# USGS-NPS VEGETATION MAPPING
## Devils Tower National Monument, Wyoming

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## EXECUTIVE SUMMARY

A vegetation association classification, vegetation map, and thematic accuracy assessment is presented for the area in and around Devils Tower National Park, Wyoming. This report is presented in two volumes: The Nature Conservancy report which presents the vegetation classification and this report which presents the methods and results of the mapping portion of this project.

The vegetation associations were developed by analysis of 28 vegetation plots and 43 observation points within the park boundaries. The classification system developed uses and augments the National Vegetation Classification System (NVCS). Sixteen vegetation associations within 3 major physiognomic groups are defined and described. Included are discussions of range, environmental variables, common species, diagnostic species, local and global descriptions, and various comments. A diagnostic key is provided for field identification of association types based on indicator plant species.

The vegetation map was developed by photographic interpretation of 1993, 1:16,000 scale color infrared photography. Two separate classification systems were used to develop the mapping units. Cultural, disturbed, or unsampled vegetation types used the Anderson Level II classification system. All other vegetation within the mapping boundary used map units derived from the NVCS. A total of 9 Anderson Level II classes and 16 NVCS classes were used. The NVCS classes were combined to form 12 vegetation mapping classes.

As part of the mapping effort we have included an accuracy assessment for the overall mapping effort as well as for individual class accuracies. These data include error reporting for both errors of omission and commission. Overall map accuracy is 81.6% within a 90% confidence interval. A few map units do not meet the 80% accuracy level but do fall within the 90% confidence interval around the 80% accuracy stipulation.

Final products developed by this mapping effort include the following:

- vegetation classification system
- vegetation key
- ACCESS database with all field data
- digital and paper vegetation map
- digital coverage with all vegetation plots
- digital coverage with all observation plots
- digital coverage with all accuracy assessment points
- graphic files (*.tif) of all digital coverages
- accuracy assessment
- metadata for all digital files
- scanned aerial photography
- annotated field photographs/slides
- all products on Compact Disk (CD)

## INTRODUCTION

This mapping effort originates from a long-term vegetation monitoring program that is part of a larger Inventory and Monitoring (I&M) program started by the National Park Service (NPS). I&M goals are, among others, to map the vegetation of all national parks and monuments and provide a baseline inventory of vegetation. The I&M program currently works in close cooperation with the Biological Resources Division (BRD) of the United States Geological Survey (USGS). The USGS/BRD continues overall management and oversight of all ongoing mapping efforts in close cooperation with the NPS. Contractors for each park vary. For Devils Tower National Monument the principal contractor is the U.S. Bureau of Reclamation (BOR), Denver Technical Center, Remote Sensing and Geographic Information Group (D-8260). The primary subcontractor is The Nature Conservancy (TNC) who also works closely with the Wyoming Natural Heritage Program.

Objectives and Scope

The purposes of the mapping effort are varied and include the following:

- Provides support for NPS Resources Management
- Promotes vegetation-related research for both NPS and USGS/BRD
- Provides support for NPS Planning and Compliance
- Adds to the information base for NPS Interpretation
- Assists in NPS Operations

## PROJECT AREA

Location: Devils Tower National Monument is in Crook County in northeast Wyoming and is part of the western most Black Hills (Figure 1). The monument lies 10 miles east of the Bear Lodge Mountains and 10 miles south west of the town of Hulett, Wyoming.

Geology: The geology of Devils Tower includes igneous and sedimentary rocks. Devils Tower itself is possibly an erosional remnant of a volcanic neck and consists of Tertiary phonolite porphyry. Unweathered specimens of the rock are light to dark-gray or greenish-gray, very fine-grained with conspicuous crystals of white feldspar, ¼ to ½ inch in diameter, and smaller dark-green crystals of pyroxene. The weathered rock is light or brownish-gray, but lichens growing on the rock may make it appear green, yellowish-green or brown.

The base of the tower is formed by a broad apron of talus. This apron extends from high on the shoulder of the tower down to and across the surrounding sedimentary rock. The talus is made up of pieces of the columns that have broken from the tower. Fragments are as large as 8 feet in diameter and 25 feet long and as small as a few inches.

The sedimentary rocks include Upper Jurassic shales, siltstones, limestones, and sandstones of the Sandanea formation. Redwater shale member, Lakmember and Stockade Beaver shale member form slopes. The Hulett sandstone member forms steep cliffs.

Soils: The soils in and around the park may be broadly described as either Gaynor-Butche-Boneek loamy soils forming on sedimentary rock on uplands or Haverson-Lohmiller-Glenberg loamy soils forming on terraces and flood plains. For more specific information please see the "Soil Survey of Crook County Wyoming."

Climate: Average annual temperature is 43.6 degrees F. Lowest and highest temperatures on record are 42 below zero and 105 degrees respectively. Average annual precipitation is 17.41 inches but ranges from a low of 11.58 to a high of 17.41. Average seasonal snowfall is 64 inches and ranges from a low of 40 to a high of 105. Most of the precipitation occurs in the summer; resulting mostly from thunderstorm activity during April through July. Winds are generally from the west or northwest (Elwonger 1983).

Elevation Range: Devils Tower rises 1,268 feet above the nearby Belle Fourche River. The elevation range of the map area excluding the tower is 564 feet.

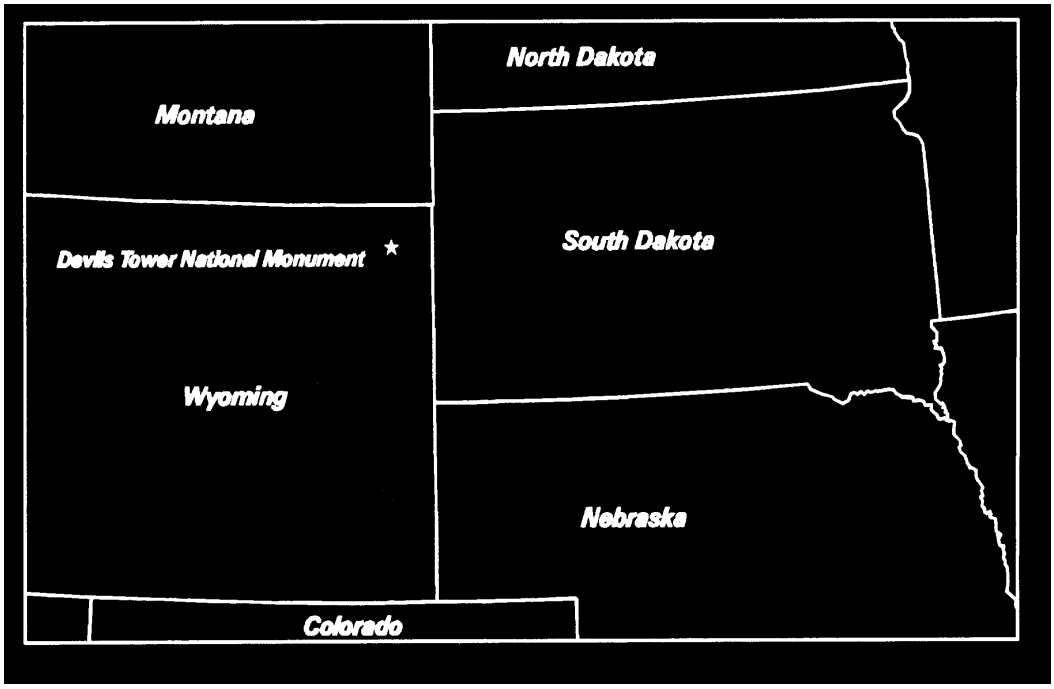


**Figure 1.** Location map for Devils Tower National Monument

## METHODS

Development of Programmatic and Technical Team: This project required the combined expertise and oversight of several organizations. Oversight and programmatic considerations are managed by the Center for Biological Informatics of the Biological Resources Division of the U.S. Geological Survey. The National Park Service provided additional guidance.

