upgradient from the wetland	Extraction, Upgrad.
Extraction of surface water or groundwater downgradient from the wetland	Extraction, Downgrad.
Extraction of water within the wetland	Extraction W/in Site
Extraction of water at a spring source	Extraction At Spring
Flow regulated by impoundment or dam	Regulated Flow
Evidence of flooding	Flooding
Wells	Wells
Other	Other
Pollution	*none*
Soil Alteration	
Channel erosion	Channel Erosion
Compaction	Soil Compaction
Displacement of soil	Soil Displacement
Erosion (general)	Soil Erosion
Excavation	Soil Excavation
Ground disturbance (general)	Ground Disturbance
Mining	Mining
Pedestals or hummocks created by people or animals	Pedestals, Animal
Pedestals (small-scale, rain-splash induced)	Pedestals, Rain
Soil pipes	Soil Pipes
Rill erosion	Rill Erosion
Vehicle ruts	Vehicle Ruts
Wind erosion	Wind Erosion
Soil mixing	Soil Mixing
Soil removal (peat mining)	Soil Removal
Trails (by people or animals)	Trails
Other	Other
Debris flow	*none*
Deposition	*none*
Slump	*none*

Table 18 (continued).

Splash erosion, creating soil crust	*none*
Evaporate deposition	*none*
Gully erosion	*none*
Mass wasting	*none*
Sheet erosion	*none*
Structures	
Buried utility corridors	Buried Utilities
Enclosure (such as spring house, spring box, or concrete enclosure)	Enclosure
Exclosure fence	Fence
Pipeline	Pipeline
Road (includes construction and maintenance)	Road
Other	Other
Erosion control structure	*none*
Oil and gas well	*none*
Point source pollution	*none*
Power lines	*none*
Recreation Effects	
Camp sites	Campsite
Tracks or trails by vehicles	Vehicle Tracks
Other	Other
Animal Effects	
Beaver activity	Beaver
Grazing or browsing (by ungulates)[(1)]	Ungulate Grazing, Browsing
Trails by animals and people	Animal Trail
Trampling (by ungulates, native or non-native)	Trampling
Other	Other
Grazing or browsing by wild ungulates[(1)]	*none*
Grazing or browsing by livestock[(1)]	*none*
Feral animal	*none*
Miscellaneous	
Fire	Fire
Tree cutting (timber harvest or other)	Tree Cutting
Refuse disposal	Refuse
Other	Other

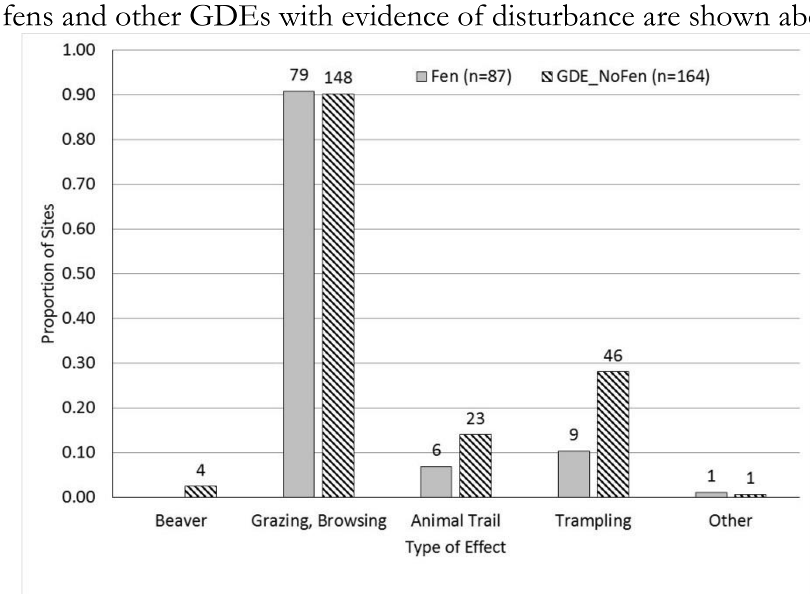
(1) "Grazing or browsing by wild ungulates" and "Grazing or browsing by livestock" were combined into the general "Grazing or browsing by ungulates" category because in many sites the types of animals could not be determined.

Figure 25. Proportions of sites with fens and sites with other GDEs in which evidence of six major categories of disturbance was noted.
The numbers of fens and other GDEs with evidence of disturbance are shown above each bar.



* Soil alteration was documented in a significantly greater proportion of non-fen GDEs than in fens ($p < 0.025$). No significant differences ($P < 0.05$) were found for other categories of disturbance.

Figure 26. Proportions of sites with fens and sites with other GDEs in which evidence of different types of disturbance by animals was noted.
The numbers of fens and other GDEs with evidence of disturbance are shown above each bar.



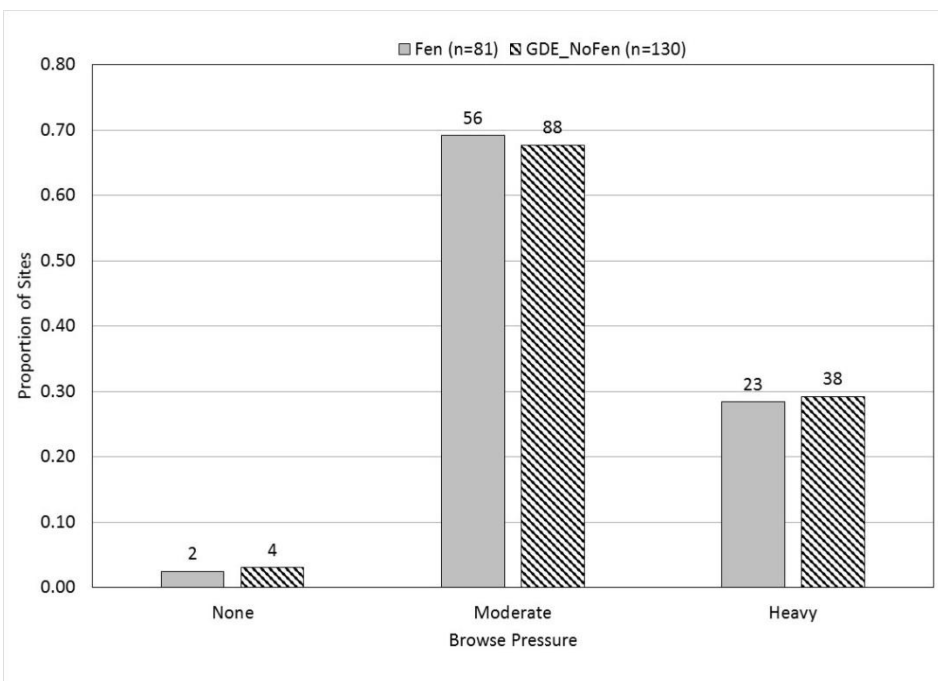
The Bighorn National Forest resource managers are especially interested in knowing the degree to which willows are being browsed, so we augmented the disturbance checklist in the standard GDE Level I sampling methods by estimating the intensity of browsing in 211 of the sample sites (81 fens and 130 other GDEs). We used three qualitative categories (Table 19). In each of the site-types, nearly 70% of the sites showed signs of moderate browsing on willows, and nearly 30% showed signs of heavy browsing (Figure 27). Only a handful of the fens or other GDEs had no signs of browsing on willows.

Table 19. Classes used for recording the amount of browsing on willows at a site.

Value Recorded	Meaning
None	None of the willows in the wetland have been browsed
Moderate	Twigs on some plants have been browsed, but few (if any) shrubs have a hedged growth-form or have been shortened in stature due to browsing
Heavy	Many or all willows have a hedged growth-form or short stature from browsing

Figure 27. Degree of browsing on willows in the fens and other GDEs.

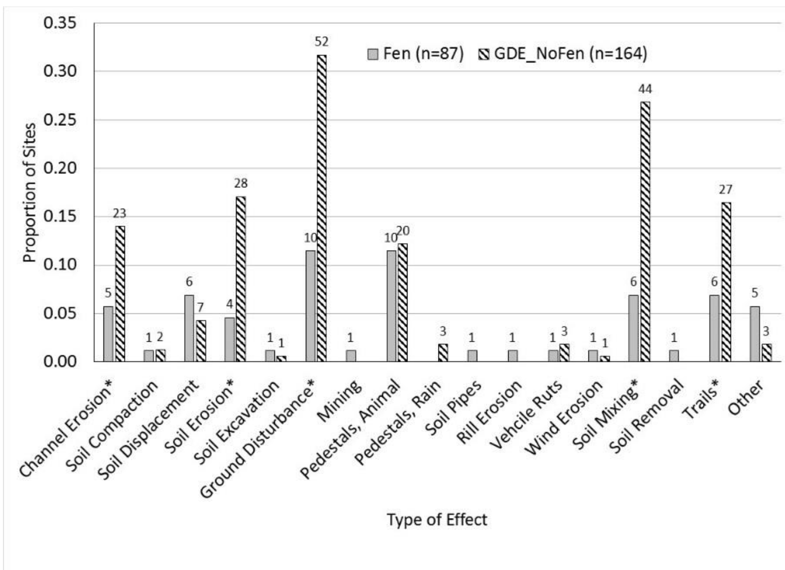
The numbers of fens and other GDEs with evidence of disturbance are shown above each bar.



Soil alteration is the second-most common category of disturbance documented in the GDEs (Figure 25). Soil alteration was documented in a higher percentage of non-fen GDEs (55%) than in fens (37%). (This is the only category of disturbance for which the proportion of fen sites where the disturbance was documented differs significantly from the proportion of non-GDE sites[8].) The higher proportion of soil alteration broadly in the non-fen GDEs is due to significantly higher proportions ($P < 0.05$) of five types of soil alteration (Figure 28): channel erosion, general soil erosion, ground disturbance, soil mixing, and trails[9].

Figure 28. Proportions of sites with fens and sites with other GDEs in which evidence of different types of soil alteration was noted.

The numbers of fens and other GDEs with evidence of disturbance are shown above each bar.



* Proportion of fens with this soil alteration differed significantly ($P < 0.05$) from proportion of non-fen GDEs.

Evidence of the remaining four categories of disturbance was relatively rare. Hydrologic alteration was documented in only 14% of sites (9% of fens and 16% of non-fen GDEs) (Figure 25). None of the individual types of hydrologic alteration was found at more than 10% of sites (Figure 29). Structures were found at 19% of all sites (14% of fens and 21% of other GDEs) (Figure 25). Individual types of structures, too, were found at < 10% of sites (Figure 30). Recreation was the least-common cause of disturbance, recorded at only 13% of fens and 9% of other GDEs (Figure 25). Vehicle tracks were the most common form of recreation disturbance noted, but even these were found in few sites (Figure 31). Miscellaneous disturbances were noted in

[8] Chi-square contingency analyses. For soil alteration, $P < 0.005$; for other disturbance categories, $P > 0.05$. See Appendix B, Table B-12

[9] Chi-square contingency analyses. Only these 5 types of soil alteration were tested. See Appendix B, Table B-12.