The technical responsibilities for the mapping effort were divided between TNC and BOR.

TNC responsibilities and deliverables included the following:

- Create a vegetation classification system based upon field species level data and consistent with the Standard National Classification System at the Alliance or Community Element level
- Provide documentation that describes the national classes at the local and global levels, with field keys, and field data in a *.dbf format.
- Provide technical opinion to BOR as the mapping portion of the project proceeds.
- Provide field notes and site descriptions

BOR responsibilities and deliverables included the following:

- Digital files of vegetation on Compact Disk (CD); including topology and labeling for height, density, and pattern subclasses; location of field sample sites; and locations of sites used for accuracy assessment in Arc/Info format
- Any ancillary digital files developed during the mapping process
- Digital FGDC compliant metadata file for each digital file delivered
- Annotated field site photographs
- Original mylar overlays of interpreted photographs
- Hard copy vegetation map
- Accuracy assessment
- Final report describing all procedures used in developing the final map and accuracy assessment

## Planning and Review Meeting

An initial meeting was held with all interested parties to discuss several aspects of the mapping effort. Foremost among these was the mapping extent. Figure 2 shows the park boundary and the area outside the park to be included in the map. Vegetation issues particular to the Park were addressed. Devils Tower National Monument was responsible for obtaining permission from adjacent land owners for sampling access. Ultimately, this was not possible and all sampling and accuracy field work was done exclusively within the Monument boundaries.

## Preliminary Data Collection and Review of Existing Information

To reduce duplicating previous work and to help in our effort, we collected existing vegetation reports and maps from the staff at Devils Tower National Monument. These materials were referenced during the mapping process and the information contained in them was incorporated where it was deemed useful.

Vegetation is often restricted or somehow affected by the geologic strata upon which it grows. Consequently, a geology map of the park was obtained and used as reference data. This geology map was scanned and registered to create a raster file. The raster geology file was then converted to a polygon coverage. Since soils also affect the distribution of vegetation, soil maps

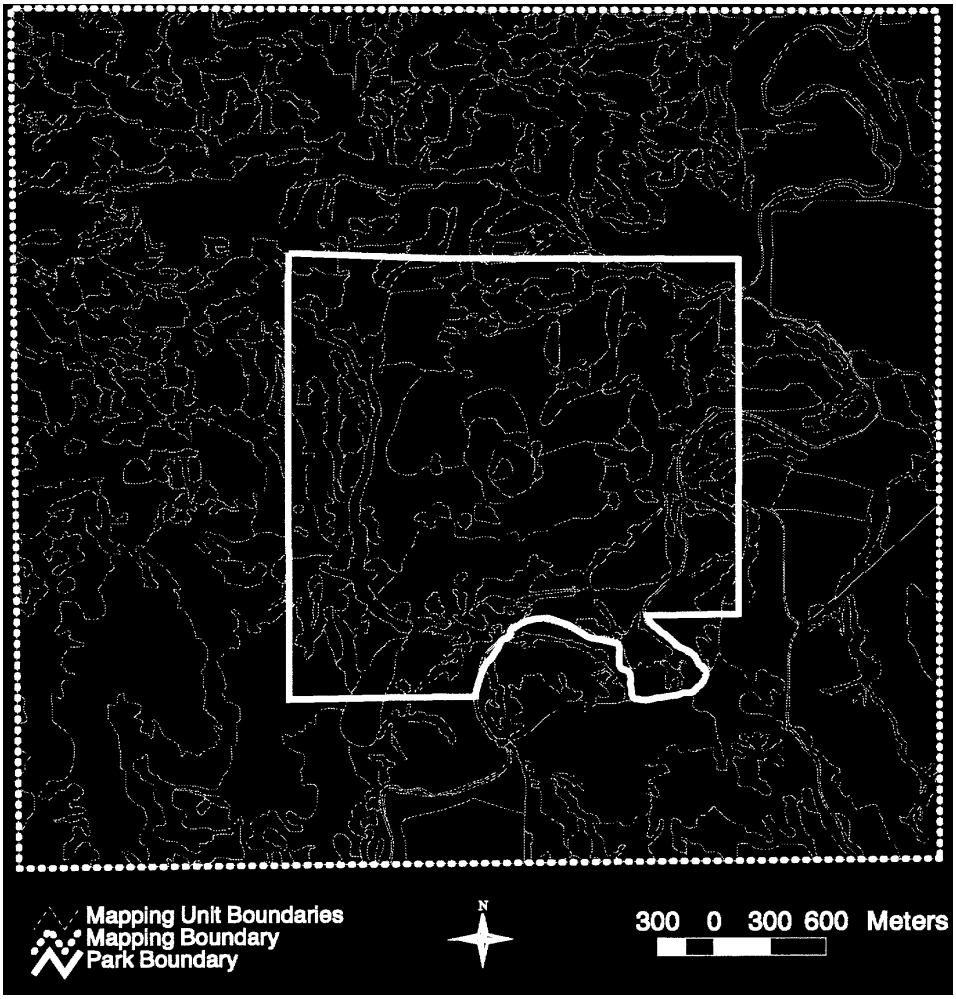


**Figure 2.** Park Boundary and Mapping Area

and soil descriptions were also obtained as references (Elwonger 1983). These were not converted to a digital file.

Digital elevation models (DEM) were obtained to create slope and aspect maps that helped in determining vegetation community distribution.

## Vegetation Sampling

The sampling approach used in this mapping effort was typical of small park sampling, where all polygons within the park boundary are sampled. Because of access restrictions, no samples, observations, or accuracy points were obtained outside the park boundaries.

Two levels of field data gathering were conducted in this park; plots and observations. Plots represented the most intensive sampling of the landscape and used TNC's 'Plot Form'. Observations were brief descriptions and were designed to obtain a quick overview of the landscape without spending a large amount of time at each sample site. The observation points

used the 'Observation Form' data sheet. Examples of both the 'Plot' and 'Observation' forms are included in the companion report by TNC.

Initially, plots were used to describe the vegetation of the park. A total of 28 plots were obtained from August 20 through August 24, 1996. These plots were used by TNC to describe the vegetation associations found within the park. These descriptions are in the companion report by TNC.

Before the accuracy assessment, we conducted a verification trip to assess the preliminary mapping effort. The verification used the observation forms described above. The verification data was then used to refine both the final map and the final vegetation description. Forty-three observation points were collected on June 1 through June 4, 1997. Figure 3 shows the locations of all plot and observation points.

Plot locations: The location of each vegetation plot or observation point was based upon several factors. These factors included the preliminary photo signature and other physiographic variables such as slope, aspect, soils, and geology. We attempted to sample the vegetation in a way that recorded the greatest amount of variability across the landscape. Plots were placed subjectively in areas that best represented the immediate landscape.

The geographic coordinates of the plot locations were determined by marking our approximate position on a mylar overlay on aerial photographs with ink. These positions were later transferred to a digital file using a digital orthophoto quadrangle (DOQ) as a base map. Observation points were located by a global positioning system (GPS) using a Precision Light Weight GPS Receiver (PLGR) device. Plot locations in dense canopies are estimated to be within 10 to 20 meters of their actual location. Observation points are generally within 10 meters of their actual location.

## Vegetation and Map Classification

This mapping effort includes a description of vegetation at two levels. The primary and most informative level is that of the vegetation classification at the association level. Because many plant associations cannot be mapped at this level, we also include a mapping classification. The map classification may be the same as the association but is usually a combination of associations in either a complex or mosaic of associations.

Vegetation Classification: The association descriptions for the vegetation and methods used to derive those descriptions are included in the TNC companion report (see Table 1 for a summary of the associations). The methods used by TNC and this office (Bureau of Reclamation, D-8260) for collecting and processing these data are also described in *Field Methods for Vegetation Mapping* (The Nature Conservancy 1994).

Mapping Classification: The final map contains elements of two separate classification systems. All vegetation sampled and described by this project use the NVCS to develop vegetation associations. All other land cover types within the mapping area use the Anderson Level II classification system (Anderson et al. 1976).

Map classes were derived from the vegetation classification (associations) and modified such that the photo-interpreted classes represented at least one vegetation class. Because many associations did not have a distinct photo signature, some associations were combined to make a map class. For example, many Ponderosa Pine associations were not distinguishable by photo signature and had to be combined into 'complexes'. Other associations may have been visually distinguishable but were so mixed that separating the associations by individual polygons was not feasible. These areas were designated 'mosaics'. Mosaics were typically grassland or shrub communities. Before combining and producing the final map classes, we worked with preliminary map classes. The preliminary map classes were typically the same as the association descriptions. The accuracy assessment was done on the original map classes. Information derived from the accuracy assessment helped us in developing the final map classification. Table 2 describes the map classes and the component community types.

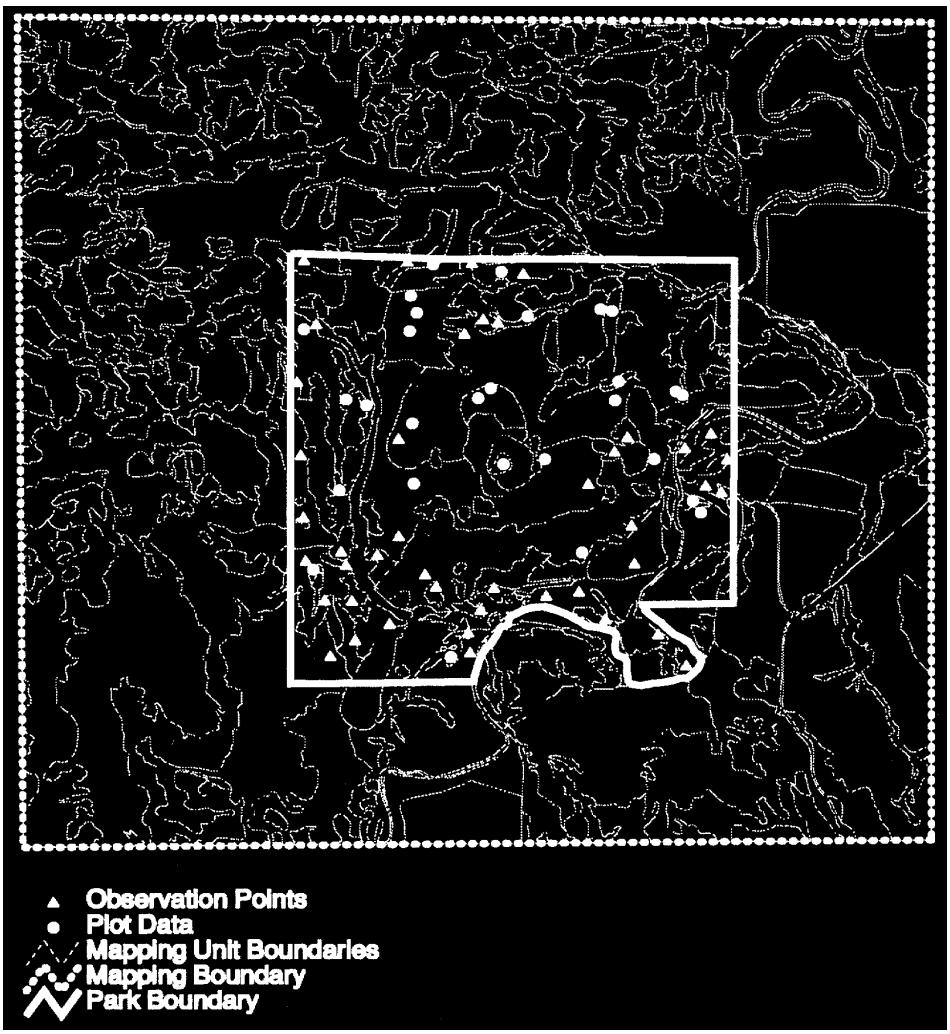


**Figure 3.** The Location of Observation Points and Plot Data in Devils Tower National Monument

| Vegetation Association |
|---|
| Skunkbush Sumac / Bluebunch Wheatgrass Shrub Herbaceous Alliance |
| Silver Sagebrush / Western-Wheat Grass Shrub Herbaceous Vegetation |
| Green Ash - American Elm / Wolfberry Forest |
| Eastern Cottonwood - Peach Leaf Willow / Narrow-Leaf Willow Woodland |
| Little Bluestem - Grama (Side-Oats, Blue) - Threadleaf Sedge Herbaceous Vegetation |
| Western-Wheatgrass - Blue Grama - Threadleaf Sedge Herbaceous Vegetation |
| Prairie Cordgrass - Three-square Bulrush Herbaceous Vegetation |
| Kentucky Bluegrass Disturbed Community |
| Ponderosa Pine / Bur Oak Woodland |
| Ponderosa Pine / Common Juniper Woodland |
| Ponderosa Pine / Little Bluestem Woodland |
| Ponderosa Pine / Sun Sedge Woodland |
| Ponderosa Pine / Oregon Grape Forest |
| Ponderosa Pine / Bluebunch Wheatgrass Woodland |
| Prairie Dog Town |

**Table 1.** The Vegetation Associations Within Devils Tower National Monument.

## Air Photo Interpretation

All map classes were interpreted from existing 1:16,000 scale, color photography flown on July 29, 1993. The photographs were acquired from the U.S. Forest Service (USFS). Photointerpretation used the standard identification features such as tone, texture, color, pattern, topographic position, and shadow. In addition, field sample locations and their vegetation descriptions aided in assigning map class to each polygon. All photographs were examined using a stereoscope. Digital elevation models (DEM's) were processed and converted to slope and aspect coverages. These helped us by providing additional perspectives of the landscape. Six photographs were interpreted for the entire mapping area. Digital scans of these photographs are included as .tif files on the CD included with this report.

## Map Validation

A field trip was conducted in June of 1997 to assess the initial mapping effort and to refine map classes. This trip included additional 'observation points' (see Vegetation Sampling above). Map classes were modified to reflect inadequacies in the initial photointerpretation.