16% of all sites and were slightly more common in fens (20%) than other GDEs (14%) (Figure 25). Cutting of trees accounted for nearly all of this miscellaneous disturbance (Figure 32).

Figure 29. Proportions of sites with fens and sites with other GDEs in which evidence of different types of hydrologic alteration was noted.
The numbers of fens and other GDEs with evidence of disturbance are shown above each bar.

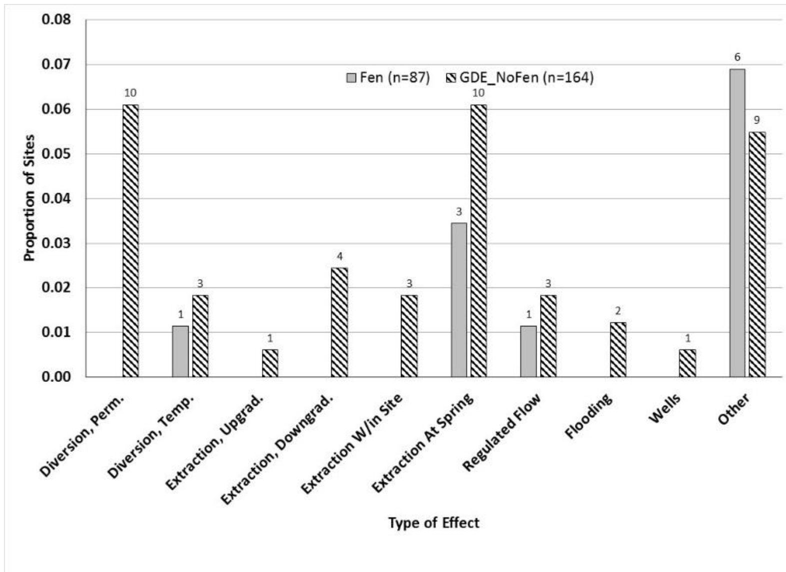


Figure 30. Proportions of sites with fens and sites with other GDEs in which structures were documented.
The numbers of fens and other GDEs with evidence of disturbance are shown above each bar.

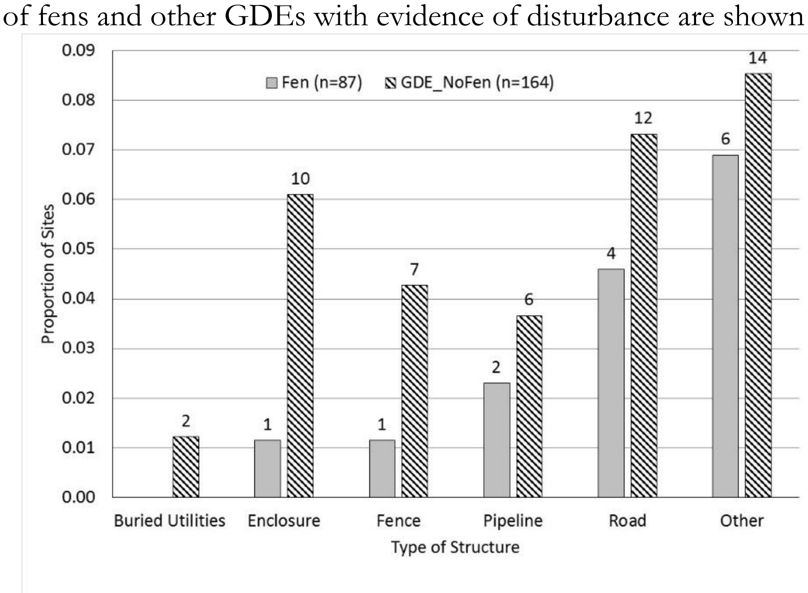


Figure 31. Proportions of sites with fens and sites with other GDEs in which evidence of disturbance from recreation was documented.
The numbers of fens and other GDEs with evidence of disturbance are shown above each bar.

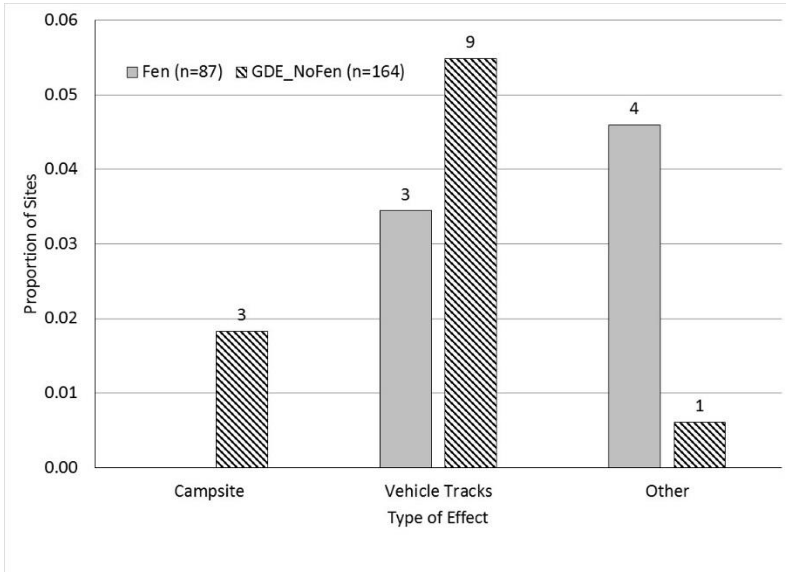
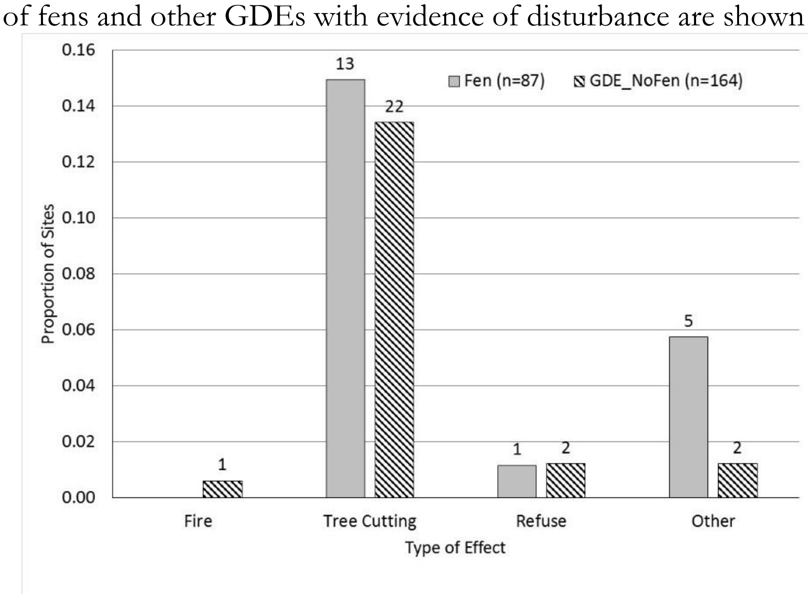


Figure 32. Proportions of sites with fens and sites with other GDEs in which evidence of miscellaneous disturbances was documented.
The numbers of fens and other GDEs with evidence of disturbance are shown above each bar.



8. Management Indicator Tool

Proportions of Sites With Possible Need For Management

The management indicator tool is used to identify sites where monitoring or management action may be needed to prevent or repair damage to wetland features and function. The tool consists of statements about 25 indicators. Each statement posits that there is no evidence of damage or threat to the feature or function that requires management action. The members of a field crew (after discussion) give one of four answers to each indicator statement: (1) "True (Yes)", the statement is true and there is no apparent need for management action; (2) "False (No)", the statement is false and there appears to be a need for management action; (3) "Does Not Apply"; (4) "Unable to Assess". Values of "False", "Does Not Apply", or "Unable to Assess" are to be explained in notes.

The management indicator tool is related to the list of disturbances in that they evaluate largely the same set of disturbances. The list of disturbances simply documents signs of different types of disturbance. In contrast, the management indicator tool requires the crew to decide whether the disturbance is serious enough to impair the status or function of the wetland.

While the full management indicator tool in the GDE Level I Inventory manual includes 25 indicators, only the first 18 of those were evaluated in this project (Table 20). These 18 indicators are grouped into four categories: Hydrology, Geomorphology and Soils, Biology, and Disturbance. The seven indicators that we did not evaluate in this project are in a Management Context category.

We calculated the frequency of "False" answers in the four categories of indicators to get a sense of how common the need for management actions is in fens and in other GDEs. For all four categories, the proportion of non-fen GDEs with at least one "False" answer was substantially greater than the proportion of fens (Figure 33).

"False" answers, suggesting the need for management action, were greatest for the three indicators in the Geomorphology and Soil category; 35% of non-fen GDEs and almost one-tenth of fens received a "False" answer for at least one of the three indicators in that category. In the non-fen GDEs, those answers were divided quite unevenly among the three indicators (Figure 34). Impacts to soil integrity were noted in between 25% and 30% of these sites, which is substantially lower than the 55% of non-fen GDEs in which signs of soil alteration were recorded (Figure 25). Approximately 20% of the non-fen GDEs had effects on the runout channel substantial enough to warrant management action (Figure 34). In the fens, the proportion of "False" answers was low for all three of the indicators (Figure 34).

"False" answers were recorded for indicators in the Biology category in approximately 20% of the non-fen GDEs (Figure 33). Most of these answers were given because vegetation composition was different from that expected in a wetland site (due to the presence of upland plants) or because invasive plants were present (Figure 35). In very few fens did the biological indicators suggest a need for management action (Figure 33). Two of the biological management indicators -- *TES, SOI/SOC, Focal Floral Species* and *TES, SOI/SOC, Focal Faunal Species* -- are problematic to assess in a survey of previously-unstudied sites, because they ask whether anticipated species are present. We had no information from previous plant and animal surveys to tell us where we should anticipate the target species, so the crew answered "Unable to Assess" for these indicators in most of the sites.

Management indicators in the Disturbance category received "False" answers for approximately 10% of the fens (Figure 33). "False" answers were rare for each of the five disturbance indicators, including Herbivory Effects (Figure 36). So, even though evidence of grazing or browsing was found in 90% of the fens (Figure 26), the data suggest that in only a few

Table 20. The 18 management indicators evaluated in the wetlands.