## Digital Files

All digital files were created with a standard format. All files are delivered with a UTM projection, zone 13, and a 1983 North American datum. Attributes and file format for each coverage are as follows:

Vegetation coverage: **deto_veg**

**Attributes**

| **Item name** | | **width** | **output** | **type** | **n. dec** | |
|---|---|---|---|---|---|---|
| map_unit | | 6 | 6 | | C | - |
| anderson_code | | 4 | 4 | | I | - |
| height | | 4 | 4 | | I | - |
| density | 4 | 4 | | I | - | |
| pattern | 4 | 4 | | I | - | |
| hectares | | 10 | 10 | | N | 2 |

Plot data coverage: **plot_data**

**Attributes**

| **Item name** | **width** | **output** | **type** | **n. dec** | |
|---|---|---|---|---|---|
| plot_no | 2 | 2 | | N | - |
| veg_code | 6 | 6 | | C | - |

Verification data coverage: **verif_data**

**Attributes**

| **Item name** | **width** | **output** | **type** | **n. dec** | |
|---|---|---|---|---|---|
| plot_no | 2 | 2 | | N | - |
| veg_code | 6 | 6 | | C | - |

Accuracy assessment coverage: **error_pts**

**Attributes**

| **Item name** | **width** | **output** | **type** | **n. dec** | |
|---|---|---|---|---|---|
| veg_code | 6 | 6 | | C | **-** |
| map_unit | 2 | 2 | | C | - |

Map Boundary Coverage: **map_boundary**

**Attributes**

| **Item name** | **width** | **output** | **type** | **n. dec** | |
|---|---|---|---|---|---|
| hectares | 10 | 10 | | N | - |

Park Boundary Coverage: **park_boundary**

**Attributes**

| **Item name** | **width** | **output** | **type** | **n. dec** | |
|---|---|---|---|---|---|
| hectares | 10 | 10 | | N | - |

| map_unit | map unit name | associations included |
|---|---|---|
| BB | Skunkbush Sumac / Bluebunch Wheatgrass Shrub Herbaceous Alliance | • Skunkbush Sumac / Bluebunch Wheatgrass Shrub Herbaceous Alliance |
| BU | Green Ash - American Elm / Wolfberry Forest | • Green Ash - American Elm / Wolfberry Forest |
| CP | Eastern Cottonwood - Peach Leaf Willow / Narrow-Leaf Willow Woodland | • Eastern Cottonwood - Peach Leaf Willow / Narrow-Leaf Willow Woodland |
| GH | Grassland Complex | • Little Bluestem - Grama (Side-Oats, Blue) - Threadleaf Sedge Herbaceous Vegetation<br>• Western-Wheatgrass - Blue Grama - Threadleaf Sedge Herbaceous Vegetation<br>• Prairie Cordgrass - Three-square Bulrush Herbaceous Vegetation<br>• Kentucky Bluegrass Disturbed Community |
| MK | Mosaic - Kentucky Bluegrass / Little Bluestem | • Little Bluestem - Grama (Side-Oats, Blue) - Threadleaf Sedge Herbaceous Vegetation<br>• Kentucky Bluegrass Disturbed Community |
| MW | Mosaic - Western Wheatgrass / Little Bluestem | • Western-Wheatgrass - Blue Grama - Threadleaf Sedge Herbaceous Vegetation<br>• Kentucky Bluegrass Disturbed Community |
| PB | Ponderosa Pine / Bur Oak Woodland | • Ponderosa Pine / Bur Oak Woodland |
| PD | Prairie Dog Town | • Prairie Dog Town |
| PJ | Ponderosa Pine / Common Juniper Woodland | • Ponderosa Pine / Common Juniper Woodland |
| P1 | Ponderosa Pine Complex I | • Ponderosa Pine / Little Bluestem Woodland<br>• Ponderosa Pine / Sun Sedge Woodland |
| P2 | Ponderosa Pine Complex II | • Ponderosa Pine / Oregon Grape Forest |
| SC | Silver Sagebrush / Western-Wheat Grass Shrub Herbaceous Vegetation | • Silver Sagebrush / Western-Wheat Grass Shrub Herbaceous Vegetation |

**Table 2.** Map unit designations and component vegetation associations descriptions for Devils Tower National Monument.

## Transfer to Digital Format

Digital products produced specifically for this mapping effort include a digital vegetation polygon coverage with labels and digital point coverages for plot, observation, and accuracy locations.

Photo-interpreted polygons and labels were transferred to a digital format using 'heads-up' digitizing on a DOQ. This process entails the visual transfer (digitizing) of line and label data directly to the computer screen with the DOQ as a backdrop/base map. The digital version of the ortho quad was created in-house by scanning and registering the northwest corner of the Devils Tower orthophotograph. The original orthophotograph was produced from 1:76,000 scale aerial photographs taken August 28, 1975. The DOQ produced by this office is included on the CD accompanying this report.

The digital point coverages were created using two different methods. 1.)The original plot data collected in the field was done without the benefit of a GPS unit. Plot locations were noted on each photograph and later transferred to a digital file by using the DOQ base map as reference. 2.) Observation points and accuracy assessment points were collected in the field using a GPS unit. These data points were transferred directly from the GPS unit into a digital file and attributed in Arc/Info using the field data sheets as reference for the attribute. Coordinate system descriptions were added after creation of the digital files.

## Data Description

Vegetation

Coverage name: **deto_veg**

map_unit: This attribute refers to the vegetation map unit. The vegetation codes and map unit names are listed in Table 2. The map unit names can also be accessed using a lookup table (veg_lut) provided with the digital coverage.

anderson_code: This item refers to the map classification using the Anderson Level II classification. The classification codes and map unit names are listed in Table 3. The map unit names can also be accessed using a lookup table (anderson_lut) provided with the digital coverage.

The height, density, and pattern items are structural descriptions of each vegetation class described under the NVCS. Table 4 describes the structural categories and the codes associated with each. Figure 4 illustrates each category associated with each code.

hectares: This item is simply a numeric figure representing the area covered by each polygon.

Plot Data

Coverage name: **plot_data**

plot_no: This item refers to the number assigned to each plot.

veg_code: This item refers to the association assigned to each plot location. Veg_code and descriptions are listed in Table 5.

Verification Data
Coverage name: **verif_data**

plot_no: This item refers to the number assigned to each verification plot.
veg_code: This item refers to the association assigned to each verification plot location.
Veg_code and descriptions are listed in Table 5.

Error Data
Coverage name: **error_pts**

veg_code: This item refers to the vegetation association assigned to each accuracy plot location. Veg_code and descriptions are listed in Table 5.
map_unit: This item refers to the map unit code

Ancillary Data
Coverage name: **map_boundary**

hectares: This item is simply a numeric figure representing the area covered by the mapping area.

Coverage name: **park_boundary**

hectares: This item is simply a numeric figure representing the area covered by the park.

| anderson_code | description |
|---|---|
| 11 | Residential |
| 12 | Commercial and Services |
| 14 | Transportation, Communications, and Utilities |
| 17 | Other Urban or Built-up Land |
| 21 | Cropland and Pasture |
| 51 | Streams and Canals |
| 53 | Reservoirs |
| 62 | Nonforested Wetland |
| 74 | Bare Exposed Rock |