Hydrology	Label in Figures
1. Aquifer function. No evidence that the aquifer supplying groundwater to the site is being affected by withdrawal or loss of recharge	1_AquiferEffects
2. Watershed Function. Within the watershed, no evidence suggests upstream or downstream hydrologic alteration that could adversely affect the GDE.	2_Watershed Effects
3. Water Quality. Changes in quality (surface or subsurface) are not affecting the GDE.	3_WQEffects
Geomorphology and Soils	
4. Landform stability. No evidence suggests that human-caused mass movement or other surfaces disturbance affects GDE site stability.	4_LandStability
5. Runout Channel. Channel, if present, functions naturally and is not entrenched, eroded, or otherwise substantially altered.	5_RunnoutEffects
6. Soil Integrity. Soils are intact & functional. E.g., saturation is sufficient to maintain hydric soils (if present); no excessive erosion or deposition.	6_SoilIntegrity
Biology	
7. Vegetation Composition. Site has anticipated cover of plant species associated with this environment; no evidence that upland species are replacing wetland species.	7_VegComposition
8. Vegetation Condition. Vegetation exhibits seasonally-appropriate health and vigor.	8_VegCondition
9. TES, SOI/SOC, Focal Floral Species. Anticipated plant species are present.	9_FloraFocTES
10. Faunal species. Anticipated aquatic & terrestrial animal species associated with this environment are present.	10_FaunaSpecies
11. TES, SOI/SOC, Focal Faunal Species. Anticipated faunal species are present.	11_FaunaFocTES
12. Invasive Species. Invasive plants and animals are not established at the site.	12_Invasive Species
Disturbance	
13. Flow Regulation. Flow regulation is not adversely affecting the site.	13_FlowRegulation
14. Construction & Road Effects. Construction, reconstruction, or maintenance of physical improvements, including roads, are not adversely affecting the site.	14_ConstrRoad Effects
15. Fencing Effects. Protection fencing and exclosures are appropriate and functional.	15_FenceEffects
16. Herbivory Effects. Herbivory is not adversely affecting the site.	16_HerbEffects
17. Recreation Effects. Recreation uses, including trails, are not adversely affecting the site.	17_RecEffects
18. Other Disturbances. Wildland fire, disease, windthrow, avalanche, or other disturbances are not adversely affecting the site.	18_OthDistEffects

Figure 33. Proportions of sites with fens and sites with other GDEs in which at least one indicator statement in a category received a “False” answer.

The numbers of fens and other GDEs with “False” answers are shown above each bar.

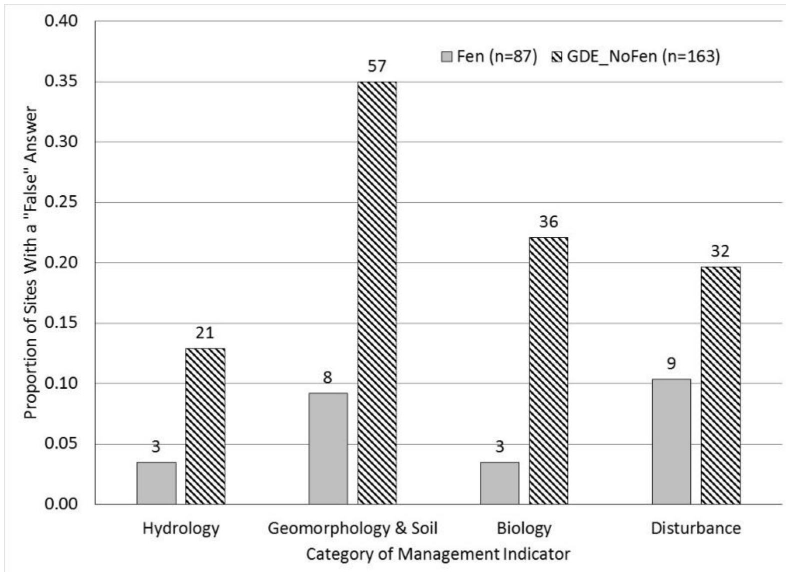


Figure 34. Proportions of fens and other GDEs in which each Geomorphology & Soil category indicator received a “False” answer.

The numbers of fens and other GDEs with “False” answers are shown above each bar.

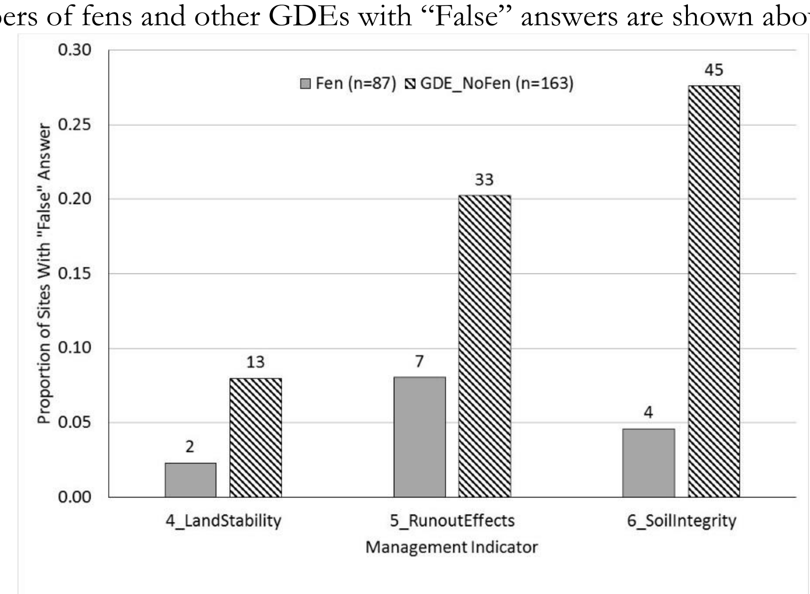


Figure 35. Proportions of fens and other GDEs in which a Biology Category indicator received a "False" answer.

The numbers of fens and other GDEs with "False" answers are shown above each bar.

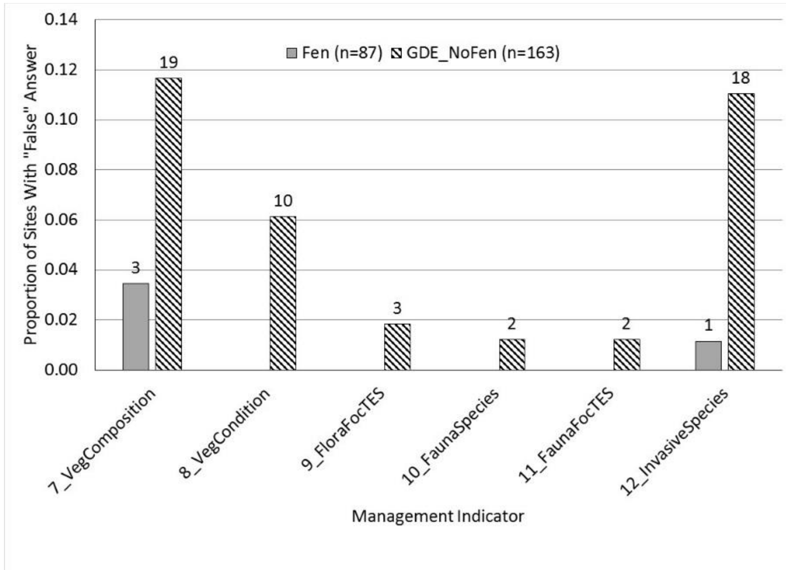


Figure 36. Proportions of fens and other GDEs in which a Disturbance Category indicator received a "False" answer.

The numbers of fens and other GDEs with "False" answers are shown above each bar.

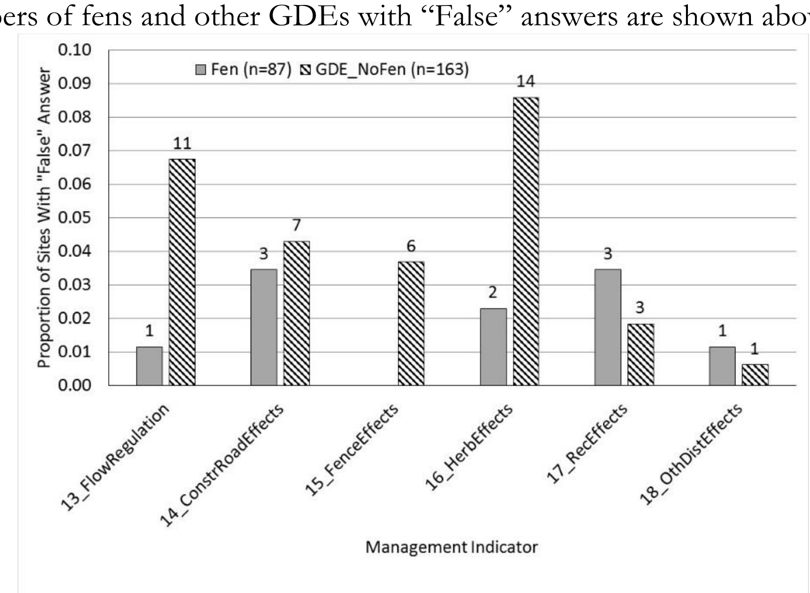
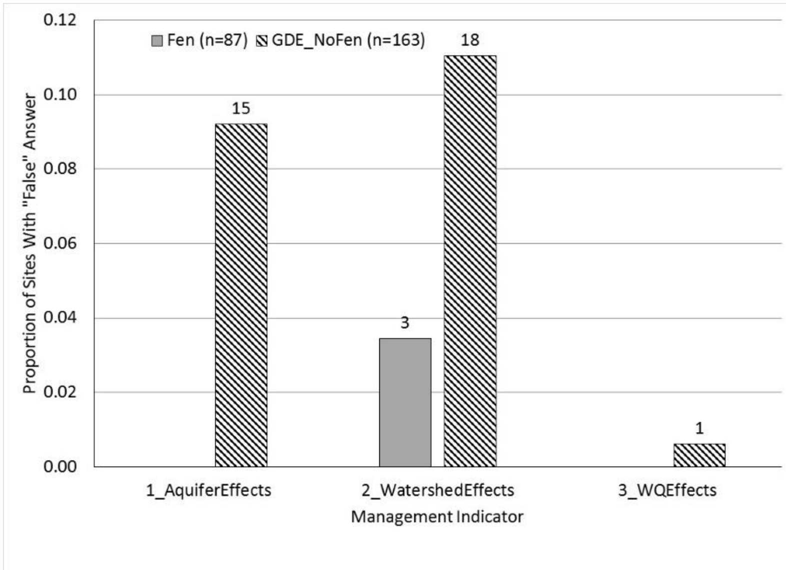


Figure 37. Proportions of fens and other GDEs in which a Hydrology Category indicator received a "False" answer.

The numbers of fens and other GDEs with "False" answers are shown above each bar.



of them did the field crew members conclude that the grazing or browsing is heavy enough to warrant management action. This explanation applies to the non-fen GDEs as well: 90% of them had signs of grazing or browsing (Figure 26), but in fewer than 9% of those sites did the field crew rate the grazing or browsing significant enough to warrant management action (Figure 35).

In the Hydrology category, between 10% and 15% of the non-fen GDEs received "False" answers (Figure 33). All but one answer was for the aquifer effects or the watershed effect indicators (Figure 37). This is nearly the same proportion of non-fen GDEs in which signs of hydrologic alteration were noted (Figure 25); the field crew apparently interpreted the signs of hydrologic alteration as serious enough to warrant management action. This is not the case for the fens: nearly 10% of fens had evidence of hydrologic alteration (Figure 25), but in less than 5% was a "False" answer given for a hydrology management indicator (Figure 33).