**Table 3.** Anderson Level II Codes and Descriptions.

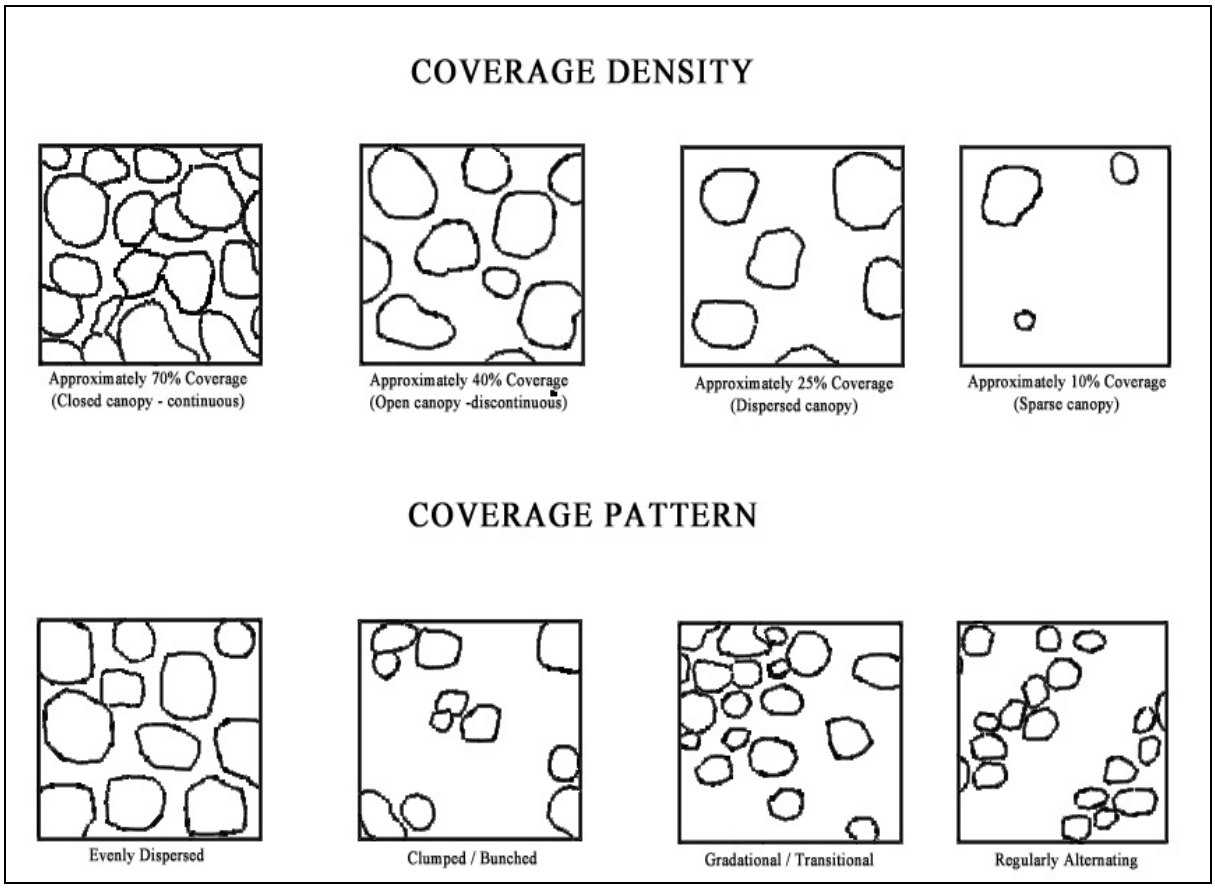


**Figure 4.** Standard Interpretative Conventions / Structural Categories.

| Structural Categories | |
|---|---|
| **HEIGHT** | |
| 6 | > 30 Meters |
| 5 | 15 - 30 Meters |
| 4 | 5 - 15 Meters |
| 3 | 1 - 5 Meters |
| 2 | 0.5 - 1 Meter |
| **COVERAGE DENSITY** | |
| 1 | Closed Canopy / Continuous |
| 2 | Discontinuous |
| 3 | Dispersed |
| 4 | Sparse |
| **COVERAGE PATTERNS** | |
| 1 | Evenly Dispersed |
| 2 | Clumped / Bunched |
| 3 | Gradational / Transitional |
| 4 | Alternating |

**Table 4.** Structural Categories for Vegetation Mapped Using NVCS.

| veg_code | description |
|---|---|
| arte | Silver Sagebrush / Western-Wheat Grass Shrub Herbaceous Vegetation |
| bbwg | Skunkbush Sumac / Bluebunch Wheatgrass Shrub Herbaceous Alliance |
| cpwf | Eastern Cottonwood - Peach Leaf Willow / Narrow-Leaf Willow Woodland |
| gplb | Little Bluestem - Grama (Side-Oats, Blue) - Threadleaf Sedge Herbaceous Vegetation |
| kbg | Kentucky Bluegrass Disturbed Community |
| m-kplb | Mosaic - Kentucky Bluegrass / Little Bluestem |
| m-wwlb | Mosaic - Western Wheatgrass / Little Bluestem |
| pdt | Prairie Dog Town |
| ppbo | Ponderosa Pine / Bur Oak Woodland |
| ppbw | Ponderosa Pine / Bluebunch Wheatgrass Woodland |
| ppcj | Ponderosa Pine / Common Juniper Woodland |
| pplb | Ponderosa Pine / Little Bluestem Woodland |
| ppsf | Ponderosa Pine / Oregon Grape Forest |
| ppss | Ponderosa Pine / Sun Sedge Woodland |
| wwbg | Western-Wheatgrass - Blue Grama - Threadleaf Sedge Herbaceous Vegetation |

**Table 5.** List of Vegetation Code (veg_code) and Vegetation Association Descriptions**.**

## Accuracy Assessment

To assess the thematic accuracy of the vegetation map we conducted an accuracy assessment that allows the user of the digital information an additional perspective upon the data. The final product attempts to achieve the 80% per class accuracy required for this product.

Not all mapping units were tested for accuracy. Since the final map contains two separate classification systems (see 'Vegetation Classification'), only the mapped areas that fall under the NVCS were included in the accuracy assessment. Areas such as rock outcrops, agricultural, undescribed vegetation units and other areas classified using Anderson Level II classification were eliminated from the sample process. Besides excluding the Anderson classified polygons we also excluded vegetation polygons visited and sampled during either the vegetation description or verification phase that were small enough to confidently say were entirely correct. These were typically riparian polygons in the flood plain. These small polygons were eliminated from the site visit in the random selection process but were included in the final accuracy assessment matrix. In addition, we eliminated all areas outside the park from consideration because of access restrictions.

The remaining areas for sampling were then stratified and sampled according to the number of polygons in each class and the area occupied by each class. Table 6 shows the recommended number of samples per class using a stratified sampling process (*Accuracy Assessment Procedures*, The Nature Conservancy 1994).

Field Procedure: The field crew consisted of two botanists that were not involved in any part of the previous work on the park. This crew either worked together or separately depending upon local conditions. Both botanists were supplied with a list of points to visit, a field key for map class identification, field data forms, and a GPS to navigate to each site (see Plant Association Key and sample field forms attached with TNC report). Both crew members worked "blind', meaning that neither one was aware of the existing mapped class designations. Upon arriving at each site, the crews scanned a wide area around the immediate location and observed any local variation in the plant associations. Using the key, the crew then assigned a plant association to the accuracy point. In cases where the variation was significant the crew made a "best fit" judgment to the class name. In addition, other associations in the area and those that might be confused with other plant associations were also noted on each field form.

Site Selection: The stratified random selection of accuracy assessment sites was done on the original map classes (see 'Vegetation Classification'). The original map classes, the number of sites selected and the number of sites visited are listed in Table 7.

The x and y coordinates of each accuracy point were derived from the original vegetation coverage. The coverage was gridded into 50 x 50 meter cells using ArcGrid. A 50-meter grid was chosen since it approximates the minimum mapping unit (MMU) for the project. Using a random number generator, we then re-selected the appropriate number of grids/samples from each class and put them into a separate grid. Additional points were selected for each class over the required number to allow the field crew some latitude in case some sites were inaccessible. The re-selected cells where then converted into a point coverage. The x and y coordinate for each point was then transferred to an ascii file. This coordinate file was then used by the field

team along with a PLGR unit to locate the position in the field. The locations of all accuracy points are shown in Figure 5. The point coverage with the accuracy locations and the assigned map unit code are included as a digital coverage.

| Scenario | Description | Polygons in class | Area occupied by class | Recommended number of samples in class |
|---|---|---|---|---|
| A | Abundant.<br>Many polygons that cover a large area | ≥ 30 | ≥ 50 ha | 30 |
| B | Relatively abundant.<br>Class has few polygons that cover a large area | < 30 | ≥ 50 ha | 20 |
| C | Relatively rare.<br>Class has many polygons, but covers a small area. Many polygons are close to the MMU. | > 30 | < 50 ha | 20 |
| D | Rare.<br>Class has few polygons, which may be widely distributed. Most or all polygons are close to the MMU. | ≥ 5, ≤ 30 | < 50 ha | 5 |
| E | Very rare.<br>Class has too few polygons to permit sampling. Polygons are close to the MMU. | < 5 | < 50 ha | Visit all and confirm |

**Table 6.** Number of Sites per Class. The recommended sample sizes for the stratified sampling process (MMU = Minimum Mapping Unit) *Accuracy Assessment Procedures* (The Nature Conservancy 1994).