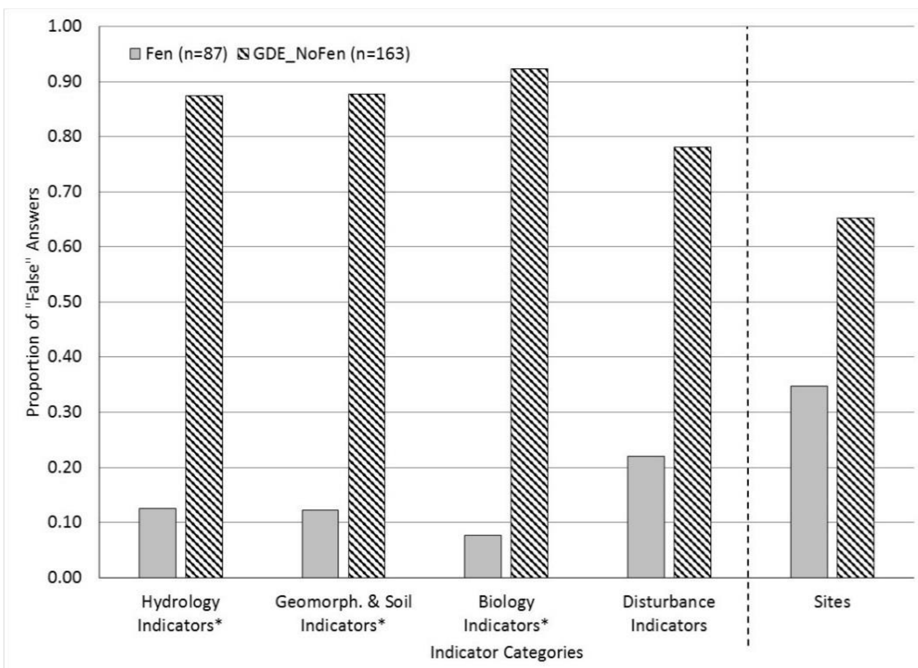
Management Indicators in Fens Vs. Other GDEs

Figure 33 through Figure 37 show that non-fen GDEs had a higher proportion than fens of "False" answers to each of the four categories of management indicator, suggesting that management actions to prevent or repair damage to wetland values are needed more in the non-fen GDEs than in the fens. Unfortunately, the proportion of fens with "False" answers for a management indicator cannot be compared more rigorously to the proportion of other GDEs with "False" answers, because it's unclear what proportions we should expect.

We do know, though, what proportion of the "False" answers for a management indicator should come from fens and what proportion from other GDEs. (Note that this is different from the proportion of fens or of other GDEs that have "False" answers for a management indicator.) If fens and the other GDEs are equal in their need for some type of management action, then whether that management indicator was answered "False" for a GDE should have nothing to do with whether it was a fen or some other GDE-type. The "False" answers should come randomly from the sites. Thirty-five percent of the GDEs are fens and 65% are other GDEs, so we expect that 0.35 of the "False" answers should come from fens and 0.65 of the "False" answers from other GDEs.

Figure 38 shows, for each category of management indicators, the proportion of the "False" answers that came from fens and the proportions that came from other GDEs. The figure also shows, for reference, the proportion of all the sites that is fens and the proportion that is other GDEs -- that is, the expected proportions for the "False" answers. For every category of management indicator, the proportion of the "False" answers from fens is smaller than expected, and the proportion from other GDEs is larger than expected.

Figure 38. Proportions of the "False" answers in each indicator category in fens or in other GDEs. "Sites" bars show the proportions of all sites that are fens or other GDEs.



* Statistically significant (P ≤ 0.05) difference, Fen vs. GDE_NoFen

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The deviations of observed proportions from the expected proportions were tested for statistical significance with chi-square goodness-of-fit tests (Zar 2010)[10]. These tests show that the proportions for the hydrology indicators, geomorphology and soil indicators, and biology indicators are significantly different from expected, but the proportions for the disturbance indicators are not. The data indicate, then, that there is less need for management actions to correct problems with

[10] Details of the chi-square tests are shown in Table B-14.

hydrological features, geomorphology, soils, and biological features in fens than in other GDEs. But this not true for the disturbances addressed by the management indicators.

IV. Discussion

A. Groundwater-Dependent Ecosystems in the Bighorn National Forest

Our sampling at 332 sites affords an understanding of the distribution and selected features of groundwater-dependent ecosystems (GDEs) throughout the Bighorn National Forest outside of the Cloud Peak Wilderness area. Our data confirm the existing impression that GDEs are concentrated in the glaciated central portion of the Bighorns (Winters *et al.* 2004), but they also show that GDEs occur in lower density all the way to the northern Forest boundary (Figure 4).

The National Wetland Inventory (NWI) digital map of wetlands is the framework for our sampling sites. In the elevation range where we sampled, between 7,545 feet (1,560 meters) and 9,515 feet (2,900 meters), the likelihood that a mapped wetland contains a GDE appears to be unrelated to elevation. Slope does have an influence, though, as GDEs occur primarily on gentle slopes (less than 13%, or 6^0). The size of the wetland mapped by the NWI also appears to influence the likelihood that a GDE is present, in that very small wetlands (< 0.1 ha) are less likely than expected to contain GDEs, while wetlands > 0.5 ha are more likely than expected to contain GDEs (Figure13).

The great majority of the GDEs on the Bighorns are either diffuse springs or seeps on gentle slopes emerging from unconfined aquifers (helocrenes) or flowing springs that emerge directly into stream channels (rheocrenes) (Figure 20). Other types, such as springs emerging into pools (limnocrenes) or wet meadows with shallow groundwater (hypocrenes) are rare in the NWI polygons.

Most GDEs are browsed or grazed (nearly 90% show some evidence of browsing or grazing), but browsing heavy enough to produce hedged growth-form in shrubs is more limited (to about 30% of the GDEs; Figure 27). Assessment of disturbance (section III.B.6) and application of the management indicator tool (section III.B.7) suggest that some form of soil disturbance affects between 30% and 35% of the GDEs on the Forest (Figure 25). The cause is trampling heavy enough to produce mixing or erosion of the surface layers (Figure 28). Other forms of disturbance are less common: our data show that trees have been cut in about 15% of GDEs (Figure 32), fewer than 20% contain any type of structure (Figure 25), and hydrologic conditions have been altered in fewer than 20% as well (Figure 25).

B. Fens in the Bighorn National Forest

1. Distribution and Environment

Our data suggest that fewer than one in five GDEs outside of the Cloud Peak Wilderness area qualify as fens using the customary criterion of peat at least 40 cm thick (Table 7). But by the criterion of 20 cm of peat, as used in the U.S. Fish and Wildlife Service's definition (USDI, Fish and Wildlife Service, 1999), nearly a third of GDEs (31%) qualify as fens. Fens are concentrated in the central glaciated portion of the Bighorns (Figure 8), as previous investigation has suggested (Heidel 2011), but they occur in the northern half of the national forest and on other substrates as well.

The influence of wetland size (as mapped by NWI) is even stronger on the presence of fens than it is on the presence of GDEs in general. Fens occur in wetlands < 0.1 ha much less often than expected, but occur in wetlands > 1 ha more often than expected (Figure 15). It's unclear what the functional relationship is between wetland size and fen presence, if there is one. The substantial proportion of sites without fens among the smallest wetlands may be due to a high rate of error in the mapping of the smallest wetlands. If this is true, then fens are unlikely to be found in the smallest NWI wetland polygons because many of those polygons are not wetlands, not because fens are unlikely to form in small wetlands. Alternatively, the very small wetlands may have been accurately mapped, but small wetlands may be short-lived or ephemeral, and disappear before peat can accumulate.

Elevation seems to have no effect on the likelihood of a fen developing in a wetland (Figure 12), within the elevation zone that we sampled (between 7,545 feet [1,560 meters] and 9,515 feet [2,900 meters]). Fens (like other GDEs) occur on gentle slopes (< 13%, or 6^0), but within the range of 0% to 13%, slope steepness apparently has no effect on whether a fen develops in a wetland.

We can generalize from the data to say that fens are most likely to be found in larger NWI-mapped wetlands on gentle slopes within the central region of crystalline bedrock and glacial deposits, and that elevation within a certain range has no effect on the likelihood that a fen is present. But such generalizations are of little use in selecting the wetlands that are especially worth visiting in a search for fens.

After the 2014 field season, we thought we had a promising tool for selecting such wetlands. That first season's data showed a statistically significant, positive relationship between the occurrence of fens and two variables, elevation and location on certain common land units (areas identified by soil-type, landform, and vegetation). Given these relationships, we constructed a logistic regression model that predicted the odds that wetland contains a fen, based on its elevation and whether or not it occurred on one of the common land units. We then used that model to calculate the odds for each of the remaining potential study sites, and biased the selection of the 2015 sampling sites toward those with relatively large odds.

Unfortunately, when we analyzed the data from 2015, we found that fens were not more likely to occur at sites with larger odds. Hence the logistic regression model appears to have no value as a tool for using GIS layers to select sites for field study. The model fit the 2014 data well, but that fit did not make it useful for selecting new sites.

2. Hydrologic Features

As is true for GDEs generally, fens on the Bighorns apparently are associated overwhelmingly with groundwater that surfaces as flowing springs, either diffuse springs or seeps (helocrenes) or more-obvious springs that form streams (rheocrenes) (Figure 20). Very few fens are associated with groundwater that emerges in pools (limnocrenes) or with buried springs that create wet meadows but do not emerge at the surface (hypocrenes).

The pH of the water in fens seems to differ depending on where measurements are made (Figure 21). Our data suggest that water in the peat (as sampled in soil-core holes) is more acidic (pH values generally between 5.5 and 6.5) than water issuing from springs and flowing into the fen or water in streams flowing out of the fen (pH values for both generally being >7.0). Water standing in the fen is intermediate in acidity. These relationships hold for both the 2014 and 2015 data, even though the 2014 values are higher than the 2015 values, for reasons that we cannot explain.

Electrical conductance of water in fens is generally low (few of our measurements exceeded 200 μS/cm: Figure 23), and it appears to vary among different locations within a fen. The pattern of this variation is hard to summarize: streams exiting fens appear to have lower conductance than standing water, but other differences are very slight. As might be expected, conductance appears to be higher in fens on carbonate substrates (Figure 24), likely due to relatively high concentrations of calcium and magnesium ions dissolved out of the limestone and dolomite. This is a tentative observation that would benefit from pH measurements at more sites.

3. Soil Features

The soil feature common to fens as we use the term is a layer of peat at least 20 cm thick. In the overwhelming majority of fens, the organic layer is uppermost and overlies at least one mineral horizon. Our observations suggest that most peat in the Bighorn fens can be considered fibric, but because we concentrated on simply documenting the presence and thickness of peat and not on classifying it into different types, we are unable to say with certainty how common hemic and sapric peat are in these fens.

The boundary between the organic layer and the underlying mineral layer often is indistinct, with the proportion of organic material decreasing gradually and the proportion of mineral material increasing gradually with depth. Underlying mineral layers usually are clays or sands.

Strongly-reducing conditions seem to be rare: we recorded a gleyed matrix in only one fen, and did not encounter hydrogen sulfide gas in any. Fluctuating water tables also appear to be rare, as we recorded redoximorphic concentrations in only four sites with fens and redoximorphic depletions in just one.

4. Vegetation Features

Given the general nature of the vegetation data collected with the GDE Level I sampling method, we are unable to describe in detail the species composition of the Bighorn fens. But the data do allow us to say that these are primarily graminoid fens (Figure 16) in which water sedge (*Carex aquatilis*) and Northwest Territory sedge (*C. utriculata*) are the most common species and usually contribute the most cover (Table 10). Shrubs, specifically diamondleaf willow (*Salix planifolia*), also are a major component of the vegetation in many fens. Forbs often are present but in smaller amounts than the graminoids or shrubs; white marsh marigold (*Caltha leptosepala*) is usually the most common forb. Mosses, too, are common or abundant in nearly all fens (Figure 17). *Sphagnum* spp. are present in over half of the fens (Table 13) but our data do not show the abundance of *Sphagnum* mosses relative to other mosses. Trees, in contrast, are minor components of the vegetation in fens on the Bighorns.

In terms of the relative dominance of plant growth-forms and the most common dominant species within growth-forms, there appears to be no clear distinction between fens and other GDEs. Fens have slightly greater relative dominance by graminoids, greater relative dominance by shrubs, and less relative dominance by forbs (Figure 16). Water sedge and Northwest Territory sedge are the most common dominant graminoids in both types of wetlands, but other species (especially bluejoint reedgrass, *Calamagrostis canadensis*) are more often dominant in non-fen GDEs than in fens (Table 10). The same can be said for shrubs: diamondleaf willow is most often the dominant shrub in both types of wetlands, but shrubs of other wetland-affinity classes (facultative wetland, facultative, facultative upland, and even upland) are more common in non-fen GDEs. Fens and other GDEs also share many of the same dominant forbs, although *Caltha leptosepala* and elephanthead lousewort (*Pedicularis groenlandica*) are more often dominant in fens, while arrowleaf ragwort (*Senecio triangularis*) stands out as being dominant more often in non-fen GDEs. Among all of these growth-forms, obligate hydrophytes dominate fens more often than they do non-fen GDEs, and the opposite is true for facultative hydrophytes (Table 11).

It appears that the conclusion reached by Driver (2010) from an analysis of detailed species composition data from Rocky Mountain National Park wetlands holds for the Bighorns as well: there is no clear difference in the vegetation between fens (wetlands with $\geq$ 20 cm of peat) and other wetlands (those with < 20 cm of peat).

The clearest distinction in vegetation between fens and other GDEs in the Bighorns appears to be found in the moss component. Mosses are present in nearly all fens and other GDEs and, in both types, are often common (Figure 17). But in many fens, mosses can be considered abundant, while they rarely are abundant in other GDEs; and in contrast, mosses often are minor components of the vegetation in non-fen GDEs, but rarely are they minor components in fens. So, if mosses form substantial cover throughout a wetland, it probably is a fen; but if mosses are present only as scattered individuals or a few small patches, the wetland is unlikely to be a fen. *Sphagnum* spp. mosses are associated more with fens than with other GDEs (Table 13): the presence of *Sphagnum* means that a wetland likely is a fen, but the absence of *Sphagnum* is not a reliable indicator that it is not a fen.

5. Sensitive/Rare Plant Species

Heidel (2011) discusses ten vascular plant species known from fens on the Bighorns and that either are on the Forest Service's sensitive species list or are rare in the Bighorns. All ten were target species in this project (Table 5). Three of the species -- mud sedge (*Carex limosa*), russet cottongrass (*Eriophorum chamissonis*), and lesser bladderwort (*Utricularia minor*) -- are present in fens throughout the central glaciated portion of the Bighorns. The other seven species are much less common: woodland horsetail (*Equisetum sylvaticum*), lesser panicled sedge (*Carex diandra*), Sartwell's sedge (*Carex sartwellii*), slender cottongrass (*Eriophorum gracile*), northern blackberry (*Rubus acaulis*), English sundew (*Drosera anglica*), and white-stem pondweed (*Potamogeton praelongus*). Heidel (2011, page 60) suggests that these rare or sensitive species be considered as a group, and that management be focused on the fen habitat that they occupy instead of on the individual species.

6. Disturbance

Disturbance by animals (chiefly browsing or grazing) is common in fens on the Bighorns (Figure 25, Figure 26). Our data suggest that nearly three-quarters of fens show evidence of moderate browsing (some shrubs have been browsed, but few have been hedged) and over a quarter show signs of heavy browsing (many willows are hedged) (Figure 27). Soil alteration of some form apparently is less common but still affects over a third of fens (Figure 25). Recreational activities, alterations to hydrology, and presence of structures apparently affect few fens (Figure 25). Cutting of trees is uncommon (our data suggest that < 20% of fens are affected; Figure 32) and in many cases only a few trees have been cut down.

In general, fens seem to be disturbed neither more nor less than other GDEs (Figure 100). The exception is disturbances that alter the soil surface, which are more common in non-fen GDEs. The most common cause of disturbance, browsing, affects fens and other GDEs equally (Figure 102).

C. Advantages and Disadvantages of Methods Used In This Study

1. Selection of Sampling Sites

This is the second project involving WYNDD-collected information about fens in the Bighorns. The two projects were conducted for different reasons and have provided different types of information, and they complement each other.

The first project (Heidel 2011) was conducted to collect information useful in management and conservation of selected wetland plant species, and fens were considered primarily as habitat for those plants. Most sampling sites were polygons in the NWI layer, and polygons were selected that appeared, from examination of aerial photographs, to have morphological features or color patterns associated with thick accumulations of peat. (That study used the customary criterion of peat at least 40 cm thick for identifying fens.) From Heidel's study, we have a good understanding of the distribution and status of the rare plant species in fens in the Bighorn National Forest, and descriptions of several noteworthy fens.

In contrast, this project is a broader study of groundwater-dependent ecosystems (GDEs) throughout the Bighorn National Forest. Emphasis is on identifying GDEs that contain fens, and then on characterizing in general terms certain hydrologic, soil, and vegetation features of the fens, and summarizing the evidence of disturbance in them. Sampling sites were chosen from the NWI layer, but were selected with a partially-random procedure. In this project, we broadened the definition of "fen" to include wetlands with peat at least 20 cm thick. This study gives us a more comprehensive picture of the distribution and nature of GDEs and fens in the Forest, which can be used as a context for the results from Heidel's study.

When an objective of a study is to provide a general description of features (e.g., wetlands), a stratified-random method such as we used to select sampling sites has several advantages over targeted selection of sites that have certain attributes or meet certain conditions. First, we can make unbiased estimates of the features we sampled. For example, we have a better understanding of the range in peat thickness throughout wetlands in the study area than we could get by sampling only in wetlands with features thought to be associated with thick peat deposits. The same is true for major features of the vegetation: we can say that there is no clear relationship between vegetation structure and relative dominance by plant growth-forms on the one hand and presence of thick peat layers on the other.

Second, we can draw more-reliable inferences about NWI wetlands in general from the data we collected in the NWI polygons. We can, for example, extrapolate from our data to say that very small NWI polygons in the study area are unlikely to contain GDEs or fens and that very large NWI polygons likely do contain GDEs and fens, but that the relationship between polygon size and occurrence of GDEs and fens is complicated.

Third, by explicitly specifying the limitations that we placed on our selection of sampling sites, we can understand the limits on how widely we should apply our results. There are several examples of this. For one, we sampled NWI palustrine, emergent wetlands with a saturated water regime (PEMB wetlands) within an elevation range of 1560 meters (5118 feet) to 2958 meters (9705 feet). Within that elevation range, we found no relationship between presence or absence of fens and elevation. Does this mean that we can rule out such a relationship in the 1,273 NWI PEMB wetlands at elevations higher than 2958 meters? No; we can only say that nothing in our data suggests such a relationship. Similarly, our data come from wetlands within 0.13 mile (approximately 200 meters) of an open road. Several thousand PEMB polygons lie farther than that from roads, and it seems reasonable to think that increasing distance from a road reduces the likelihood of certain types of disturbance. Again, our conclusions should be applied with caution.

A procedure such as we used for selecting sampling sites is less suitable when the objective is to sample only at sites with a high probability of containing specific attributes, such as wetlands with certain rare plants. In those cases, selecting exclusively (or mostly) sampling sites where there is a high probability that the plants will be found is more efficient. Even in those cases, though, tightly restricting the sampling to certain sites may come at the cost of learning less about the range of sites that the plants occupy.

2. Field Sampling

The GDE sampling methods are designed for collecting information about a wide array of ecosystem features in a way that allows different types of wetland ecosystems to be systematically compared with one another. Because the GDE protocol is part of a national program, Forest Service biologists and managers are not limited to drawing inferences about the wetlands on the Bighorn National Forest; they can also compare those wetlands to groundwater-dependent wetlands on other national forests and grasslands where the GDE protocols are being used.

At the same time, the GDE methods give local forest staff flexibility to design sampling programs that provide them the information they most need. In our project, for example, a list of target plant species that our crews looked for was drawn from the body of information already known about rare wetland plants in the Bighorns. To the standard vegetation and disturbance information collected in the GDE Level I protocol, we added information about the presence or absence of *Sphagnum* spp. mosses, and the abundance of willow shrubs and the amount of browsing on them.

Because the sampling methods are part of the Forest Service's national GDE initiative, local staff members who want to use them can receive assistance from agency scientists in designing their sampling programs and training the people involved in their projects. The scientists with the national GDE program also help with understanding the results of GDE studies.

The GDE methods worked well in this project and, for several reasons, ought to be the methods-of-choice in most groundwater-dependent wetland surveys. But people planning to use them should be aware that collecting all of the types of information in the GDE protocol requires a crew with expertise in a variety of technical areas, and thorough training of the crew members. Our project illustrates this in several ways. The budget was sufficient for visiting a large number of wetlands and collecting information about a relatively limited number of features at each, or visiting a smaller number of wetlands and sampling each one much more thoroughly. Given the objectives of our study, we did the former, and employed a two-person crew composed of a botanist and a technician with some experience in sampling wetland soils. The training that our crew members received from the national GDE scientists enabled them to collect credible and complete information about vegetation, target plant species, peat thickness, mineral soil texture, water pH and electrical conductivity, type of GDE, and standard physical features such as slope and aspect. In contrast, the information that we recorded about geological features is incomplete and merits less confidence, because none of our crew members had backgrounds in geology and we decided that the needs of the project did not justify the time and expense needed to train them in geology.

Our experience with the GDE methods suggests that the management indicator tool is different enough from other components that it should be given special attention in the training of the sampling crew. Completing the tool requires crew members to exercise considerable judgment in deciding whether some forms of disturbance or modification to the wetland are severe enough to require action by managers. The instructions for the GDE methods caution that the management indicator tool must be validated with additional information in the office. Forest Service biologists and managers using the GDE methods may want to remove the management indicator tool from the set of components that are completed in the field in a standard survey or inventory, and have resource specialists complete it later in a subsequent survey and in the office.

Fortunately, the structure of the GDE database used for storing information collected with these methods allows for additional data to be easily added in subsequent surveys. Questionable data, too, can be strengthened with data collected in later surveys. For example, if managers on the Bighorn realize that they need good information about geological features in the sites that we visited in this study, they can have qualified Forest Service staff collect it in subsequent visits and add it to the records for the sites we sampled. Similarly, additional pH measurements can be made and the data entered into the records for these sites, and the puzzle about our 2014 pH values vs. our 2015 values perhaps cleared up.