Data Analysis: Due to the inherent heterogeneity of many natural systems, many of the map class determinations to be incorrect. However, when considered in the larger context were correct. To address this issue we attempted to include a 'fuzzy' protocol in analyzing the field accuracy data. For example, when the field crew visited a site they noted not only the appropriate vegetation association designation for the immediate area but also other associations present. When field codes where then compared with the mapped class the point was designated correct if it agreed with any of the associations noted on the field form.

Using the original interpretations and map units we then created a contingency matrix to identify the source and magnitude of map errors. The preliminary matrix is shown in Table 8. The table

identified consistent sources of error that allowed us to combine certain classes into the final contingency table (Table 9). Classes were combined where they made some ecological sense. For example, pine types were often combined into north and south facing slopes. Grassland types were also combined into one map class.

Statistical Methods: This mapping effort only evaluates the thematic accuracy of the final product and ignores the positional accuracy. Positional accuracy is assumed to have been met because polygon delineations were transferred to a highly accurate base map. In addition, the lines transferred to the base map are often abstractions and really represent a continuum of change from one plant association to another. The continuum may also be considered an ecotone. These ecotones are not being mapped nor classified.

The statistical methods for the production of the contingency tables are discussed in *Accuracy Assessment Procedures* (The Nature Conservancy 1994). The statistical parameters are as follows: the overall and individual accuracies are calculated using overall measures of accuracy rather than the Kappa index (Kappa index for overall accuracy is included in the contingency table) The confidence intervals are calculated using a two tailed 90% confidence interval. Accuracy standards for overall or individual class accuracies are assumed to have been met if they fall within the confidence interval.

| Preliminary Map Class Name | Number of sites selected for sample | Number of sites actually visited |
|---|---|---|
| *Artemisia cana* - *Pascopyrum smithii* Shrub Herbaceous Vegetation | 3 | 3 |
| *Quercus macrocarpa* - *Fraxinus pennsylvanica* Woodland | 1 | 1 |
| *Populus deltoides* - *Salix exigua* Woodland | 5 | 5 |
| *Schizachyrium scoparium* - *Bouteloua curtipendula* - *Carex filifolia* Herbaceous Vegetation | 5 | 5 |
| *Poa pratensis* Herbaceous Vegetation | 20 | 20 |
| Mosaic - *Poa pratensis* / *Schizachyrium scoparium* Herbaceous Vegetation | 2 | 2 |
| Mosaic - *Pascopyrum smithii* / *Schizachyrium scoparium* | 1 | 1 |
| *Pinus ponderosa* / *Quercus macrocarpa* Woodland | 5 | 5 |
| *Pinus ponderosa* / *Juniperus communis* Woodland | 3 | 1 |
| *Pinus ponderosa* / *Schizachyrium scoparium* Woodland | 20 | 20 |
| *Pinus ponderosa* / *Mahonia repens* Forest | 20 | 19 |
| *Pinus ponderosa* / *Carex heliophila* Woodland | 20 | 20 |
| *Symphoricarpos albus* Shrubland * | 1 | 1 |
| *Pascopyrum smithii* / *Bouteloua gracilis* Herbaceous Vegetation | 5 | 4 |

**Table 7.** List of preliminary map classes used during the accuracy assessment. (* *Symphoricarpos albus* Shrubland was later combined into *Artemisia cana* - *Pascopyrum smithii* Shrub Herbaceous Vegetation within the NVCS and is therefore not included in the final list of vegetation associations.)

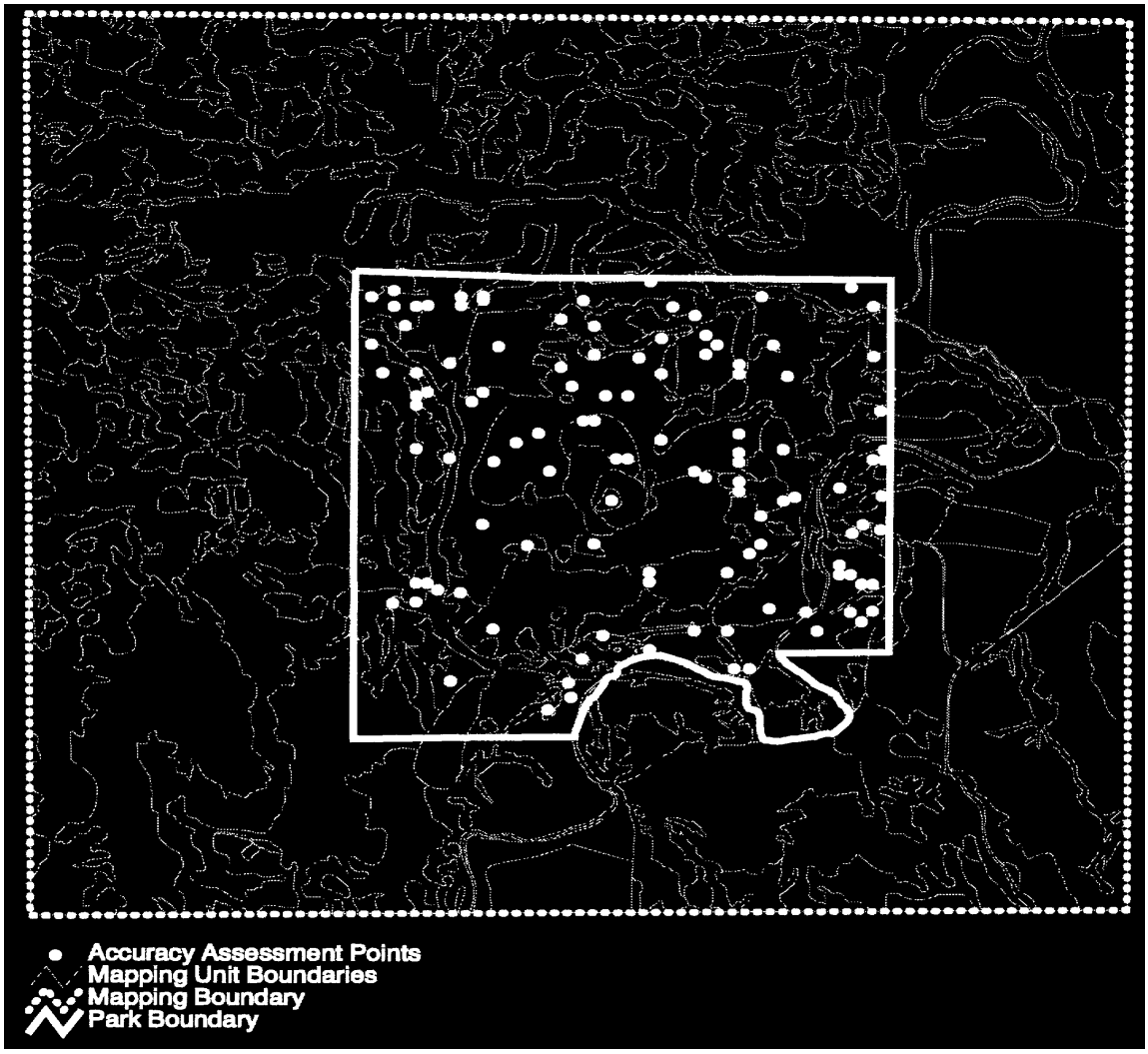


**Figure 5.** The Locations of accuracy assessment points for Devils Tower National Monument

| | | | | | | | | | | | | | | | | | | | | COMMISSION | CONFIDENCE | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | | | | | | | | | | | | | | |
| | | REFERENCE CLASS | | | | | | | | | | | | | | | | | | | | |
| M | | | AR | BU | CP | GP | KB | MK | MW | PB | PC | PF | PJ | PL | PS | PW | WS | WW | | | - | + |
| A | L | AR | 3 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 3 | 100 | 46.4 | 100 |
| P | A | BU | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 100 | 10 | 100 |
| P | S | CP | 0 | 0 | 5 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 5 | 100 | 63.1 | 100 |
| E | S | GP | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 1 | 0 | 0 | 2 | 5 | 0 | 0 | 0 | 0 |
| D | | KB | 0 | 1 | 0 | 0 | 16 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 2 | 20 | 80 | 63.7 | 88.6 |
| | | MK | 0 | 0 | 0 | 0 | 0 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 100 | 32 | 100 |
| | | MW | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 100 | 10 | 100 |
| | | PB | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 4 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 5 | 80 | 41.6 | 93.4 |
| | | PC | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 |
| | | PF | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 5 | 0 | 5 | 0 | 1 | 5 | 3 | 0 | 0 | 19 | 26.3 | 13.4 | 48.1 |
| | | PJ | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 1 | 100 | 10 | 100 |
| | | PL | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 17 | 3 | 0 | 0 | 0 | 20 | 85 | 69.3 | 91.9 |
| | | PS | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 4 | 12 | 3 | 0 | 0 | 20 | 60 | 42.8 | 74.3 |
| | | PW | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | | WS | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 |
| | | WW | 0 | 0 | 0 | 1 | 3 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 4 | 0 | 0 | 0 |
| | | TOTAL N | 4 | 4 | 5 | 1 | 20 | 2 | 1 | 9 | 0 | 5 | 1 | 25 | 21 | 6 | 0 | 0 | 108 | | | |
| | | | | | | | | | | | | | | | | | | | | | | |
| OMISS ERR % | | | 75 | 25 | 100 | 0 | 80 | 100 | 100 | 44.4 | 0 | 100 | 100 | 68 | 57.1 | 0 | 0 | 0 | | | | |
| CON INTERVAL | | | | | | | | | | | | | | | | | | | | | | |
| - | | | 32.1 | 2.6 | 63.1 | 0 | 63.7 | 31.6 | 10 | 21.1 | 0 | 63.1 | 10 | 52.3 | 41 | 0 | 0 | 0 | | | | |
| + | | | 92.7 | 86.2 | 100 | 0 | 88.6 | 100 | 100 | 71.4 | 0 | 100 | 100 | 79.5 | 71.4 | 0 | 0 | 0 | | | | |
| | | | | | | | | | | | | | | | | | | | | | | |
| OVERALL TOTAL ACCURACY = 62.0% | | | | | | | | | | | | | | | | | | | | | | |
| OVERALL KAPPA INDEX = 56.3% | | | | | | | | | | | | | | | | | | | | | | |
| OVERALL TOTAL ACCURACY 90% LOWER & UPPER CONFIDENCE INTERVALS: 54.7%, 68.6% | | | | | | | | | | | | | | | | | | | | | | |
| (OMMISSION & COMMISSION ERRORS CALCULATED USING TOTAL ACCURACY, NOT KAPPA INDEX) | | | | | | | | | | | | | | | | | | | | | | |

Abbreviations:

| | | | | | |
|---|---|---|---|---|---|
| AR | Silver Sage Brush / Western-Wheat Grass Shrub Herbaceous Vegetation | MK | Mosaic - Kentucky Bluegrass / Little Bluestem Grassland | PJ | Ponderosa Pine / Common Juniper Woodland |
| BU | Green Ash - American Elm / Wolfberry Forest | MW | Mosaic - Western Wheatgrass / Little Bluestem Grassland | PL | Ponderosa Pine / Little Bluestem Woodland |
| CP | Eastern Cottonwood - Peach Leaf Willow / Narrow-Leaf Willow Woodland | PB | Ponderosa Pine / Bur Oak Woodland | PS | Ponderosa Pine / Sun Sedge Woodland |
| GP | Great Plains Little Bluestem Prairie | PC | Prairie Cordgrass Streambank Community | PW | Ponderosa Pine / Bearberry Woodland |
| KB | Kentucky Bluegrass Disturbed Community | PF | Ponderosa Pine / Snowberry Forest | WS | Wolfberry Shrubland |
| | | | | WW | Western Wheatgrass Grassland |

**Table 8.** Preliminary Contingency Table for Vegetation Accuracy Assessment

| | | | | | | | | | | | | | | | | COMMISSION | CONFIDENCE | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | | | | | | | | ERROR % | INTERVAL | |
| | | REFERENCE CLASS | | | | | | | | | | | | | TOTAL N | CORRECT | | |
| | | | BB | BU | CP | GH | MK | CW | PB | PD | PJ | PP1 | PP2 | SC | | | - | + |
| | | BB | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 100 | 10 | 100 |
| | | BU | 0 | 5 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 5 | 100 | 63.1 | 100 |
| M | C | CP | 0 | 0 | 5 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 5 | 100 | 63.1 | 100 |
| A | L | GH | 0 | 1 | 0 | 25 | 0 | 0 | 0 | 0 | 0 | 4 | 0 | 0 | 30 | 83.3 | 70.9 | 89.9 |
| P | A | MK | 0 | 0 | 0 | 0 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 100 | 31.6 | 100 |
| P | S | CW | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 100 | 10 | 100 |
| E | S | PB | 0 | 1 | 0 | 0 | 0 | 0 | 4 | 0 | 0 | 0 | 0 | 0 | 5 | 80 | 41.6 | 93.4 |
| D | | PD | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 1 | 100 | 10 | 100 |
| | | PJ | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 1 | 100 | 10 | 100 |
| | | PP1 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 36 | 3 | 0 | 40 | 90 | 80.8 | 94.1 |
| | | PP2 | 0 | 0 | 0 | 0 | 0 | 0 | 5 | 0 | 0 | 6 | 8 | 0 | 19 | 42.1 | 26.1 | 60.7 |
| | | SC | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 4 | 100 | 56.3 | 100 |
| TOTAL N | | | 1 | 8 | 5 | 25 | 2 | 1 | 9 | 1 | 1 | 46 | 11 | 4 | 114 | | | |
| | | | | | | | | | | | | | | | | | | |
| OMISS ERR % | | | 100 | 62.5 | 100 | 100 | 100 | 100 | 44.4 | 100 | 100 | 78.3 | 72.7 | 100 | | | | |
| CON INTERVAL | | | | | | | | | | | | | | | | | | |
| - | | | 10 | 34.4 | 63.1 | 91.1 | 31.6 | 10 | 21.1 | 10 | 10 | 68 | 48.9 | 56.3 | | | | |
| + | | | 100 | 82.6 | 100 | 100 | 100 | 100 | 71.4 | 100 | 100 | 85.1 | 86.2 | 100 | | | | |
| | | | | | | | | | | | | | | | | | | |
| OVERALL TOTAL ACCURACY = 81.6% | | | | | | | | | | | | | | | | | | |
| OVERALL KAPPA INDEX = 76.2% | | | | | | | | | | | | | | | | | | |
| OVERALL TOTAL ACCURACY 90% LOWER & UPPER CONFIDENCE INTERVALS 75.5% AND 86.0% | | | | | | | | | | | | | | | | | | |
| (OMMISSION & COMMISSION ERRORS CALCULATED USING TOTAL ACCURACY, NOT USING KAPPA INDEX) | | | | | | | | | | | | | | | | | | |