V. USING THE RESULTS OF THIS PROJECT

A. SELECTING SITES FOR MANAGEMENT ACTION

This project has yielded information about 88 wetlands that qualify as fens by our criterion (peat $\geq$ 20 cm thick). This is a set of sites that Bighorn Forest staff can examine for those that seem to merit management action, because they either have characteristics of particular interest to resource specialists, or disturbance is impairing resource values. Different Forest Service resource specialists likely will use different criteria for selecting wetlands in these two groups. Below, we offer one way of selecting wetlands in each group.

No matter how sites are selected, the next step is to have resource specialists visit the sites to verify the information that we collected and correct errors when necessary, and to collect more complete information than the GDE Level I methods that we used provides. The boundary of the wetland (now approximated by the boundary of the NWI polygon) can be mapped more accurately, the limits of the peat deposit can be determined and mapped, additional photographs can be taken to document disturbance and features of interest, and the disturbance checklist and management indicator tool can be reviewed. The GDE Level II survey methods have been designed to collect detailed information and managers should consider using those methods, especially if they decide to start monitoring wetland features. If the GDE Level II methods are not used in those visits, then Level I data sheets should be used for recording information. The information collected with either method should be entered into the GDE database.

1. Sites With Features of Interest

If Forest Service managers are interested in making sure that large fens are receiving adequate protection from disturbance, a logical first step is to review the information we collected at each of the sites in the larger size-classes, and from that review choose the sites that seem to warrant visits. Table 24 lists the 88 sites with fens by size-class

Wetland size is only one criterion by which sites of interest can be identified. Others are abundance of willows, presence of *Sphagnum* spp. moss, and presence of the target vascular plant species. The data collected in this project can help in selecting such sites, and others.

2. Identifying Fens That Need Better Management of Disturbance

In contrast to especially large or well-developed fens, managers might want to direct their attention to sites where disturbance may be heavy enough to require some change in management. A number of criteria might be used to identify these sites, such as heavy browsing, presence of ground disturbances, and large numbers of "false" scores on the management indicator tool. Such sites can be selected from a review of the information collected in this project. Field surveys can then be scheduled so that the existing information can be reviewed and additional, more-detailed information gathered.

Table 24. Identification numbers of fens (peat ≥ 20 cm thick) in different size-classes.

500,000 sq m	
R202-15-8370	
50,000 sq m	
R202-15-150729	R202-15-69
R202-15-5420	R202-15-7327
R202-15-65	R202-15-SCW
R202-265	R202-15-07
30,000 sq m	
R202-185	
25,000 sq m	
R202-171	R202-293
R202-183	
20,000 sq m	
R202-155A	
11,000 sq m	
R202-250	
10,000 sq m	
R202-068	R202-240
R202-234	
7,500 sq m	
R202-128	R202-15-6717
R202-15-09	R202-15-90
R202-15-2462	R202-15-9872
R202-15-27	R202-15-43
R202-15-3415	
R202-15-43	
7,000 sq m	
R202-232	R202-266
6,000 sq m	
R202-214	
5,000 sq m	
	R202-220
R202-15-55	R202-237
4,000 sq m	
R202-176	R202-299
R202-267	
3,000 sq m	
R202-212	R202-263
R202-233	

2,800 sq m	
R202-202	
2,500 sq m	
R202-034	R202-15-32
R202-041	R202-15-33
R202-069	R202-15-3680
R202-085	R202-15-41
R202-15-10098	R202-15-52
R202-15-12	R202-15-58
R202-15-14	R202-15-6545
R202-15-189	R202-15-6793
R202-15-2334	R202-15-778
R202-15-28	R202-15-7785
R202-15-287	R202-15-93
R202-15-3018	R202-201
R202-15-31	R202-238
R202-15-02	R202-15-3749
1,700 sq m	
R202-112	
1,250 sq m	
R202-174	
1,200 sq m	
R202-248	
700 sq m	
R202-218	
500 sq m	
R202-15-19	R202-15-5246
R202-15-35	R202-15-5634
R202-15-3571	R202-15-60
R202-15-3653	R202-15-6128
R202-15-42	R202-15-75
R202-15-48	R202-15-86
R202-15-5224	R202-15-87
50 sq m	
R202-15-2845	R202-15-7220

B. GUIDING ADDITIONAL SURVEYS

The work of this project can be expanded into additional survey for GDEs and fens in two ways: selecting groups of wetlands to visit for various reasons, and incorporating the field methods into other projects on the Forest. Each of these approaches is discussed below.

1. Selecting Groups of Wetlands For Survey

We identified a set of 2,063 NWI PEMB polygons that lie within the elevation range over which we sampled and whose centroids lie within 500 meters (0.31 mile) of open roads, but that our crews did not visit. The locations of these wetlands are provided in the shape file accompanying this report. If the Bighorn Forest biologists and managers want to test the conclusions that we have reached from this two-year study, or increase their confidence in our conclusions, then they could sample at additional partially-random subsets of these points.

It's very likely, though, that the Bighorn staff is more interested in targeting future sampling than they are in extending this study. Here are several ways that sampling points could be selected from among these 2,063 wetlands to meet different objectives.

a. If the objective is to sample fens, then the larger of these NWI wetlands can be selected, on the basis of our finding that fens are more common in large NWI wetland polygons than in small ones. These larger wetlands could be examined on aerial photographs for the presence of features associated with fens. Or, wetlands could be selected for sampling that are close to already-sampled wetlands known to have fens, since our results and those of Heidel (2011) suggest that fens are clustered. (But note that fens, other GDEs, and even wetland polygons without GDEs can be intermingled with one another; see section III.B.1. above.)

b. Information may be needed about wetlands in an area where a certain project is planned. Selecting wetlands for sampling in this case would be a simple matter of overlaying a polygon of the project area onto the shape file of the wetlands.

c. If Forest staff are interested in getting a better idea of the distribution of fens, they could select for survey wetlands in areas where we did not find fens, to see if the apparent absence of fens is an artifact of inadequate sampling. In this case, selecting the larger of the wetlands might result in sampling in more fens.

Note that the only reason to restrict future sampling for any reason to these 2,063 polygons is that they are relatively quick to reach. Within the elevation range over which we sampled, there are 2,813 additional PEMB polygons with saturated water regimes farther from open roads. And removing the elevation restriction adds another 1,496 wetlands. Points representing these wetlands also are in the shape file from this project.

The sampling methods that we used are appropriate for surveying sites selected for any of these reasons, although as noted in section V.A.2 above, the methods for collecting the supplemental information might have to be changed to meet certain objectives.

2. Incorporating GDE Sampling Into Other Projects

Other opportunities for surveying for GDEs and fens will arise when crews visit wetlands in their work on range, wildlife, or botany projects. If staff people in these programs are trained to use the methods that we used in this project, and have access to the instruction manuals, data sheets, and equipment, they can collect information that will add to the understanding of GDEs and fens on the Forest, and that may document well-developed fens.

C. Coordinating GDE Work On The Forest

We don't know how best to encourage the use of the GDE protocols in future projects, but we have two observations that might be helpful. First, it might be important for someone on the forest staff to be given the responsibility for making the GDE program known to other staff members and managers, seeing that field crews are trained, assuring access to instruction manuals and field forms, seeing that data are entered into the database, and assuring that information from the database is provided to resource staff and managers in useful formats when they need it. Dissemination of this report might be a good way to advertise the GDE program.

Second, scientists with the Forest Service's national GDE program are available to help with methods, training, and interpreting results. Two of those scientists, Joe Gurrieri and Kate Dwire, have participated in this project and no doubt will be glad to continue assisting with GDE work on the Bighorn forest.

D. Identifying Opportunities to Answer Research Questions

Finally, the results from this project might be expanded into GDE and fen research that would increase the understanding of fens generally. Because this work is not directly relevant to management, it probably is of greater interest to Forest Service and academic researchers than to staff of the Bighorn National Forest.

Here are four subjects for possible research projects.

a. Driver (2010) demonstrated that, in wetlands of Rocky Mountain National Park, a threshold of 40 cm of peat is not a reliable predictor of fen vegetation vs. other wetland vegetation, and is not consistently associated with particular hydrologic regimes. With the information from this project, researchers could select a variety of wetlands with a range in peat thickness, to see if the situation that Driver documented also occurs in the Bighorn Mountains.

b. Study sites in fen projects often are selected by examination of aerial photographs: photo interpreters look at the photos for the presence of color patterns, and various surface and hydrologic features, that are associated with relatively thick peat deposits. One example among many is Heidel's (2011) survey of sensitive plant species on the Bighorns. The current project has documented the locations of wetlands representing a wide range in peat thickness. They, combined with the wetlands in Heidel's study (the locations of which also are well documented), offer an opportunity for testing the success of photo interpretation in identifying wetlands with thick peat. If a quantitative or semi-quantitative scale was developed for expressing the presence or clarity of the colors and features, the photo interpreters could then use that scale to assign ranks to the wetlands, and the strength of the relationship between the ranks and the thickness of peat assessed.

c. A statistical tool or remote-sensing tool for identifying wetlands likely to contain fens could be a useful addition, or perhaps an alternative, to photointerpretation as a way of selecting fens. After analyzing the data from the first season of the project, we thought that we had a statistical tool in the form of a logistic regression model. When we evaluated the results from both field seasons, though, we discovered that the model did not assign higher odds to the wetlands with fens than to those without fens. Despite our failure to find a way of identifying wetlands with fens, our sampling sites with known locations and peat thicknesses might provide a suitable data set for a different statistical analysis with other predictor variables, or a remote-sensing analysis.

d. The cause of the difference in pH values measured at different locations in the wetlands is unclear, and detailed study in some of the Bighorn wetlands might be useful in elucidating the physical and biological processes that influences pH throughout wetlands.[11]

E. Managing Data

The GDE sampling methods provide a structured way to systematically collect information about wetlands, and that information will be most useful if it is entered into a database that is as well-structured as the sampling methodology. In this project, we entered the standard GDE Level I information into the Microsoft Access® GDE database designed and constructed by the Springs Stewardship Institute specifically to be used with the GDE sampling methods. We entered the data in our office, into a copy of the database that we had obtained from the Institute. The smaller amount of supplemental information that we collected was entered into a second, smaller database of our own design. We're providing both of those databases to the Bighorn National Forest, and they can be used to store data from additional surveys in the future.

Exiting data sets also can be entered into the GDE database, so that information about wetlands on the Bighorn Forest is held in one place. For example, Heidel (2011), in her survey of rare fen plants on the Bighorns, collected valuable information about the fens in which she found the plants. That information could be entered into the GDE database, even though it was not collected with the GDE Level I methods and its entry might require some familiarity with the database.

The GDE database works well for entering the data from sites and surveys one at a time and for looking at the information about sites and surveys. It also features a selection of reports for getting the information out in various formats. A user with some knowledge of Microsoft Access® can design queries that give customized reports.