Abbreviations:

| | | | |
|---|---|---|---|
| BB | Wyoming Big Sagebrush / Bluebunch Wheatgrass Shrub Herbaceous Vegetation | MW | Mosaic - Western Wheatgrass / Little Bluestem Grassland |
| BU | Green Ash - American Elm / Wolfberry Forest | PB | Ponderosa Pine / Bur Oak Woodland |
| CP | Eastern Cottonwood - Peach Leaf Willow / Narrow-Leaf Willow Woodland | PJ | Ponderosa Pine / Common Juniper Woodland |
| GH | Grassland Complex | PP1 | Ponderosa Pine Complex I |
| MK | Mosaic - Kentucky Bluegrass / Little Bluestem Grassland | PP2 | Ponderosa Pine Complex II |
| | | SC | Silver Sage Brush / Western-Wheat Grass Shrub Herbaceous Vegetation |

**Table 9.** Final Contingency Table for Vegetation Accuracy Assessment

## RESULTS

Hectares for all mapping units are summarized in Table 10 for both the entire mapping area and the park itself. The listed codes are described in Tables 2 and 3.

| map_unit | anderson_code | Hectares | |
|---|---|---|---|
| | | Within Mapping Area | Within Park Boundary |
| - | 11 | 0.4 | 0.4 |
| - | 12 | 1.4 | 0.1 |
| - | 14 | 3.7 | 0 |
| - | 17 | 7.0 | 0.8 |
| - | 21 | 117.9 | 0 |
| - | 51 | 15.9 | 3.7 |
| - | 53 | 0.5 | 0 |
| - | 62 | 0.2 | 0 |
| - | 74 | 52.5 | 24.3 |
| BB | - | 0.9 | 0.9 |
| BU | - | 39.6 | 11.8 |
| CP | - | 34.9 | 14.3 |
| GH | - | 956.4 | 137.7 |
| MK | - | 36.9 | 28.3 |
| MW | - | 18.9 | 18.3 |
| P1 | - | 691.6 | 176.9 |
| P2 | - | 256.5 | 81.1 |
| PB | - | 65.8 | 25.8 |
| PD | - | 10.0 | 10.0 |
| PJ | - | 6.6 | 4.8 |
| SC | - | 12.6 | 4.6 |
| **Total** | | **2330.2** | **543.8** |

**Table 10.** Hectares of mapping units within the mapping area and within Devils Tower National Monument.

## DISCUSSION

During this mapping effort we encountered situations that, in retrospect, we would have approached differently. These include both the initial field work and the photointerpretation. However, this mapping effort gave great insight into the feasibility of mapping to the association level.

Initial field work included the placement of vegetation plots which were used to describe the vegetative associations that exist within Monument boundaries. These vegetation plots were very time intensive and provided us with a limited perspective of the variation present within the park. During the map validation field trip we used the more rapid observation plots which allowed us to visit a larger portion of the park during the time allotted. The validation trip provided us with a much greater perspective of the variation and spatial extent of these associations. The information gathered from the second field trip would have benefitted us greatly during the first field trip. Future mapping efforts should begin with a broader and quicker 'look' at the vegetation with observation plots and followed up with vegetation plots.

Problems with the photointerpretation were related to the lack of a firm classification system from which to work. We originally thought we could map to the association level. Therefore, initial photointerpretive classes were the same as the initial vegetation association classes. We thought we could probably separate many classes with similar signatures on some environmental indicator such as soils, slope, aspect, etc. This did not bear out. For example, the distribution of pine types had only very general tendencies for north and south aspects. Consequently, our final mapping units reflected these tendencies. In addition, grass associations were very difficult to discern and were combined into one class. Exceptions to the grass map unit were the mosaic grass map units. These were only separable because these areas were visited in their entirety. Photo signatures for all grass types were variable and unpredictable. Future mapping should take into account the cosmopolitan distribution of pine types in the Black Hills in addition to the unreliability of distinguishing many grassland types. An initial review of preliminary association classes and subsequent combining of classes into realistic map units would prevent a great deal of confusion and frustration.

The accuracy assessment underscored the problems associated with the original classification discussed above. In fact, the accuracy assessment showed us where the confusion occurred and directed the construction of the final map unit designations. Initial map units were combined, where it made ecological sense, to produce the final map classification. The final map classification was then assessed again using the combined classes to produce the final accuracy assessment. Combining classes increased the initial overall accuracy assessment from 62.0% to a final overall map accuracy of 81.6%. Most individual class accuracies also exceeded the target value of 80% for errors of both omission and commission. Those individual classes that did not meet the target value of 80% were at least within the 90% confidence interval in either omission or commission errors. These classes may have been combined with others to produce an even higher map accuracy for both individual class accuracy and overall map accuracy. This option was discussed at length with members of the USGS/BRD and NPS staff. Any further combination of classes was rejected due to the significant loss of information. For example, the final classification contained two Ponderosa Pine complexes that showed considerable confusion between the two. Both complexes were below the 80% requirement for individual class accuracy. Combining the two would have created a pine complex with more

than 90% accuracy. However, these two pine types also make up more than 40% of the entire mapping area. We decided to accept the lower individual accuracies for some classes to preserve some detail. Information about the distribution of associations can still be acquired from the three point coverages delivered with this report. These point coverages can be accessed and queried with most GIS's.

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# APPENDICES

## Annotated List of Slides

1) Cottonwood - Peach Leaf Willow Woodland
2) Cottonwood - Peach Leaf Willow Woodland
3) Green Ash / American Elm Woodland
4) Green Ash / American Elm Woodland
5) Silver Sagebrush
6) Silver Sagebrush
7) View of Belle Fourche River southeast from the base of the tower
8) Ponderosa Pine / Sun sedge Woodland
9) Western Wheatgrass Blue Grama Grassland
10) Mahonia repens
11) Ponderosa Pine / Bur Oak Woodland
12) Ponderosa Pine / Bur Oak Woodland
13) Ponderosa Pine / Little Bluestem Woodland
14) Juniperus scopulorum in Ponderosa Pine / Little Bluestem Woodland
15) Juniperus scopulorum in Ponderosa Pine / Little Bluestem Woodland
16) Ponderosa Pine / Little Bluestem Woodland
17) Devils Tower, view from south west
18) Devils Tower, view from west of Monument Headquarters
19) Devils Tower, view of tower from south east side of the tower
20) Ponderosa Pine / Oregon Grape Woodland, north side of tower
21) Ponderosa Pine / Oregon Grape Woodland, north side of tower
22) Ponderosa Pine / Little Bluestem Woodland, north west corner of Monument - note fire scars
23) Ponderosa Pine / Sun sedge Woodland
24) Ponderosa Pine / Sun sedge Woodland
25) Ponderosa Pine / Little Bluestem Woodland
26) Ponderosa Pine / Bur Oak Woodland, north west corner of Monument
27) Kentucky Bluegrass Disturbed Herbaceous Vegetation
28) Cottonwood - Peach Leaf Willow Woodland
29) Ponderosa Pine / Little Bluestem Woodland
30) Location of all vegetation and verification plots
31) Location of all accuracy assessment points