During this project, we were assisted in solving some data-entry problems by the database designer at the Springs Institute, Ms. Jeri Ledbetter. It's unclear whether this support for the GDE database will be available to users at the Bighorn National Forest, though, because apparently the GDE database is being replaced by Springs Online, a web-based tool for entering data. We do not know if the Springs Institute will continue to support use of the GDE database by people on the national forests.

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APPENDIX A. DATABASES AND OTHER MATERIALS

We are supplying the following information and materials from the project

1. Databases. The folder **BighornNF_GDE-fen_Databases** contains:

a. The GDE database, in the sub-folder **BNF GDE_Database**. As explained in the file "READ THIS FILE_GDE_Database folder.docx" in that folder, the GDE database consists of a front end linked to a back end, both of which are in the sub-folder. Also in the sub-folder are:

(i) **Photos_BothYears**, a folder with the photos taken at the sites visited in 2014 or 2015. This folder must be kept with the GDE database.

(ii) **SiteSketches**, a folder containing the site sketches made at the sites visited in 2014 or 2015.

(iii) "GDE_UserGuideVersion5(1).pdf", the manual for installing and using the GDE database

b. The supplemental database, in the sub-folder **BNF_Supplemental Database**.

Both of these database can be used on the Bighorn National Forest for collecting information from surveys in the future in additional wetlands.

2. Data from 2014 and 2015. Data collected in this project are in the folder **BighornNF_GDE-Fen Survey 2014-2015_Data**, organized as follows:

a. The sub-folder **Shape Files** contains a shape file of the 6,377 qualifying points selected for potential sampling, which shows which points were visited. The spreadsheet in that sub-folder contains information exported from the attribute table.

b. The sub-folder **Spreadsheet From Supplemental Database** has a spreadsheet of information exported from the supplemental database.

c. The sub-folder **Spreadsheets From GDE Database** contains several spreadsheets of information from the sites visited in 2014 and 2015, exported from the GDE database. The file "READ THIS FILE_Spreadsheets From GDE Database.docx" explains these spreadsheets. Note that different spreadsheets can be easily exported from the GDE database as Excel reports.

3. Sampling forms. The folder **BNF_GDE_2014-2015_Field Forms & Instructions** contains the sampling forms used in this project. As explained in the file "READ THIS FILE_BNF 2014-2015_GDE_Forms&Instructions.docx" in this folder, these forms are slight modifications of the standard GDE Level 1 forms. The folder also contains instructions that supplement the GDE Level 1 Field Guide.

APPENDIX B. DETAILS OF STATISTICAL TESTS REFERRED TO IN THE REPORT

Table B-1. Chi-square test of the numbers of sites with fens on geologic substrate-classes.

Null hypothesis, H_0: Sites with fens occur on substrate-classes in the same proportions as do all sample sites. **Alternative hypothesis, H_A:** Sites with fens occur on substrate-classes in different proportions than do all sample sites.

Substrate-type		Numbers of sites	
		Fen	All Sites
Carbonate	Observed, O	5	43
	Expected, E	*11.40*	
	(O-E)2/E	3.5910	
Crystalline	Observed, O	56	186
	Expected, E	*49.30*	
	(O-E)2/E	0.9102	
Glacial	Observed, O	13	54
	Expected, E	*14.31*	
	(O-E)2/E	0.1205	
Other	Observed, O	14	49
	Expected, E	*12.99*	
	(O-E)2/E	0.0789	
All		88	332

Test statistic = $\sum[(O - E)^2/E] = 4.701$, degrees of freedom = 3, $0.10 < p < 0.25$. Therefore, do not reject H_0.

Table B-2. Chi-square test of the proportions of sites with fens on CLUs.

Null hypothesis, H_0: The fens occur on the CLUs in the same proportions as do the sample sites.
Alternative hypothesis, H_A: The fens occur on the CLUs in different proportions than do the sample sites.

CLU		Points With Fens	CLU		Points With Fens
29	Observed, O	0	19A	Observed, O	2
	Expected, E	*5.83*		*Expected, E*	*2.92*
	(O-E)²/E	5.8313		(O-E)²/E	0.2876
16	Observed, O	25	25	Observed, O	4
	Expected, E	*18.02*		*Expected, E*	*4.51*
	(O-E)²/E	2.6999		(O-E)²/E	0.0568
10	Observed, O	10	19B	Observed, O	5
	Expected, E	*6.63*		*Expected, E*	*4.51*
	(O-E)²/E	1.7174		(O-E)²/E	0.0542
11	Observed, O	1	40	Observed, O	20
	Expected, E	*2.92*		*Expected, E*	*19.35*
	(O-E)²/E	1.2586		(O-E)²/E	0.0219
18	Observed, O	8	30	Observed, O	4
	Expected, E	*5.57*		*Expected, E*	*4.24*
	(O-E)²/E	1.0641		(O-E)²/E	0.0137
26	Observed, O	6	Other*	Observed, O	3
	Expected, E	*3.98*		*Expected, E*	*9.54*
	(O-E)²/E	1.0304		(O-E)²/E	4.4854

* "Other" includes CLUs 14, 17, 20, 21, 23, 33, 34 36, 39, 42, 43, W

Test statistic (Pearson chi-square) = $\sum[(O - E)^2/E] = 18.5213$, degrees of freedom = 11, $0.05 < p < 0.10$. Therefore, do no reject H_0.

Table B-3. Results of Mann-Whitney U-Test For Difference in Percent Slope as Measured in the Field, Points With Fens Vs. Points Without Fens.

Null hypothesis, H_0: The range of slopes where points with fens occurred does not differ from the range of slopes where points without fens occurred. **Alternative hypothesis, H_A:** The range of slopes where points with fens occurred differs from the range of slopes were points without fens occurred.

	N	Median
Points With Fens	88	2.000
Points Without Fens	244	3.000

Point estimate for (Median With Fens) - (Median Without Fens) = -0.5000. 95% Confidence Interval is (-1.000, -0.0001). W = 13205.5. **p = 0.0610**. Do not reject H_0.

Table B-4. Chi-square contingency test of the frequency of GDEs in 8 wetland size-classes.

Null hypothesis, H_0: The ratio of sites with GDEs to sites without GDEs is the same in all wetland size-classes. **Alternative hypothesis, H_A:** The ratio or sites with GDEs to sites without GDEs differs among wetlands size-classes.

		Wetland Size-class (Ha)								
Type of Site		**<0.1**	**0.1-0.25**	**0.25-0.5**	**0.5-1**	**1-2**	**2-5**	**5-10**	**>10**	**All Sizes**
GDE present	Observed Frequency	60	52	40	46	40	37	4	8	287
	Expected Frequency	*71.7500*	*53.5964*	*40.6295*	*42.3584*	*36.3072*	*31.9849*	*3.4578*	*6.9157*	*287*
No GDE	Observed Frequency	23	10	7	3	2	0	0	0	45
	Expected Frequency	*11.2500*	*8.4036*	*6.3705*	*6.6416*	*5.6928*	*5.0151*	*0.5422*	*1.0843*	*45*
All Sites		83	62	47	49	42	37	4	8	332

$\chi^2 = 27.383$. Degrees of freedom = 14. $0.01 < P < 0.025$. Therefore, reject H_0.

Table B-5. Chi-square contingency test of the frequency of fens or other GDEs in sites with GDEs, in 8 wetland size-classes.

Null hypothesis, H_0: The ratio of sites with fens to sites with other GDEs is the same in all wetland size-classes. **Alternative hypothesis, H_A:** The ratio of sites with fens to sites with other GDEs differs among wetland size-classes.

		Wetland Size-class (Ha)								
Type of GDE		**<0.1**	**0.1-0.25**	**0.25-0.5**	**0.5-1**	**1-2**	**2-5**	**5-10**	**>10**	**All Sizes**
Fen	Observed Frequency	4	11	18	13	17	20	3	2	88
	Expected Frequency	*18.3972*	*15.9443*	*12.2648*	*14.1045*	*12.2648*	*11.3449*	*1.2265*	*2.4530*	*88*
Other GDE	Observed Frequency	56	41	22	33	23	17	1	6	199
	Expected Frequency	*41.6028*	*36.0557*	*27.7352*	*31.8955*	*27.7352*	*25.6551*	*2.77352*	*5.54704*	*199*
All GDEs		60	52	40	46	40	37	4	8	287

$\chi^2 = 38.432$. Degrees of freedom = 14. < P < 0.0001. Therefore, reject H_0.

Table B-6. Linear regression analysis of peat thickness on wetland area.

Null hypothesis, H_0: Size of a wetland has no effect on the thickness of peat in the wetland. **Alternative hypothesis, H_A:** Size of a wetland has an effect on the thickness of peat in the wetland.

The regression equation is: Peat (cm) = - 6.87 + 7.42 Log of Area (SqM)

Predictor	Coef	SE Coef	T	P
Constant	-6.872	5.683	-1.21	0.227
AreaSqM_log	7.420	1.615	4.60	0.000

S = 21.7859. R-Sq = 5.8%. R-Sq(adj) = 5.6%. n = 342

Reject H_0. Size of a wetland has a positive effect on thickness of peat.

Table B-7. Analysis of variance for differences in pH values from different locations in 2014 (Minitab 16.2.4, general linear model).

Null hypothesis, H_0: Mean pH is the same for exit streams, soil holes, spring sources, and standing water (i.e., pH does not differ among these locations). **Alternative hypothesis, H_A:** Mean pH is not the same for exit streams, soil holes, springs sources, and standing water (i.e., pH differs among these locations).

Fixed factor = Location, with 4 levels:

Level	n	Mean	Variance
Exit stream	15	7.2450	0.1257
Soil hole	19	6.8104	0.1327
Spring source	12	7.288	0.115
Standing water	13	6.9623	0.1169

Model Term	Degrees of Freedom	Sequential Sum of Squares	Adjusted Sum of Squares	Adjusted Mean Square	F value	Probability, p
Location	3	2.4899	2.4899	0.8300	6.26	0.001
Error	55	7.2873	7.2873	0.1235		
Total	58	9.7772				

Conclusion: $p = 0.001$. Therefore, reject H_0: pH differs among the sampling locations

Pairwise comparisons of locations: (Tukey-Kramer method with joint confidence level = 0.05)

Location	N	Mean	Group
Spring source	12	7.288	A
Exit stream	15	7.254	A
Standing water	13	6.962	AB
Soil hole	19	6.811	B

Means that do not share a group letter are significantly different.

Conclusion: Mean pH is the same in spring sources and exit streams, but significantly lower in soil holes. Mean pH in standing water does not differ from that in the other locations.

Table B-8. Two-sample t-test of pH values from soil holes in 2014 vs. 2015 (Minitab 16.2.4, equal variances assumed)

Null hypothesis, H_0: Mean pH from 2014 is the same as from 2015. **Alternative hypothesis, H_A:** Mean pH from 2014 is not the same as from 2015.

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Year	N	Mean	Variance	Std. Error of Mean
2014	19	6.811	0.1327	0.084
2015	68	6.129	0.1607	0.049

Mean 2014 pH - mean 2015 pH = 0.682. 95% confidence interval for difference: 0.479 to 0.885
T-value = 6.68, probability = 0.000, degrees of freedom = 85.

Conclusion. Reject H_0: Mean pH in 2014 is not the same as mean pH in 2015

Table B-9. Kruskal-Wallis Test For Differences in Electrical Conductance Measured at Different Locations Within Sites (Minitab 16.2.4)

Null hypothesis, H_0: Electrical conductance is the same among the 4 locations. **Alternative hypothesis, H_A:** Electrical conductance differs among the 4 locations.

Location	N	Median	Average Rank	Z
Exit stream	17	35.00	43.8	-2.59
Soil hole	87	62.00	68.8	1.18
Spring source	12	32.00	48.5	-1.68
Standing water	15	131.00	89.0	2.50
Overall	131		66.0	

H = 14.37, DF = 3, P = 0.002
H = 14.37, DF = 3, P = 0.002 (adjusted for ties)

Conclusion. Reject H_0: Measurements of electrical conductance are not the same among the four sampling locations.

Table B-10. Pairwise Comparisons of Electrical Conductance Measured at Different Locations Within Sites.

Procedure is from: Zar (2010) Section 11.5a, Nonparametric Multiple Comparisons with Unequal Sample Sizes

	Exit stream	Spring source	Soil hole	Standing water	N
Rank sum, *R*	744.5	581.5	5984.5	1335.5	
Mean rank, $\bar{R}$	43.79	48.50	68.79	89.03	
n	17	12	87	15	131

m = 27, $\sum t = 415$

Standard Error = SE = $\sqrt{\{(\{[N * (N+1)]/12\} - \{\sum t/[12*(N-1)]\}) * [(1/n_A) + (1/n_B)]\}}$

Critical Q value, $Q_{0.05,4} = 2.639$

Q statistic = $(\bar{R}_B - \bar{R}_A)/SE$

For every comparison: **H_0** = Measurements of electrical conductance are the same in the two locations. **H_A** = Measurements of electrical conductance differ between the two locations.

Comparison	Difference, $\bar{R}_B - \bar{R}_A$	SE	Q statistic	Conclusion
Exit stream vs. Standing water	45.24	12.838	3.524	**Reject H_0. Measurements differ between the locations**
Exit stream vs. Soil hole	25	10.065	2.484	Do not reject H_o. Measurements do not differ between locations
Exit stream vs. Spring source	4.71	14.311	0.329	Do not reject H_o. Measurements do not differ between locations
Spring source vs. Standing water	40.53	14.701	2.757	Do not reject H_o. Measurements do not differ between locations
Spring source vs. Soil Hole	20.29	11.688	1.736	Do not reject H_o. Measurements do not differ between locations
Standing water vs. Soil Hole	20.24	10.612	1.907	Do not reject H_o. Measurements do not differ between locations

Table B-11. Two-sample t-test of electrical conductance values from soil holes in 2014 vs. 2015 (Minitab 16.2.4, equal variances assumed)

Null hypothesis, H_0: Mean electrical conductance from 2014 is the same as from 2015. **Alternative hypothesis, H_A:** Mean electrical conductance from 2014 is not the same as from 2015.

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Year	N	Mean	Variance	Std. Error of Mean
2014	19	128	10368.5	23
2015	68	92	10278.9	12

Mean 2014 - mean 2015 = 35.8. 95% confidence interval for difference: -16.7 to 88.3
T-value = 1.36, probability = 0.178, degrees of freedom = 85.

Conclusion. Do not reject H_0: Mean electrical conductance in 2014 is the same as mean electrical conductance in 2015

Table B-12. Chi-square contingency test for equality of proportions of fens and of other GDEs with signs of soil alteration.

Null hypothesis, H_0: The proportion of fens with signs of soil alteration is the same as the proportion of GDE_NoFens with signs of soil alteration. **Alternative hypothesis, H_A:** The proportion of fens with signs of soil alteration is not the same as the proportion of GDE-NoFens with signs of soil alteration.

Wetland Type		Soil Alteration Present	Soil Alteration Absent	n
Fen	Observed	32	55	87
	Expected	*42.6335*	*44.3665*	
GDE_NoFen	Observed	91	73	164
	Expected	*80.3665*	*83.6335*	

$\chi^2 = 7.960$. Degrees of freedom = 1. $0.001 < P < 0.005$. Conclusion. Reject H_0: The proportion of fens with signs of soil alteration is less than the proportion of GDE-NoFens.

Table B-13. Chi-square contingency tests for equality of proportions of fens and of other GDEs with signs 5 types of soil alteration.

For all tests, **Null hypothesis H_0 =** The proportion of fens with signs of soil alteration is the same as the proportion of GDE_NoFens with signs of soil alteration. **Alternative hypothesis, H_A =** The proportion of fens with signs of soil alteration is not the same as the proportion of GDE-NoFens with signs of soil alteration.

a. Channel erosion

Wetland Type		Soil Erosion Present	Soil Erosion Absent	Row Total
Fen	Observed	5	82	87
	Expected	*9.7052*	*77.2948*	*87*
GDE_NoFen	Observed	23	141	164
	Expected	*18.2948*	*145.7052*	*164*
Column total		28	223	251

$\chi^2 = 3.930$. Degrees of freedom = 1. $0.025 < P < 0.05$. Conclusion: Reject H_0.

b. Soil erosion

Wetland Type		Soil Erosion Present	Soil Erosion Absent	Row Total
Fen	Observed	4	83	87
	Expected	*11.0916*	*75.9084*	*87*
GDE_NoFen	Observed	28	136	164
	Expected	*20.9084*	*143.0916*	*164*
Column total		32	219	251

$\chi^2 = 7.953$. Degrees of freedom = 1. $P < 0.005$. Conclusion: Reject H_0.

c. Ground disturbance

Wetland Type		Soil Erosion Present	Soil Erosion Absent	Row Total
Fen	Observed	10	77	87
	Expected	*21.4900*	*65.5100*	*87*
GDE_NoFen	Observed	52	112	164
	Expected	*40.5100*	*123.4900*	*164*
Column total		62	189	251

$\chi^2 = 12.487$. Degrees of freedom = 1. $P < 0.005$. Conclusion: Reject H_0.

Table B-13 (continued).

d. Soil mixing

Wetland Type		Soil Erosion Present	Soil Erosion Absent	Row Total
Fen	Observed	6	81	87
	Expected	*17.3307*	*69.6693*	*87*
GDE_NoFen	Observed	44	120	164
	Expected	*32.6693*	*131.3307*	*164*
Column total		50	201	251

$\chi^2 = 14.158$. Degrees of freedom = 1. $P < 0.005$. Conclusion: Reject H_0.

e. Trails

Wetland Type		Soil Erosion Present	Soil Erosion Absent	Row Total
Fen	Observed	6	81	87
	Expected	*11.4382*	*75.5618*	*87*
GDE_NoFen	Observed	27	137	164
	Expected	*21.5618*	*142.4382*	*164*
Column total		33	281	251

$\chi^2 = 4.556$. Degrees of freedom = 1. $P < 0.05$. Conclusion: Reject H_0.

Table B-14. Chi-square goodness-of-fit tests of "False" answers to management indicators that came from fens vs. from other GDEs

For each test, **Null hypothesis H_0** = The ratio of "False" answers from fens to the ratio from other GDEs is 0.35:0.65. **Alternative hypothesis, H_A =** The ratio of "False" answers from fens to the ratio from other GDEs is not 0.35:0.65.

Because degrees of freedom = 1, Yates correction for continuity was used in calculating expected frequencies (Zar 2010, p. 469):

$$\chi^2_c = \sum [(|\text{Observed freq.} - \text{Expected freq.}| - 0.5)^2 / \text{Expected freq.}]$$

n = the number of "False" answers for indicators in the category being tested.

a. Hydrology indicators category

	Fen	Other GDEs	n
Observed	3	21	24
Expected	*8.3520*	*15.6480*	

$\chi^2_c = 4.323$. $P < 0.05$; reject H_0.

b. Geomorphology & Soil indicators category

	Fen	Other GDEs	n
Observed	8	57	65
Expected	*22.6200*	*42.3800*	

$\chi^2_c = 13.519$. $P < 0.01$; reject H_0.

c. Biology indicators category

	Fen	Other GDEs	n
Observed	3	36	39
Expected	*13.5720*	*25.4280*	

$\chi^2_c = 11.464$. $P < 0.01$; reject H_0.

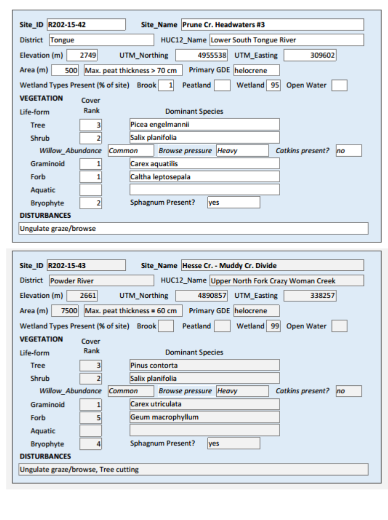
d. Disturbance indicators category

	Fen	Other GDEs	n
Observed	9	32	41
Expected	*14.2680*	*26.7320*	

$\chi^2_c = 2.444$. $P > 0.05$; Do not reject H_0.

Appendix C. Summary of Information About Each of the 88 Fens.

Information about each of the fens is in the PDF file, "Appendix C.pdf". That PDF file can be opened by double-clicking on this image of the first page.



Site_ID R202-15-42 **Site_Name** Prune Cr. Headwaters #3
District Tongue HUC12_Name Lower South Tongue River
Elevation (m) 2749 UTM_Northing 4955538 UTM_Easting 309602
Area (m) 500 Max. peat thickness > 70 cm Primary GDE helocrene
Wetland Types Present (% of site) Brook 1 Peatland Wetland 95 Open Water

VEGETATION

Life-form	Cover Rank	Dominant Species
Tree	3	Picea engelmannii
Shrub	2	Salix planifolia
Willow_Abundance	*Common*	*Browse pressure* *Heavy* *Catkins present?* *no*
Graminoid	1	Carex aquatilis
Forb	1	Caltha leptosepala
Aquatic		
Bryophyte	2	Sphagnum Present? yes

DISTURBANCES
Ungulate graze/browse

Site_ID R202-15-43 **Site_Name** Hesse Cr. - Muddy Cr. Divide
District Powder River HUC12_Name Upper North Fork Crazy Woman Creek
Elevation (m) 2661 UTM_Northing 4890857 UTM_Easting 338257
Area (m) 7500 Max. peat thickness ≈ 60 cm Primary GDE helocrene
Wetland Types Present (% of site) Brook Peatland Wetland 99 Open Water

VEGETATION

Life-form	Cover Rank	Dominant Species
Tree	3	Pinus contorta
Shrub	2	Salix planifolia
Willow_Abundance	*Common*	*Browse pressure* *Heavy* *Catkins present?* *no*
Graminoid	1	Carex utriculata
Forb	5	Geum macrophyllum
Aquatic		
Bryophyte	4	Sphagnum Present? yes

DISTURBANCES
Ungulate graze/browse, Tree cutting

Page 1

The cover ranks show the relative contribution of cover to the vegetation by each of five plant growth-forms. 1 = greatest amount of cover, 5 = least amount.